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November 2021

Centre for Climate Change Economics and Policy Working Paper No. 399
ISSN 2515-5709 (Online)

Grantham Research Institute on Climate Change and the Environment Working Paper No. 372
ISSN 2515-5717 (Online)

Economic and Social Research Council

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Suggested citation:
Mathews S, Roezer V, Surminski S (2021) *The risk of corporate lock-in to future physical climate risks: the case of flood risk in England and Wales*. Centre for Climate Change Economics and Policy Working Paper 399/Grantham Research Institute on Climate Change and the Environment Working Paper 372. London: London School of Economics and Political Science

The risk of corporate lock-in to future physical climate risks: the case of flood risk in England and Wales

Shilpita Mathews, Viktor Roezer and Swenja Surminski (all Grantham Research Institute on Climate Change and the Environment/LSE)

Key words: lock-in, SME, flooding, climate change, risk disclosure, risk assessment

Abstract

There has been a big shift in corporate awareness of climate risks in recent years. While external pressure from investors and regulators to disclose and mitigate exposure of businesses to climate risks is increasing, many projected impacts are still hardly understood. This includes the risk of lock-ins in the face of increasing physical risks from climate change. Using the example of flood risk in England and Wales, the study looks at both the evidence and drivers of business lock-ins to physical risks from climate change. The paper adopts a multi-methods approach consisting of a summary of the empirical evidence of lock-ins in the literature, a case study analysis of current and future flood risk of recently completed business premises in England and Wales and the results of a survey among business owners in the UK. The findings show that business decisions made today, such as site selection or operational choices, can lock businesses to future risk trajectories that may be difficult and costly to change. Gaps between flood risk awareness and exposure in sectors such as manufacturing and finance were identified and attributed to low business capacity to understand site-level risk exposure and poor internal alignment between organisational actors. The results demonstrate that there is a business case for corporate risk assessment, disclosure and adaptation investments.

Acknowledgements

The authors would like to acknowledge the support of the Committee on Climate Change (CCC) in the business survey conducted as part of the Third UK Climate Change Risk Assessment (CCRA 3) project. The authors would like to thank Kate Gannon, Denyse Dookie and Roger Fouquet, from the Grantham Research Institute, for their time and effort reviewing the paper and their helpful comments and support. Analysis of long-term flood risk has been supported by the Z Zurich Foundation, Switzerland; the Grantham Foundation for the Protection of the Environment and the ESRC via the Centre for Climate Change Economics and Policy under Grant number: ES/R009708/1.

1. Introduction

Over the last few years, climate change as a corporate issue has received much attention (Averchenkova et al., 2016; Li et al., 2020). More and more larger companies are responding to external pressure from regulators and investors by adopting net zero targets and by fulfilling climate risk disclosure requirements (Ginglinger & Moreau, 2019; TCFD, 2019; HM Treasury, 2020; Surminski et al, 2021). This is underpinned by growing knowledge about the impacts that physical climate risks pose to business and industry (see for example McKinsey Global Institute, 2020; Surminski et al., 2016). However, many businesses, in particular Small and Medium sized Enterprises (SMEs)[1] who account for 99% of businesses globally, often lack tools and information to assess and manage risks (Surminski et al, 2021; Zurich Insurance, 2016), while at the same time being disproportionately affected by physical climate risks (UNDRR, 2020).

A particular concern for climate risk management are so-called 'lock-in' effects. In the context of climate change, lock-ins refer to a type of path dependency where business decisions made today determine climate risk levels today and tomorrow (Seto et al., 2016; Ürge-Vorsatz et al., 2018). As per the UK government's Third Climate Change Risk Assessment (CCRA 3) (Surminski et al, 2021), "*lock-in effects entail a degree of irreversibility. This can occur through choices about site location, infrastructure, supply chain networks or core business models, which are difficult to reverse and can increase exposure to subsequent risks long-term or lock-in to future interventions to manage exposure*". For example, risk-insensitive site selections or investments can put a company on a trajectory that would be difficult and costly to change in the future. The CCRA 3 report (Surminski et al, 2021) identifies this as a key challenge and mentions some areas where lock-ins are expected to negatively impact the resilience of companies in the UK, such as coastal areas in North Norfolk due to their locational risks to coastal flooding. However, there is still very little evidence showing these lock-ins empirically, nor have there been investigations of driving factors or implications. This paper considers these aspects and aims to answer:

1. What is the empirical evidence for lock-ins? What examples support the theoretical literature?
2. What are the key drivers of lock-in risks?

Failure to recognise the emergence of lock-ins may increase losses and prevent early detection and mitigation of systemic risks in global financial systems and supply chains. Corporate lock-ins can also entail broader costs to the economy and society by heightened vulnerability through income and revenue streams, adversely impacting employment and labour productivity, health and wellbeing of workers, access to public goods and services, climate innovation and technology adoption and use of natural resources by businesses.

This paper adopts a multi-methods approach to assess lock-in effects for companies in the UK. It demonstrates the key drivers of lock-in effects drawing on findings from the Grantham Research Institute (GRI) Business Survey and underpins this with new analysis using a case study of flood risk in England and Wales (Surminski and Mathews, 2021). The paper specifically focuses on locational lock-in risks, given empirical evidence of site locations of businesses available in the UK. Flooding was used as a case study given that it is the most

[1] As per Ward (2021) a small and medium sized enterprises (SMEs) is any business with fewer than 250 employees.

frequent prolonged and extreme-weather event experienced by businesses in the UK (Surminski and Mathews, 2021). In fact, the Committee on Climate Change's 2019 progress report demonstrated 1.4 million people in England currently face a risk of 1:75 or greater risk of flooding of any kind (UK Committee on Climate Change, 2019).

2. The concept of lock-in effects

While lock-ins to transition risks have been explored previously, literature on physical lock-ins remains nascent (Dietz, Dixon, et al., 2016). Lock-ins to transition risks include financial investments in carbon-intensive sectors such as oil and gas, which are considered 'stranded assets' given changing regulatory measures (Caldecott, 2018; Seto et al., 2016; Unruh, 2019). Conversely, physical risk lock-ins can occur when a decision today to develop business premises on a flood risk site, can lock-in the business to current and future flood risk that may be irreversible or costly to change later. Since its First Progress Report on Adaptation (2013) the UK Committee on Climate Change has regularly highlighted the importance of lock-ins and urged greater recognition of physical risk trends when making important decision, and for the CCRA3 technical report, lock-in risks became a central feature of investigation. In the context of business and industry CCRA3 found that lock-ins are most concerning when risk-insensitive behaviour results in higher risk magnitude due to slower adaptation, mal-adaptative response or when it creates new barriers to adaptation (Surminski et al, 2021). Risk levels can be understood as a factor of hazard, exposure and firm vulnerability (Rose, 2016). Business decisions can influence all three aspects directly and indirectly, but across very different timelines. This has been discussed in the business continuity literature (Hiles, 2010; Kuruppu et al., 2014) and in studies on corporate climate adaptation (Averchenkova et al., 2016; Surminski et al., 2018; Westcott et al., 2020). While lock-ins can relate to a wide range of business decisions, CCRA 3 highlighted those relating to 1) site locations and infrastructure, 2) supply chain networks and 3) core business models failing to integrate different climate risks as of particular concern in a UK context (Surminski et al, 2021). These are discussed in turn, followed by potential implications of lock-ins. A summary of the different types of lock-ins is provided in Table 1.

Table 1. Types of lock-ins

Type of lock-ins	*Examples*
Locational lock-ins	Analysis by Four Twenty-Seven highlights over 20% of Edinburgh, Glasgow and Sheffield's retail assets are located in flood-prone areas. In the same study, coastal flooding in Europe, without any adaptation investment, is expected to cost up to €1 trillion in damages by the end of the century under a 5C scenario (Chatain, 2019).
Supply chain lock-ins	Lock-ins to critical supply chains have been noted in the food manufacturing sector, leading to high costs in the aftermath of a disaster (Colwill et al., 2016). Studies indicate that indirect losses, through supply chain or income streams can be much greater than direct physical damages (Stéphane Hallegatte, 2008, 2016).
Core business models lock-ins	Modelling physical and transition risks separately poses the danger of operating in silos (Goldstein et al., 2019; Surminski et al., 2018). This could result in inadequate disaster preparedness, even when climate risk assessment is conducted by businesses.

Locational lock-ins

Risk insensitive site location decisions are a key climate risk driver (Hsiang et al., 2017; McKinsey Global Institute, 2020; Xie et al., 2015). Lock-ins to future flood risk have been demonstrated in the case of residential location (Rözer & Surminski, 2021), but are yet to be extended to businesses. Stress-testing by financial regulators under different scenarios is an attempt to incorporate these 'unhedgeable' locational investment risks into financial planning (Prudential Regulation Authority, 2019; Surminski et al., 2018). Lock-ins have also been considered in the insurance sector in terms of current low insurance premiums and future limits to insurability (CISL, 2019). As Magnan et al. (2016) highlight, businesses often make location specific investment decisions under the false assumption that they will always be able to buy insurance and transfer their risk. This however might not hold if risks are increasing, and insurers might not underwrite the risk or only for a much higher premium. This corroborates with business concerns around future insurance costs (Power et al., 2020). A false sense of security may also arise due to overreliance on government-led location-based interventions (Pottinger & Tanton, 2014; Power et al., 2020). For example, there is a risk of lock-in if future flood risk levels are not considered during the planning stage or if new developments go ahead under the assumption that government will maintain protection levels through new flood risk management investments and upgrades (Surminski et.al. 2021). Importantly, the perceived longevity of institutional interventions may be misguided, as found in a study in Wales (Buser, 2020).

Supply chain lock-ins

Evidence for supply chain lock-ins is more nascent. However, specific transport lock-ins have been found, with rail networks unable to cope with increased temperatures (Marteaux, 2016) and susceptible to coastal erosion (Brooks et al., 2020). This jeopardises economy-wide supply chains. Thus, even though supplier contracts are short-term, existing supply routes can be at risk. Another example is overdependence on international suppliers with high physical risk exposure, which is projected to have significant downstream impacts (Lemma et al., 2015). This was notably seen in the aftermath of the 2011 floods in Thailand which affected one of the largest producers of hard drives globally, disrupting international supply chains (Haraguchi et al., 2015).

Core business models lock-ins

Similarly, there are lock-ins to core business models that lack strategic and holistic risk perspectives. For example, lock-ins to current corporate risk management processes may fail to recognise climate as an underlying risk driver, or ignore the interplay between different types of climate risk (Averchenkova et al., 2016). Another example is existing accounting standards which do not capture the extent of physical climate risks and reconfirm management and planning perspectives unfit for climate adaptation (Deloitte, 2019). Another example are lock-ins to pre-existing technologies when making business decisions about future products and services. Outdated technologies with upfront costs can result in low firm capacity to respond to uncertainties in the adaptation to climate change (Chhetri et al., 2010; Kuklicke & Demeritt, 2016; Nicholas & Durham, 2012). This may prevent early adoption of digital innovation such as artificial intelligence, which can expedite climate adaptation (Power et al., 2020). Similarly, decision-making based on algorithms can change businesses understanding of physical risks (Ford et al. 2016). Whilst this has the potential of enhancing

business resilience (Huntingford et al., 2019), there is little understanding of the role of business investment in climate data or machine learning and associated benefits.

Importantly lock-ins can lead to maladaptation. An example is overreliance on air-conditioning at business premises as a response to increased temperatures (Power et al., 2020). Not only does this have threshold effects, since air conditioning can only help with cooling to a certain degree, it also increases energy demand and magnifies the risk of blackouts in areas experiencing prolonged heatwaves (McEvoy et al., 2012). Most concerningly, air conditioners have been found to exacerbate heatwave conditions due to wasted heat generated during operation (Salamanca et al., 2014). In this context, the emission mitigation literature raises the question whether a focus on optimization (e.g. based on a carbon price) instead of transformation leads to a delay in difficult and costly decisions, which hinders progress and ultimately puts businesses on pathways that can end in lock-ins later on (Rosenbloom et al, 2020; Fouquet, 2016).

In view of the adverse implications of lock-in effects, this paper provides evidence for locational lock-ins with a focus on flood risk. Flood risk was selected since it is the most frequent prolonged or extreme-weather event that impacts businesses in the UK (Surminski and Mathews, 2021). We investigate the factors driving lock-in effects and consider the implications for businesses.

3. Methodology, approach, and existing evidence base

Our research follows a multi-methods approach including an empirical case study as well as survey and document analysis, relying on three types of evidence: 1) a review of 67 business surveys and 83 academic papers on business lock-in risks from physical risk, 2) results from a unique flood exposure dataset at the business premise level, and 3) original business survey results. Site-specific locational lock-ins were investigated as opposed to the other types of lock-ins discussed in section 2, since they are easier to identify than lock-ins such as supply-chain dependencies. Locational lock-ins were investigated with respect to flooding in the UK given the availability of granular data for England and Wales as described in Table 2. Flooding was chosen over other climate hazards given the significant financial impact it has on UK businesses, as described in section 1. These research strategies were used to answer the two research questions:

1. What is the empirical evidence for lock-ins?
2. What are the key drivers of lock-in risks?

The methods used are outlined in detail in Table 2. All lines of evidence are complementary as they help address the two research questions through different perspectives (see Figure 1). For example, the flooding case study empirically supports the theoretical lock-ins established in the evidence base. Similarly, gaps in the literature and document analysis, are filled by the GRI survey results. Finally, gaps in business risk and perception are identified by using both the flooding case study and GRI survey results.

Table 2. Detailed research strategies

Research approach	*Description*	*Research question*	*Sections*
Document analysis and literature review	For the document analysis, 67 business surveys and 83 academic papers were reviewed to establish the existing evidence base, alongside reports and other grey literature produced by business and industry. These reports and grey literature often outlined the business surveys in detail. Key sources included: findings from the business and industry chapter of the UK CCRA 3 (Surminski et al, 2021), a report by Power et al (2020) produced as part of CCRA 3 and the Carbon Disclosure Project (CDP)'s 2018 business survey results. The following terms were used in searches on Google Scholar: "climate change", "adaptation", "physical risk", "lock in", "sustainability", "business continuity" and "resilience" in combination with "business", "SMEs" and other diminutives such as "small business", "private sector", "firm", "corporation", "industry" and "organisation". The following words were used to search for reporting: "TCFD", "ESG", "risk report". Business survey results were used to identify gaps and compare with findings from the GRI survey outlined below. *Limitation: Given that this is a rapidly changing area of literature, some studies may be outdated. For this reason, only business surveys after 2008 were considered.*	*1, 2*	*4.1*
Flooding case study in England and Wales	For the flood risk case study, current and future flood risk of new business premises, built between 2008 and 2018 in England and Wales, is analysed The case study uses property level data, provided by the Ordnance Survey (OS) (OS, AddressBase, 2019) and filtered for properties built in or after 2008. The property data covers the location and business sector of all new business premises in England and Wales between 2008 and 2018.[2] The property data was overlayed with the Risk of Flooding from Rivers and Sea (RoFRS) and Risk of Flooding from Surface Water (RoFSW) maps provided by the Environment Agency to help understand current business flood exposure by sector and region. The maps show the chance of flooding, considering flood defences and their condition based on cells of 50 metres. Of all new premises build between 2008-2018, the number of businesses in flood prone areas under different scenarios were used to	*1*	*4.2.*

[2] No data for Scotland and Northern Ireland were available at this time.

	calculate per-sector rates. Future flood risk for the 2050s under a 2°C (2C) and a 4°C (4C) increase in Global Mean Temperature (GMT) scenario are estimated following the approach described in Rözer & Surminski (2021). *Limitation: The dataset does not allow to distinguish between SMEs and larger corporations. The described data and methods are used for the case-study in section 4 and are detailed in Appendix A.*		
Original business survey results	The Grantham Research Institute (GRI) business survey was undertaken specifically for CCRA 3 and was used to address the gaps found in the evidence base (Surminski and Mathews, 2021). The survey ran from 21st November 2019 – 2nd March 2020 and was open to businesses across the UK. The survey was shared with business stakeholders (e.g., insurers, business associations, consultancies etc.) participating in the CCRA 3 process and circulated with their business contacts on a discretionary basis. Business participation was voluntary, and all results were anonymised. Businesses reported their current and future climate risks and opportunities, financial impact and adaptation strategies. They also reported on their climate risk preparedness, reporting, and engagement with internal and external stakeholders. Businesses are most likely to understand physical risk at a site-specific scale or via value chain impact (Surminski et al., 2018). Therefore, the survey followed the UK CCRA (Committee on Climate Change, 2016) business function framework which lends itself well to understand the multifaceted impact of climate impacts ranging from business location (Brooks et al., 2020; Buser, 2020), supply chain (Albornoz et al., 2009; Altay & Ramirez, 2010; Azadegan & Jayaram, 2018; De Mel et al., 2012; Koks et al., 2019), labour markets (Day et al., 2019; Leiter et al., 2009) and capital risks (CISL, 2019; IMF, 2020; Mandel et al., 2020). The survey received 225 responses from across the UK from 19 different sectors, as per UK's Office for National Statistics' (ONS) business sector classification. *Limitation: Survey results should be treated as indicative as the sample size was limited and non-representative across sectors and countries. Moreover, to increase participation, the survey was open to respondents with different roles in the business (e.g., CEO, CRO), which may have influenced the subjectivity of some responses.*	*1,2*	*4.3*

To answer the first research question two lines of evidence are considered:
1) A literature review including numerous businesses surveys and academic papers was done to establish the existing evidence base for lock-ins.
2) The importance and scale of lock-ins is analysed using an empirical case study of flooding in England and Wales to identify locational lock-ins. The findings of the literature review and the flooding case study are presented in section 4.1. and 4.2., respectively.

The second research question is addressed by analysing the GRI survey results (Surminski and Mathews, 2021) to learn about business perception and key drivers of lock-ins. The results are presented alongside findings from other business surveys in section 4.3. For that, the GRI survey results are compared with the findings on current and future flood exposure from the case study presented in 4.2 to identify business risk awareness-exposure gaps. The different timescales of the datasets studied, such as the long-term time horizon of the future flooding risk scenario data (up to 2050) and short-term horizon of business perception (next 3 – 5 years) assist in exploring risk awareness-exposure gaps and analysing short-termism in business decision-making in view of longer-term physical climate risk materiality.

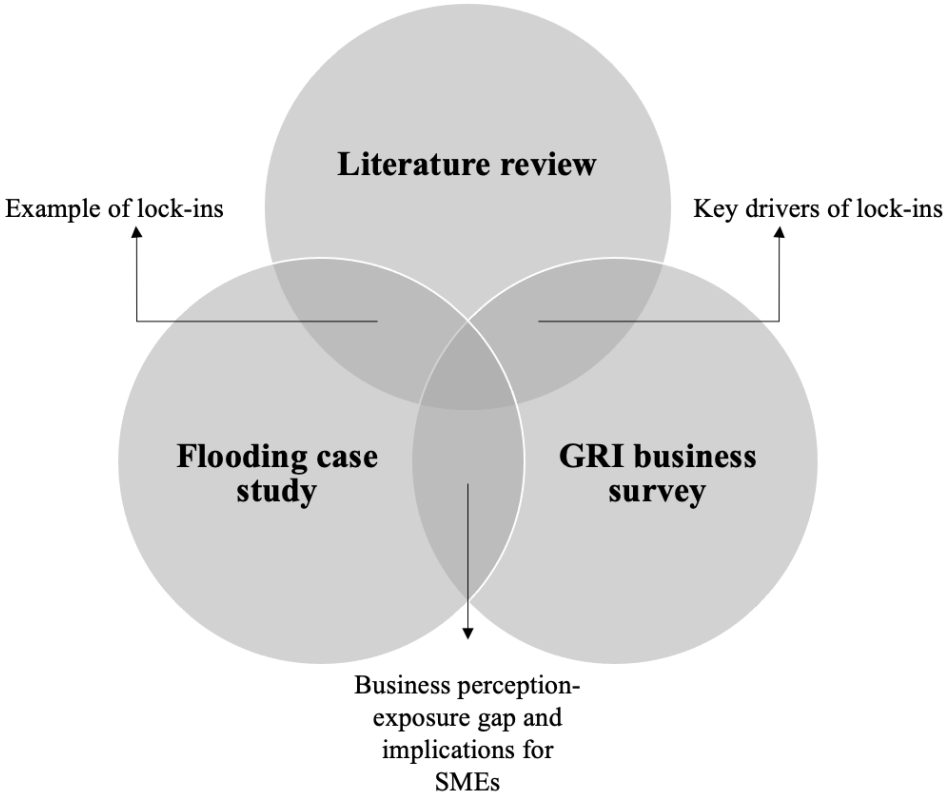


Figure 1. Research strategies and evidence base overlap

4.Findings and Discussion

4.1 Empirical evidence for lock-ins in the literature

The evidence concerning scale, implications and business perceptions of lock-ins is limited in the documents reviewed. Only 6% of business surveys analysed consider the impacts of hazards at the business function level, such as supply chain impacts (Appendix B). This is not surprising. Despite the growing understanding and recognition of the importance of lock-ins amongst experts working on corporate climate risk management (see section 2), corporate physical risk quantification is nascent, with most academic papers and corporate studies

being qualitative (Goldstein et al., 2019). There have been assessments by the government (Committee on Climate Change, 2016) and private sector (CDP, 2019) to analyse business risk exposure. However, there remains debate regarding progress made and methodologies employed (Goldstein et al., 2019; Surminski et al., 2018). Only 12% of existing business surveys report on physical risk.

Moreover, only 9% of business surveys reviewed enquired about financial impacts of physical climate risks. This underpins the view that physical and transition risks are often viewed separately, with the latter dominating corporate discourse (Goldstein et al., 2019). As per CDP 2018 survey results, which mainly attracts larger companies, businesses expect the total financial impact from direct losses due to climate risks (not just flooding) to be approximately £56.17 billion for the 176 UK business respondents. Results from Sayers et al. (2020) suggest that expected annual damages from all sources of flooding in non-residential properties amount to £670 million in present day terms and this is likely to increase by 27% in a 2C scenario and 44% in a 4C scenario by 2050 if no adaptation is taken.
If current planned adaptation is undertaken, Sayers et al. (2020) report that the expected annual damages for non-residential properties in the UK (which includes businesses) will increase by 10% by 2050 under a 2C scenario and by 23% under a 4C scenario. Concerningly, annual damages as a result of coastal flooding are expected to increase by 128% under a 4C scenario in England, which in present terms amounts to £79 million out of a total of £120 million UK-wide damages.

Another study by Schroders (2020) finds that insuring against physical risk could cost companies 4% of market values, with sectors such as oil and gas most affected. The estimated insurance costs suggest that total direct and indirect losses from the event itself could be much higher. Moreover, when costs of expected damages are compared to costs of adaptation management, only 3.5% of damage is being addressed by UK firms as per the CDP results (2018). Similarly, Bikakis (2020) finds that 0.11% of all of the UK's common equity tier (CET) 1 capital, or most common stock held by banks and financial institutions, is at risk of flood related mortgage defaults. This is in line with studies that demonstrate a negative impact of natural hazard-related disasters on firms' financial leverage using a forward-looking measure for physical climate risk at the firm level (Elnahas et al., 2018; Li et al., 2020).

While there have been case studies highlighting the financial impacts of climate hazards at the firm-level (Cole et al., 2019; Elliott et al., 2019; Hu et al., 2019; Strobl, 2019), there has been no attempt to systematically quantify firm-level losses. Farmers' Weekly (2020) survey responses, in which approximately 75% of UK farmers said extreme weather events had cost them more than £50,000, and an average of more than £10,000 per year. However, these results are not reflective of financial impacts across sectors. The extent of financial impacts is important to understand, since Gasbarro & Pinkse (2016), find that firms which are highly impacted by extreme weather events are more likely to invest in resilience.
Most surveys do not capture location specific risk, or direct risk to business site location, with only 24% surveys capturing risks at the country, region or city level, and none capturing further granularity. For example, many surveys outline the top weather-related risks faced by businesses, but do not specify where in the value chain or which particular sites will be affected.

The use of scenario analysis (3%) and climate modelling (1%) is scarcely disclosed in business surveys. Even where quantitative analysis is conducted and disclosed, data is too

limited for a systematic assessment to be made. Comparisons are difficult since physical risks are dynamic, multi-faceted and locally diverse (Surminski et al., 2018). Diverging methodologies, models and timescales means a holistic review cannot be undertaken.

Importantly, merely 6% of surveys differentiate between current and future risk levels. For example, where businesses are reporting risks from certain prolonged or extreme weather-related risks, it is unclear if these are risks anticipated now, or in a future timeframe (e.g. 2030 or 2050 risks). This makes it impossible to differentiate lock-in effects. Furthermore, most business reporting, like the PwC CEO Survey, is at the board or investor level and may not be representative of ground level physical risk quantification. Even when businesses distinguish between short- and long-term risks, this tends to be over a short-term time horizon. For example, the CCCEP survey asked respondents, "When your organisation needs to make important decisions that can't be changed easily, (such as where to be located or building new premises, or making big new investments), how far into the future would you tend to plan at most?". In 2021, 53% of 1687 private sector respondents indicated that they plan within a less than 10-year horizon (Dookie, Conway and Dessai, 2021).

There is also uncertainty around tail risks, interdependencies and indirect losses, with impacts being systematically underestimated (Goldstein et al., 2019). Despite gaining significant prominence in the theoretical literature, tail risks are not well understood or quantified by businesses or financial actors (Dietz, Bowen, et al., 2016).

Finally, surveys are not representative of SMEs. For example, surveys like the World Economic Forum survey are targeted towards larger companies and lack a climate-specific focus. The same lack of representation is noted in business surveys focusing on Sustainable Development Goals (SDGs), Environmental, Social, and Corporate Governance (ESG) or business continuity reporting, which target listed companies, most of which are large firms. This creates a significant knowledge gap given the importance of SMEs to the UK economy. The GRI survey (Surminski and Mathews, 2021) aimed to address these evidence gaps.

The GRI survey addresses the inability to make comparisons in the literature by using UK country specific data, including SMEs and non-listed firms and adopting a business function approach. Unlike previous surveys, the GRI survey reports sources used by firms to inform climate-related decision-making and the importance placed on business collaboration by firms. Detailed findings from the GRI survey results in direct comparison with results from the flood risk case study (see section 4.2.) are presented in 4.3.

4.2 Evidence of locational lock-ins: Case study of flooding in England and Wales

To address the first research question, the OS data introduced in Table 2 was used. The analysis of the data on new business premises shows evidence of locational lock-ins in England and Wales. Overall, the OS data shows that 2731 new business premises were built in high or medium flood risk areas (HFR) (1% or lower annual chance of flooding from river and surface water and 0.5% annual chance of flooding from the sea) between 2008 and 2018. This accounts for 7.82% of all new premises built in this period. Top three sectors at risk from flooding are *water supply, sewerage, waste management and remediation activities* (14.29%), *accommodation and food services* (12.36%) and *transport and storage*, (9.50%). On average 12% of all new premises in the aforementioned sectors were built in HFR areas in the studied period. These results are seen in Figure 2, which shows the percentage of new

premises in HFR areas built between 2008-2018 by sector. It must be noted that there were no new business premises built in the administrative and support service activities and construction sectors in 2008-2018. Data for the education sector was unavailable.

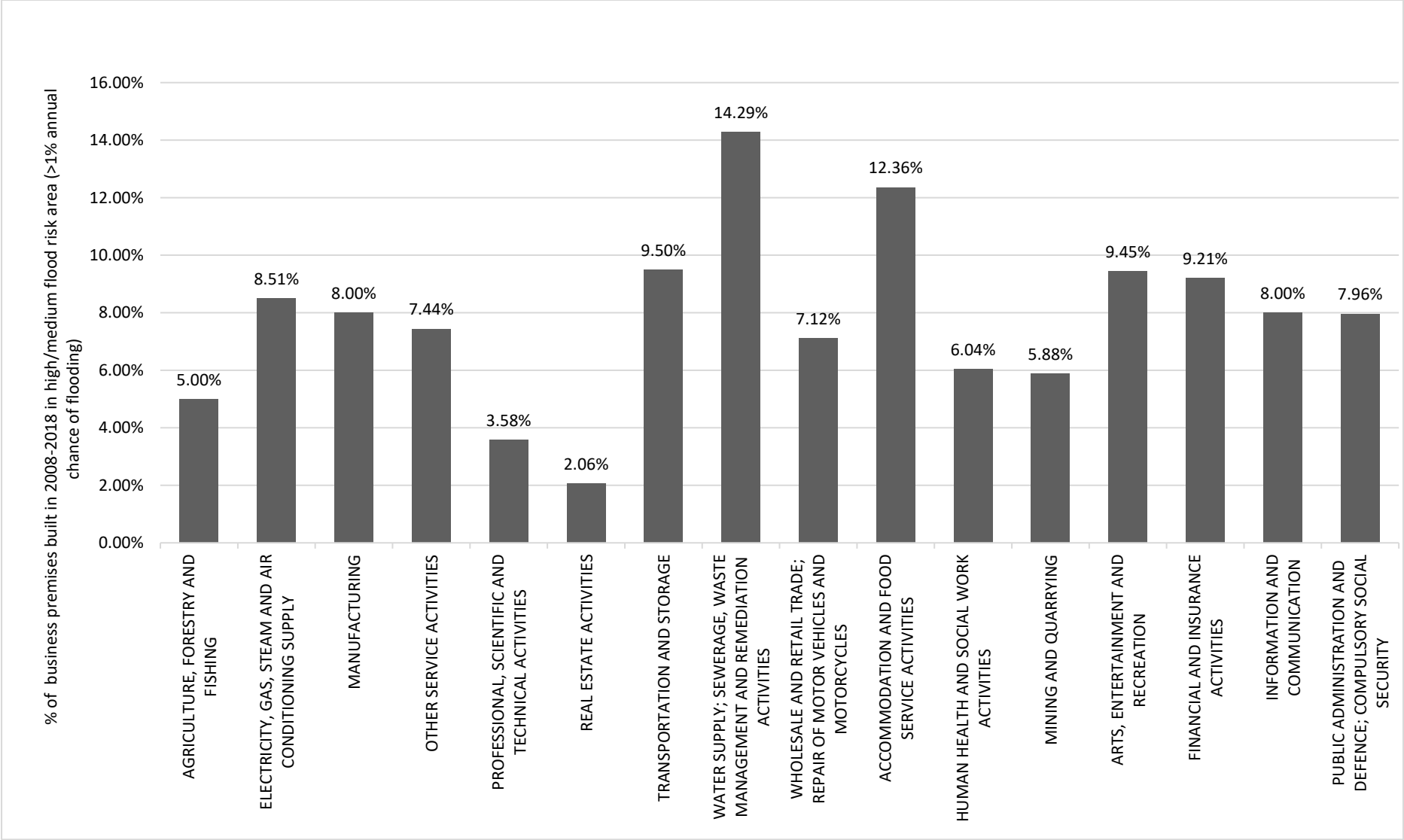


Figure 2. Percentage of business premises (2008 - 2018) in current high or medium flood risk areas (HFR) areas by sector (OS data, 2020)

A sectoral division of risks is seen by region in Appendix E. On the whole, percentage of new premises in HFR zones are highest in Wales, with over a third (33.3%) of new premises in the electricity and gas sector built in HFRs.

In England, the accommodation and food service sector have a higher proportion (13.5%) of newly built premises in HFR areas as compared to Wales. Lowest percentage of business premises built in HFR areas are in the real estate sector (2.3% in England), which may highlight precautionary measures prior to construction. Highest per-sector rates in London were observed in the manufacturing sector (11.1%), despite dominance of the financial sector in the city. There could be various explanations for this. For instance, the services sector is concentrated in central London which benefits from large scale flood protection measures, such as the Thames barrier, which are considered in the analysis. Conversely, manufacturing may be more flood exposed due to proximity to waterways for transport and cooling. Manufacturing is also often located in city outskirts and may not benefit from flood protection spill-overs from residential properties.

In terms of coastal risk, there is a divergence in sectors by region. In England, the top sectors in HFR areas are electricity and gas (4.88%) followed by accommodation and food (4.26%) whereas in Wales, coastal flood risk is much higher at 15.38% for all businesses in the public and administrative sector and 9.09% in the transport and storage sector (Appendix E). Geographically, England (9.06%) has the highest share of all business premises built in HFR zones between 2008-2018 (Figure 3).

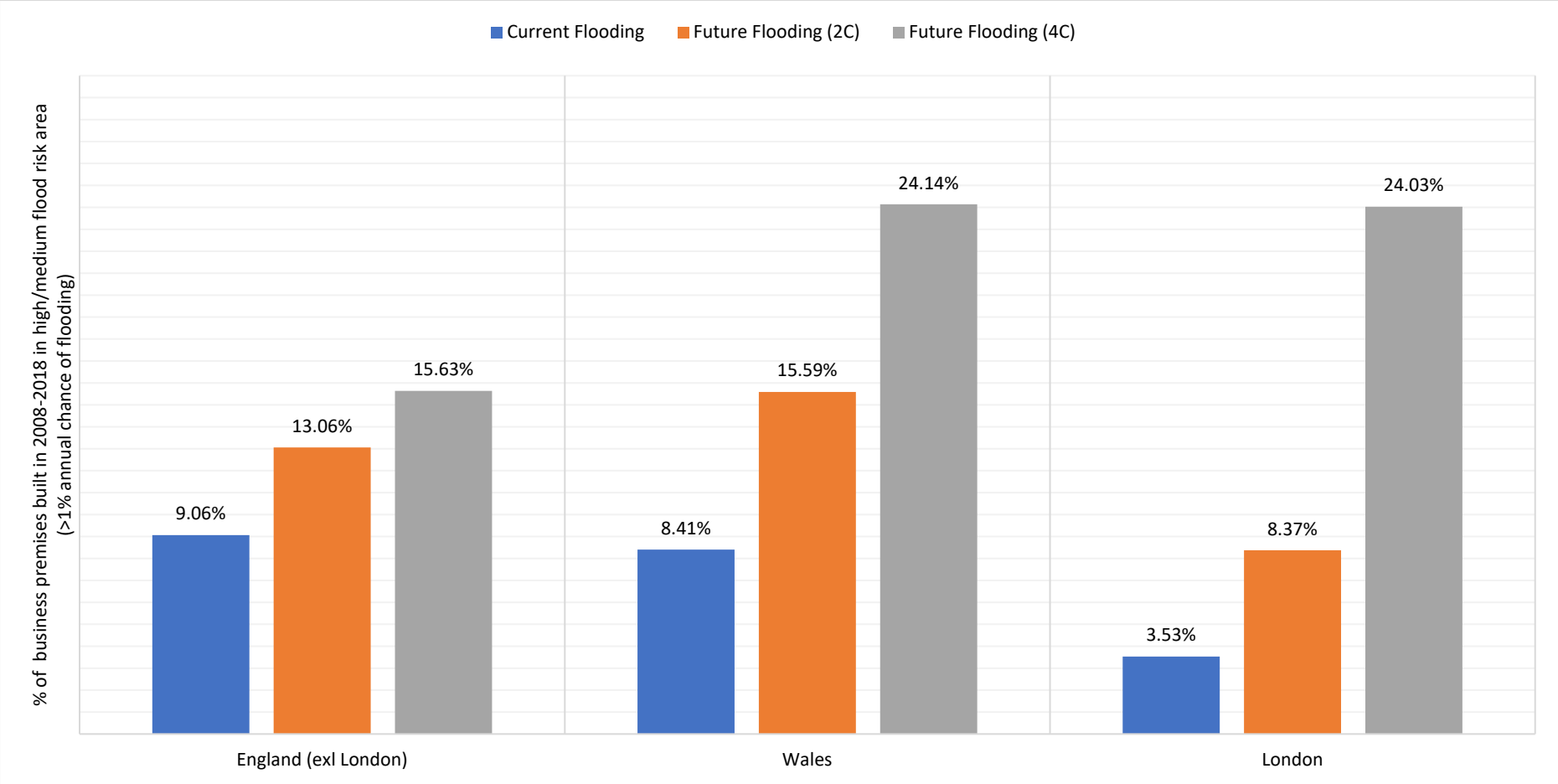


Figure 3. Percentage of business premises (built between 2008 and 2018) in HFR areas by region facing flood risk (2050 2C and 4C) (OS data, 2020)

Left bars: Under current flood risk levels. Middle bars: Under flood risk levels by 2050 with 2C warming. Right bars: Under flood risk levels by 2050 with 4C warming.

The future flood exposure is an indicator of locational lock-ins. In terms of future risk, 10% of all new business premises built in 2008-2018 are exposed to flood risk under a 2C scenario and 15% are in HFR zones in a 4C scenario by 2050. This modelling is under the assumption that no new adaptation measures are being undertaken. The importance of adaptation measures are further discussed in section 5.

Similar to current flood exposure, future exposure of businesses built between 2008 and 2018 is mainly in information and communication (40%), water services (28.6%) and electricity sectors (23.4%), with highest percentage of business premises in HFR zones in a 4C scenario, seen in Figure 4. The implications of the disproportionate impact for certain sectors is further explored in section 4.3.

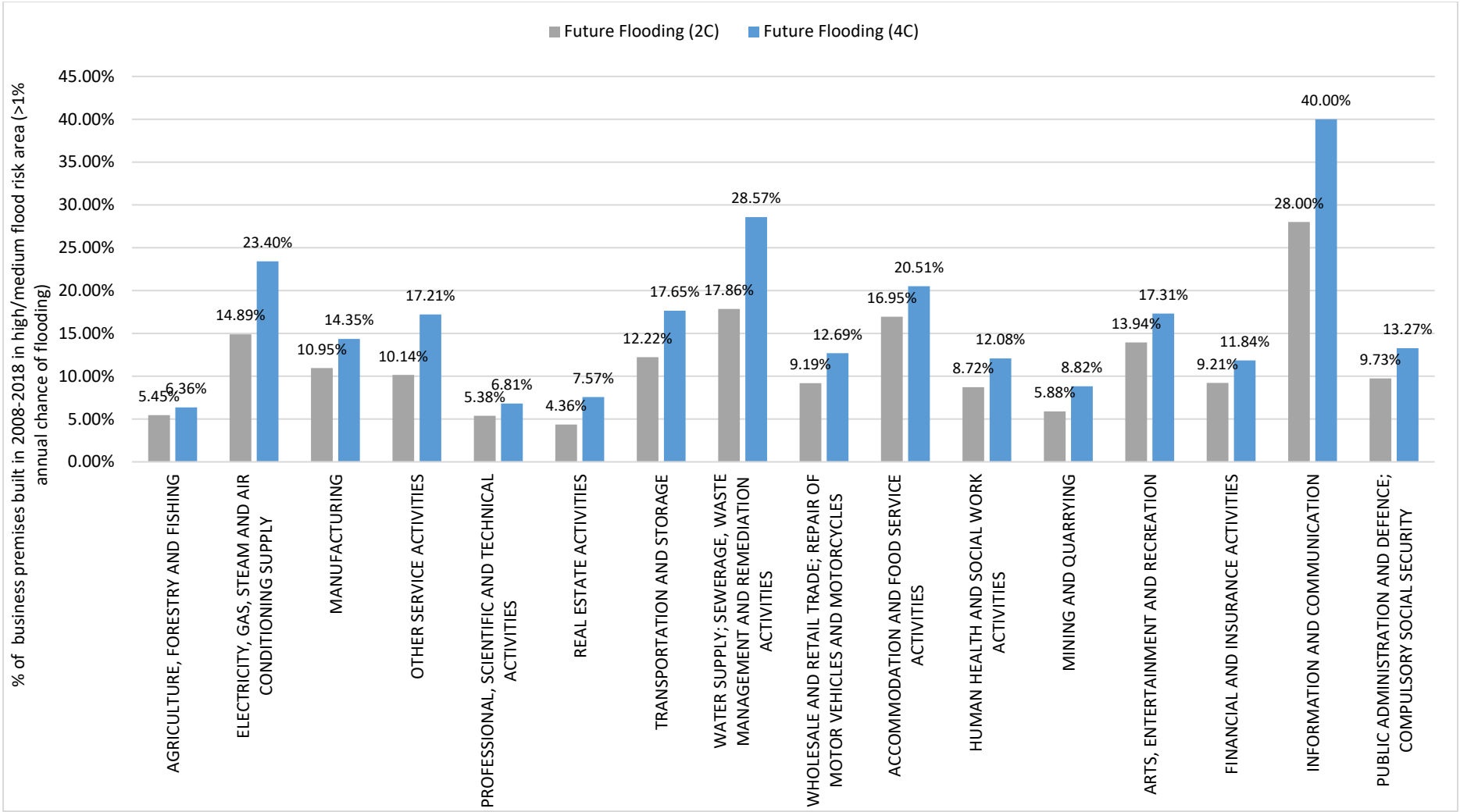


Figure 4. Percentage of business premises (2008 - 2018) affected by future changes in flooding risk (2050 2C and 4C) by sector (OS Survey, 2020)

Beyond sectoral divisions, there are also differences in location (Figure 3). Risk from lock-ins based on site selection decisions are highest in London and Wales with 24.03% and 24.14% of premises built between 2008 and 2018 projected to be in a HFR area by 2050 under a 4C scenario, respectively (see Figure 3). Future coastal flood exposure of these premises is expected to be highest in Wales, with 5.62% business premises at HFR under a 2C scenario and 10.29% premises at risk under a 4C scenario by 2050. This does not account for areas that currently have no quantifiable risk of flooding but might be affected in the future. This is because the data only accounts for a change in flood risk in areas that are already at some risk of flooding (including cases where the risk of flooding is currently very low, but flooding is theoretically possible).

4.3 Findings of the GRI business survey and drivers of lock-in risks

In response to the second research question, we use the GRI survey results (introduced in Table 2) and the case study presented in 4.2 to understand the drivers of locational lock-ins. The key factors investigated include 1) physical risk perception, 2) physical risk quantification and 3) levels of physical climate risk assessment. These factors were investigated given the lack of granularity on all these measures from previous business surveys.

Low physical risk perception
Physical risk awareness is essential for corporates to reduce economic losses (Gasbarro et al., 2017). In terms of business flood perception reported in the GRI survey, all those businesses surveyed in the information and communication sector in England and Wales consider surface water flooding as one of the most important future climate risks to their business. This may indicate higher awareness and support for adaptation measures in highly vulnerable industries (Figure 4) and warrants further research. Risk perception is the lowest in the services (24%) and construction (25%) sectors in England. Overall, businesses in Wales are more concerned than businesses in England about flood risk as seen in Appendix C. Results are similar for risk of surface water flooding identified in the GRI survey, with some sectors, such as agriculture in England (75%) more concerned about surface water flooding than fluvial and coastal flooding. Results are disaggregated for London in the GRI survey, where businesses in water supply and management and information and communication perceive surface water flooding to be one of the most important future climate risks. Lowest risk perception is in the real estate industry (25%) in Wales and in construction (25%) in England.

Business perception is in line with flooding experience over the last year. For example, all respondents to the GRI survey in Wales in the professional and scientific and arts sectors experienced fluvial and coastal flooding directly or indirectly last year (Appendix D). This corresponds with high business perception of flood risk in these sectors. Similarly, business perception of surface water flooding is related to direct or indirect impact last year. Surprisingly, while all real estate businesses in England experienced surface water flooding in the past year, only 67% of businesses perceived it to be an important future climate risk. This is consistent with CCRA 3 findings (Surminski et al, 2021), which highlight that low previous flood history and inexpensive flood insurance in some sectors results in low-risk perception, disincentivising businesses from prioritising risk-sensitive investment and taking adaptive action.

The GRI survey results demonstrate that while most businesses (45.38%) are concerned about possible climate risks, these are not assessed by them. According to the GRI survey, most common risks perceived by businesses were surface water flooding (22.73%), heatwaves (18.88%) and fluvial and coastal flooding (14.69%). These hazards impacted businesses via increased operation costs, physical damage, and reduced labour productivity. This is similar to the results of other business surveys reviewed, such as a recent organisational risk survey conducted by the Centre for Climate Change Economics and Policy (CCCEP) (Dookie, Conway and Dessai, 2021) and the CDP business survey, one of the most comprehensive business surveys reviewed.

While risk perception is captured in the GRI survey only 20.17% of firms conduct periodic risk assessments which are followed up by identifying and implementing solutions. Moreover, there is no streamlined way of quantifying physical risks. For instance, even though over half of the firms (51.49%) in the GRI survey experience a financial impact, most cannot quantify this. This confirms existing literature which indicates that even when risk assessments are conducted, these are based on varying methods, assumptions and models. Low risk perception is also demonstrated in the divergence between business decision making (short-term horizon as captured in the GRI survey) and climate risk horizons (2050 scenario explored in the flooding data), resulting in risk-awareness gaps.

Risk awareness-exposure gaps are concerning given the longevity of site location lock-ins, given the lifespan of commercial real estate. While commercial buildings in the UK are often refurbished within 25 – 30 years (Pearman, 2011), not many are demolished. Therefore, the "effective lifetime", or "projected life" of buildings can be up to a thousand years (UCL Engineering, 2021).

Risk awareness-exposure gaps in the case study of flooding in England and Wales

Business premises were mapped against the GRI business survey sector classification (Appendix F). Given the current and future flood exposure (see in section 4.2), there are numerous gaps in business perception of risk both at the sectoral and regional level. Economically critical sectors with a high percentage of new built premises in HFR areas, such as finance and insurance (9%) and manufacturing (8%), fall between the 10^{th}-50^{th} percentile of both fluvial and coastal flooding and surface water flooding risk perception, indicating that businesses are not adequately aware of current flooding risks.

In a similar vein, as per the GRI survey, agricultural, forestry and fishing businesses are most likely to be expecting future flood risk. This is in line with the literature, which demonstrates high physical risk awareness amongst agricultural businesses due to direct natural capital impacts (Crick et al., 2018) and quantified damages (Ritchie et al., 2020). They are also most likely to have experienced flooding in the last year. Nonetheless, as per the case study results, only 7% of new businesses premises built in 2008-2018 are in HRF areas.

The indicative awareness-exposure gaps in these sectors may reflect internal organisation disconnect. For instance, one way to strengthen the GRI survey would be to identify who is filling out physical risk surveys. Responses can vary significantly between CEOs, CROs and site location managers. For example, site managers may be most informed on day-to-day functioning at the site level whereas CEO responses may reflect whether physical risk is perceived as a strategic business priority.

Some awareness-exposure gaps may also be due to differences in classification in the OS AddressBase database. For example, the risk awareness-exposure discrepancy in agriculture may be because the OS AddressBase data focuses on business premise exposure, such as farmhouses or storage facilities, as opposed to decline in crop yields, land quality or livestock impacts. Therefore, high risk perception in the sector could be resulting from risk to income streams or geographic concentration of risks. In some sectors such as finance and insurance, low risk perception is surprising at first instance given higher uptake of scenario analysis (UNEP-FI, 2019) and stress-testing in the sectors (Prudential Regulation Authority, 2019). This suggests that site location or business operations may be of lower priority in the industry. For example, in finance, most revenue is generated from intangible as opposed to physical assets.

Finally, risk awareness-exposure gaps can also be identified by region. For example, although 86% of all firms surveyed in London consider flooding to be the most important future climate risk to their business, by 2050, under a 4C scenario 24.03% of all newly built premises between 2008-2018 in London will be in HFR zones. This indicates that businesses concern over climate risks are not influencing their decision-making, resulting in lock-ins.

These results are in line with the literature, which shows that a linear and incremental perception of physical risk results in lack of understanding and quantification of tail risks. Businesses consider physical risks to be manageable whereas in fact, high uncertainties and large expected losses should entail more aggressive policies than prescribed under standard benefit-cost analysis methods (Nordhaus, 2011; Weitzman, 2011).

Quantification of financial impacts

Low quantification of financial losses from flood risk were investigated as a potential driver of site-location lock-ins. As per the GRI survey, merely 13.40% of business impacted by flooding could specify quantified impact (Figure 5). Of the firms that have quantified financial impact in the GRI survey, impacts range between £12,000 - £250,000 over 2019-2020.

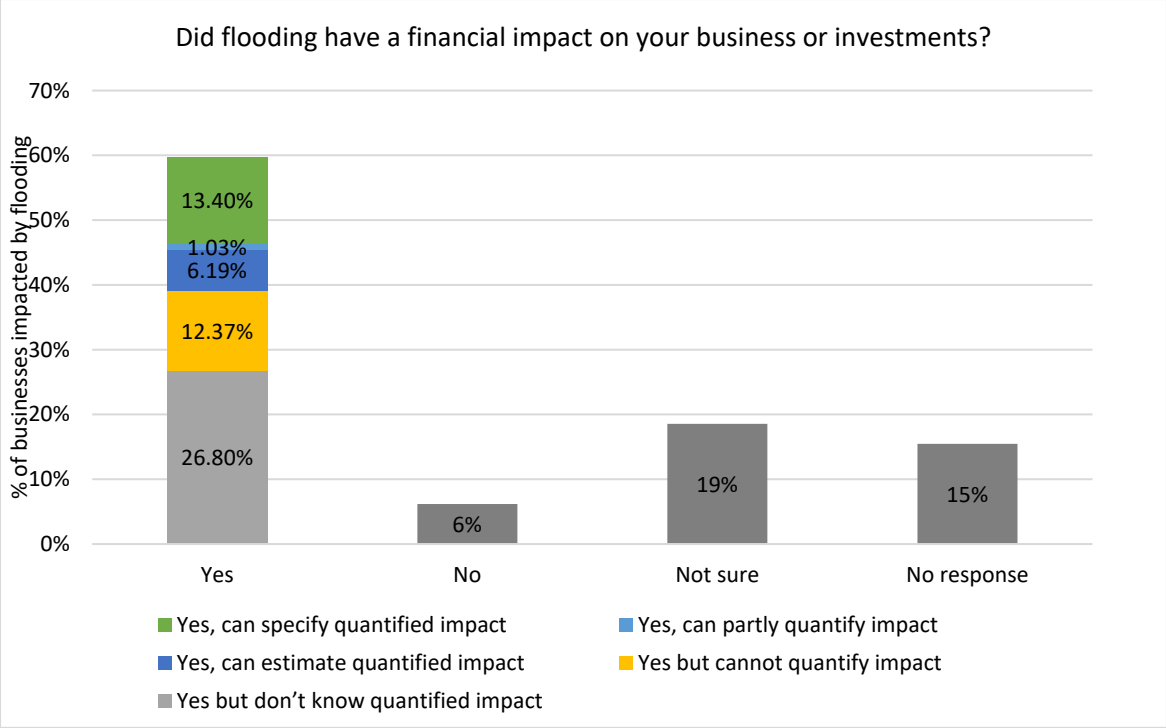


Figure 5. Financial impact of flooding on business or investments in the last year (GRI Survey, 2020)

Despite the poor quantification of financial impacts, 49.5% of businesses affected by flooding in the past year expect potential financial impact to increase over the next 3-5 years, as per the GRI survey. The financial impacts expected from flooding are higher than the average across climate hazards (38.61%). Of the businesses that are expecting financial impacts to increase, 28.87% expect an increase between 1-5%, seen in Figure 6.

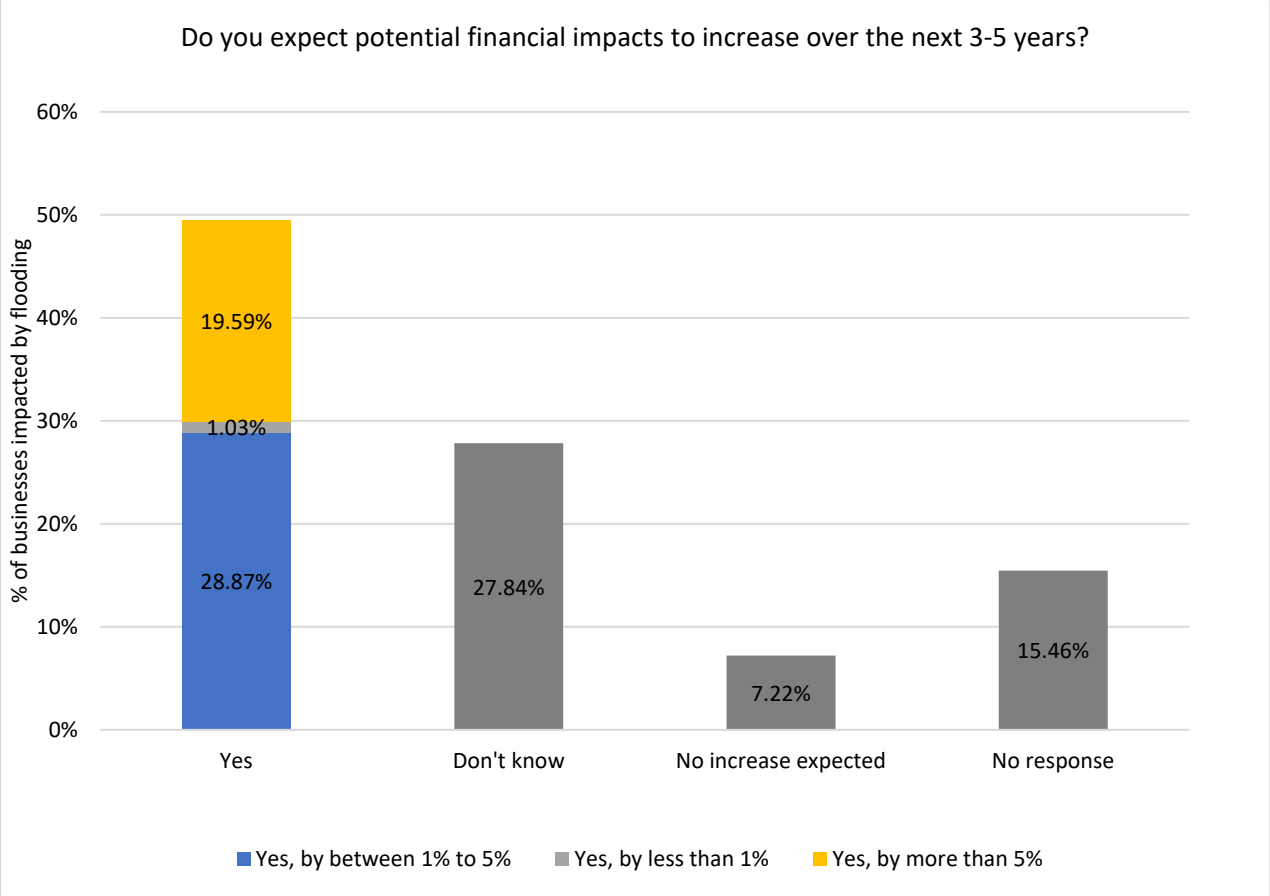


Figure 6. Expected increase in potential financial impacts from flooding (GRI Survey, 2020)

Most businesses expect only minor increases in direct loss and damage over the next five years, despite recent increases in flood exposure. For instance, on average 8% of all new business premises built between 2008-2018 are located in HFR areas, as found in section 4.2. Moreover, only 32.6% of all businesses surveyed, are investing in 'hard' engineering solutions, such as upgrades to flood protection. Therefore, the total amount of expected damage could be higher given the extent of infrastructure exposed.

When the GRI results are triangulated with studies using physical climate risk data, it is evident that corporate reporting on financial impacts from physical climate risks remains incomplete (Li et al., 2020; McKinsey Global Institute, 2020; Surminski et al., 2018; TCFD, 2019). Concerningly, lock-ins to site-location decisions can exacerbate future financial impacts. This holds true for lock-ins beyond the scope of this case study, such as lock-ins in supply chains.

Corporate physical risk assessment

Business assessment of physical risks is essential to inform adaptive decision-making. This in turn can reduce the emergence of lock-in effects (Gasbarro & Pinkse, 2016; Peace et al., 2013). However, as per the GRI survey, physical climate risk is only discussed at the board level within 52.34% businesses. Interestingly, SMEs are more likely to discuss climate risks at the board level (58%) than larger firms (Appendix G). While this could be attributable to the survey sample, there is some literature supporting these findings. For instance, IDB (2020) posit SMEs are better positioned to create innovative resilience solutions and

capitalise on local opportunities. However, there is no evidence indicating climate risk discussions directly inform business location decisions.

Similarly, disclosure and reporting mechanisms can incentivise uptake of physical climate risk assessment. For example, among GRI survey respondents, businesses which are disclosing financial impacts of physical climate risks to regulators and investors are more likely to have climate risk as part of their governance mechanisms (Appendix G). Early identification can prevent lock-ins from emerging. However, majority of businesses which discuss climate risk at the board level are not reporting on climate risks (41.8%) (Appendix H). Of those that are reporting risks, most convey results via sustainability reports (35.8%), annual reporting (19.4%) and other statutory reports for regulators (16.4%). Moreover, the majority of businesses (54.46%) are not disclosing financial impacts to investors and regulators. This is unsurprising given that adoption of TCFD recommendations is mainly prevalent amongst larger listed companies. These findings indicate that not all climate risk board discussions lead to disclosure, reporting and importantly, changes in business decision-making.

5.Conclusion

This paper explores corporate lock-ins to physical climate risks by looking at business perceptions and awareness and assessing locational lock-ins to flooding in England and Wales. Lock-ins may arise due to 1) low awareness of physical climate risks, 2) poor quantification of financial implications and 3) inadequate corporate risk assessment. We show that physical climate risks (as seen in the flooding dataset used) have lower materiality in view of shorter-term business horizons (3-5 years as explored in the GRI survey). Consequently, results indicate that businesses are underestimating physical climate risks. When risk assessment does occur, there is little evidence of risk-informed decision-making. Gaps in risk awareness and exposure, demonstrate the need for urgent action in specific sectors such as manufacturing and finance. These results have significant consequences including site-level damages, asset write-downs, stranded assets and development implications. Our analysis offers insights into corporate climate lock-ins and provides lessons for those who are tasked with managing climate risks at corporate and government levels as well as for researchers who are supporting this through their analysis.

The modelling assumed no property level adaptation measures in place, demonstrating that lock-ins can be damaging in HRF areas, especially if businesses do not implement sufficient measures to manage risks. In particular, the risk from surface water flooding to businesses may be higher than the risk from fluvial and coastal flooding given uncertainty and heterogeneity of surface water flooding. Moreover, surface water flooding lock-ins can have higher private costs than fluvial and coastal flooding since coastal and river flood protection is better defined by the government (Environment Agency, 2009). In such cases, government oversight may be required via information provision, such as updated surface water flood maps and data granularity at the business premise level.

Infrastructural lock-ins can be exacerbated by overreliance on ‘hard engineering’ solutions, such as flood protection. Such lock-ins can have threshold effects and entail additional carbon costs (Goldstein et al., 2019). Maladaptive measures can be prevented by increasing business awareness and trust in a wide-range of adaptation options, like Nature-based Solutions (NbS) (Surminski & Szoenyi, 2019). The current reliance on insurance to meet

business flood risk losses is being tested by the increased magnitude and frequency of flooding events.

The GRI survey found that businesses that collaborate with regulators, suppliers, banks, investors and insurers, undertake a more diverse range of adaptation actions than their counterparts. Regulators can influence risk assessment by supporting stress testing, scenario analysis and disclosure. Whilst regulators in the financial sector have integrated this in their climate strategy, a more formal approach to physical risks is required in other sectors. Moreover, given that the magnitude of physical risks is likely to be underestimated, investors and insurers must be wary when interpreting outputs, particularly for asset classes which are exposed to multiple risks.

Given the momentum around mandatory TCFD disclosures, seen in the UK Treasury's announcements of mandatory financial and non-financial disclosures by 2025, businesses will have a first-mover advantage from conducting physical risk assessments and reporting risks pre-emptively and correctly (HM Treasury, 2020). This ambition is expected to increase in scope, as the IMF (2020) recommends incorporating climate risk disclosures in financial statements in compliance with the International Financial Reporting Standards in the long-term. Mandatory disclosure was also mentioned in stakeholder discussions of the CCRA as a means of increasing investor pressure (Surminski et al, 2021). Even though, the granularity and universality of disclosure is debatable, a baseline must be established to ensure businesses are aware of physical risks and potential lock-ins to adapt accordingly.

Ultimately, corporate climate-decision making should be undertaken holistically. The climate-economic development nexus deserves further attention given that lock-ins to physical climate risks jeopardise economic growth and sustainable development objectives. For instance, the impacts on employment and labour productivity in the aftermath of climate events requires a better understanding of the interface with SDG frameworks (Tsalis et al., 2020). Streamlining climate-related reporting with pre-existing sustainability standards can assist firms with this process (Impact Management Project et al., 2020).

Areas of further research

Early identification of lock-in effects necessitates improvements to scenario analysis and risk assessment techniques. Recent initiatives have included corporate physical risk frameworks to understand climate impacts on real estate lending and investment portfolios (Cambridge Institute for Sustainability Leadership, 2019). However, these fall short in fully incorporating lock-in risks and corporate maladaptation. Other initiatives, such as the Bank of England BES, is not a strict stress test, as it does not consider the resilience of firms to tail risks. Including tail risks in scenario analysis involves considering thresholds and non-linearities. This can prevent lock-ins to risky and costly business decisions by alerting firms of site exposures and vulnerabilities. Moreover, assessing future scenarios is difficult given uncertain and diverging physical risk exposure, socio-economic pathways and psycho-social dynamics (Bowen et al., 2020).

Physical risk impacts on businesses have not been explored in tandem with background risk (Cameron & Shah, 2015) or the presence of multiple risks (e.g. interdependencies between climate, health and development risks) (Stéphane Hallegatte et al., 2016; Martin & Pindyck, 2015; Sumner et al., 2020). For instance, in the flooding case study considered in section 4, physical risk exposure to coastal flooding can be exacerbated by sea level rise, or other ecological thresholds being crossed (Bowen et al., 2020). These areas require advancing current modelling techniques. From a policy perspective, it would be helpful to investigate whether there is a correlation between industries most vulnerable to physical climate risk and awareness and support for climate adaptation. For example, does high vulnerability to future climate risks in sectors such as the information and communication technology sector have implications for the expansion of the digital economy? This could help generate more awareness of lock-ins and build a corporate case for avoiding these.

6. Appendix

Appendix A: Flood risk exposure data and methodology

The business property level dataset for newly constructed business premisses between 2008 and 2018 in England and Wales is based on location and industry type from the AddressBase Premium product provided by the Ordnance Survey (2019). The dataset was filtered by property type and introduction year of a new postcode using the ONS (Office for National Statistics, 2019) directory, to identify new business premises and the year of their completion.

Overall, the flood risk of a new business premise is based on whether the geolocation of the property is inside a flood risk area defined by the official risk maps for flooding from river and sea (fluvial and coastal flooding) and from surface water in England and Wales. The 'risk of flooding from river and sea' (RoFRS) and 'risk of flooding from surface water' (RoFSW) maps have a spatial resolution of 50m, are publicly available and consider pre-existing flood defences and their present condition (Environment Agency, 2020a, 2020b; Natural Resources Wales, 2020a, 2020b).

The 2050 scenarios for flood risk as a result of climate change are estimated for different flood types (coastal, fluvial, surface water) across England and Wales. The two scenarios presented are based on definitions by the UK CCC on: a lower end scenario based on a 2° change in Global Mean Temperature (GMT) (2C) and a 4°C change (4C) (Kovats & Osborn, 2016). Business premises are considered as being at a high to medium risk of flooding (HFR), when the property is in an area with a 1% or higher annual chance of fluvial and surface water flooding and a 0.5% or higher annual chance of coastal flooding.

Appendix B: Review table of pre-existing business surveys

Key features	% out of 67 surveys reviewed
Reporting on physical risk	12%
Differentiating between current versus future risk	6%
Differentiating between risk to specific business functions (e.g., supply chain, capital, location, employees, distribution, products and services)	6%
Differentiating between risk and opportunities	7%
Quantification of financial impact/loss	9%
Include location-specific analysis (e.g., country-level or lower focus)	24%

Disclosing scenario analysis uptake	3%
Disclosing climate modelling used	1%
Reporting under CDP, TCFD, other voluntary disclosure platforms	12%

List of all 67 surveys reviewed (2008-20)

#	Business Survey Name	Date
1	Climate change adaptation in the UK wine sector: Managing risks and opportunities in cool climate viticulture / Temporal and relational dimensions of adaptation in UK viticulture, CREWS Paper, 2020	2020
2	IIF/EBF Global Climate Finance Survey	2020
3	EY Barometer	2020
4	Deloitte Climate Check Survey	2020
5	TPI 2020 survey	2020
6	The PW/UKGBC Climate Crisis Perceptions Survey, 2020	2020
7	PwC CEO Survey	2020
8	WEF and PwC CEO Survey	2020
9	Marsh, Resiliency: Adapting to Extreme Weather Events and a Changing Climate	2020
10	The Importance of Climate Risks for Institutional Investors, European Corporate Governance Institute	2020
11	Private Markets for Climate Resilience, Global Report, NDF	2020
12	The Responsibility100 Index, Tortoise	2020
13	Deloitte Goal 13 Impact Platform	2020
14	Captains of Industry research study, Carbon Trust (2019)	2019
15	Aon (2019), Global Risk Management Survey	2019
16	FTI Consulting (2019), Resilience Barometer 2019	2019
17	Resilience: Risk, reward and resilience: what businesses think, EY and Resilience First, 2019	2019
18	BCI Supply Chain Resilience Report 2019, BCI and Zurich Insurance, 2019	2019
19	Feeling the heat? Companies are under pressure on climate change and need to do more, Deloitte Sustainability Services, 2019	2019
20	TCFD 2019 Status Report	2019
21	Climate-related corporate reporting (FRC, 2019), LAB survey	2019
22	CDP 2018, Major risk or rosy opportunity: Are companies ready for climate change?	2019
23	KPMG CEO Outlook	2019
24	Oil pressure gauge: 2019 survey of fund managers' attitudes to climate risk and investment in fossil fuel companies, UKSIF	2019
25	Leading With Impact: 2019 Authenticity Gap Report	2019

26	You Gov, Perception for climate action responsibility	2019
27	ACI: Resilience and Adaptation to Climate Change Survey	2019
28	PwC SDG Challenge 2019	2019
29	WWF, Scotland Companies Survey	2018
30	PRA review, Bank of England	2018
31	Client Earth and You Gov (2018) A survey of UK attitudes towards climate change and its impacts	2018
32	CDP Climate Change Disclosure 2018	2018
33	Schroders: Port Industry Survey	2018
34	Got it covered? Insurance in a changing climate (ShareAction and TCFD)	2018
35	Bain Transforming Business for a Sustainable Economy survey	2018
36	Physical Risk Assessment, Schroders	2018
37	DNV GL Are companies resilient enough to climate change?	2017
38	CDP Climate Change Disclosure 2017	2017
39	Crick, F., Eskander, S., Fankhauser, S., & Diop, M. (2018). How do African SMEs respond to climate risks? Evidence from Kenya and Senegal. World Development, 108, 157–168.	2017
40	Asariotis, R. et al. (2017) Port industry survey on climate change impacts and adaptation	2017
41	UNFCC Adaptation Committee, Advancing the engagement of the private sector in adaptation, Results of the survey of private sector organizations	2017
42	Insurer climate risk, Ceres	2016
43	ONS Survey consultation, also in CCRA Evidence list	2016
44	BSR, Four Twenty-Seven and Notre Dame Global Adaptation Index	2015
45	PwC CEO Survey	2015
46	Business NZ: Business survey on climate change	2015
47	Federation of Small Businesses (FSB). 2015. “Severe Weather: A More Resilient Small Business Community”. http://www.fsb.org.uk/frontpage/assets/fsb-severe-weather- report-final.pdf	2015
48	Climate-KIC. 2015. “European business is willing, but not equipped, for low carbon transition”	2015
49	Titans or Titanics? Understanding the business response to climate change and resource scarcity (Carbon Trust, 2015)	2015
50	Make it your business: Engaging with the Sustainable Development Goals	2015
51	IEMA Beyond the Perfect Storm	2014
52	Charted Management Institute	2014
53	CEO Survey on Climate Change, PwC	2014
54	Acclimatise, Pilot Climate Change Adaptation Market Study: Turkey	2013
55	BSI Weathering Storm	2013
56	How Serious Is Climate Change to Business? BCG and MIT Sloan Management Review	2013
57	Weathering the Storm: Building Business Resilience to Climate Change, Centre for Climate and Energy Solutions	2013
58	IEMA, Climate Change Adaptation, Building the Business Case	2013

59	Climate North-East. 2012. "Business attitudes, perceptions, exposure and vulnerability to climate change – Executive Summary". Climate North- East.	2012
60	UNEPFI, Advancing adaptation through climate information services	2011
61	Managing Threats in a Dangerous World, Chartered Management Institute Business Continuity Survey 2011	2011
62	UK Trade & Investment.2011. "Adapting to an Uncertain Climate: A World of Commercial Opportunities".	2011
63	Caring for Climate, WRI, Oxfam, UN survey: Adapting for a Green Economy	2010
64	IPSOS Mori, A Survey of Private, Public and Third Sector Organisations	2010
65	PwC, Business leadership on climate change adaptation	2010
66	CMI, Business Continuity Management 2008	2008
67	Indian business and climate change - survey results, Carbon Copy	n.d.

Appendix C: GRI Survey: Business flood risk perception

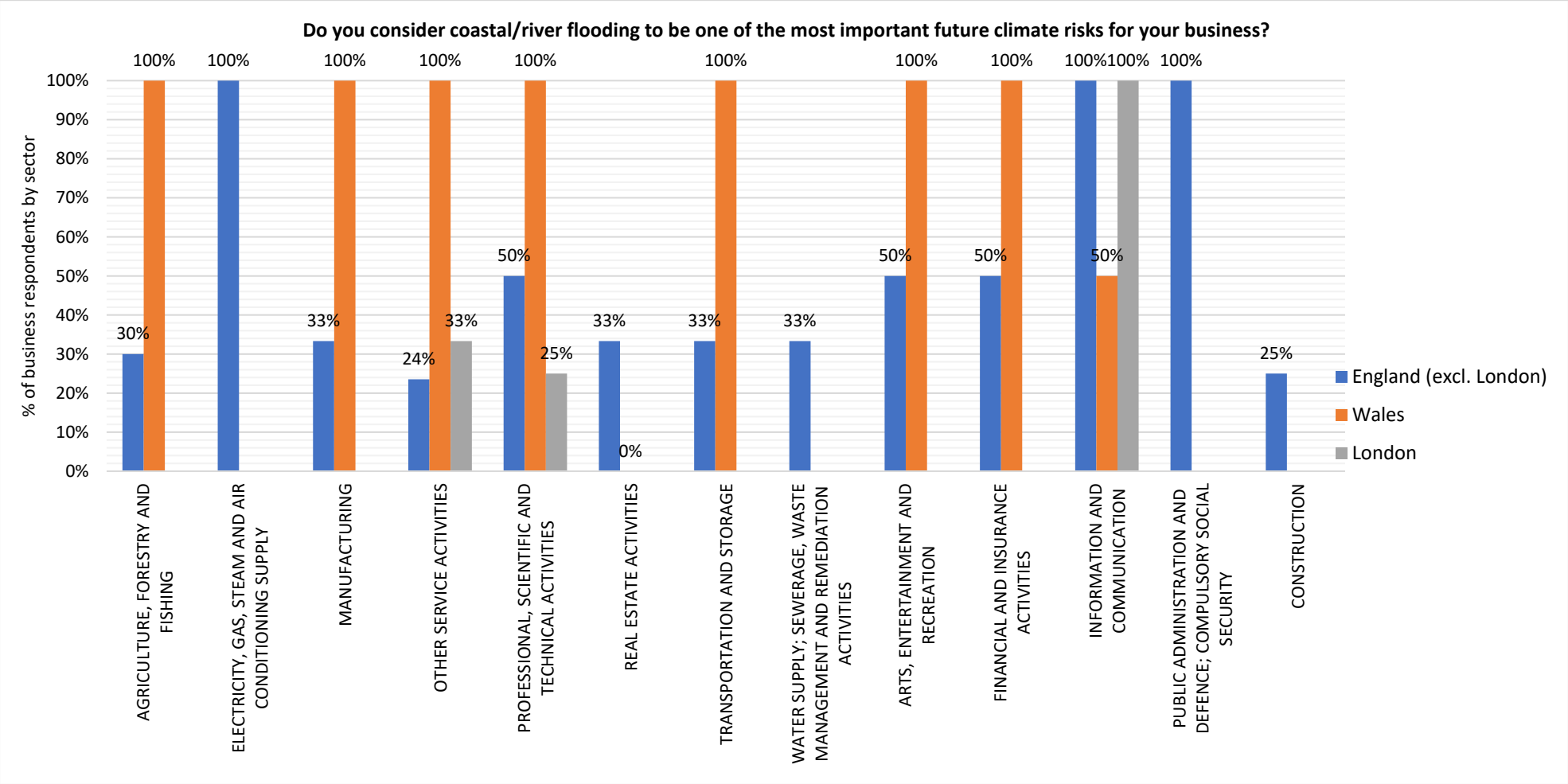


Figure C1. Perception of fluvial and coastal flooding by sector

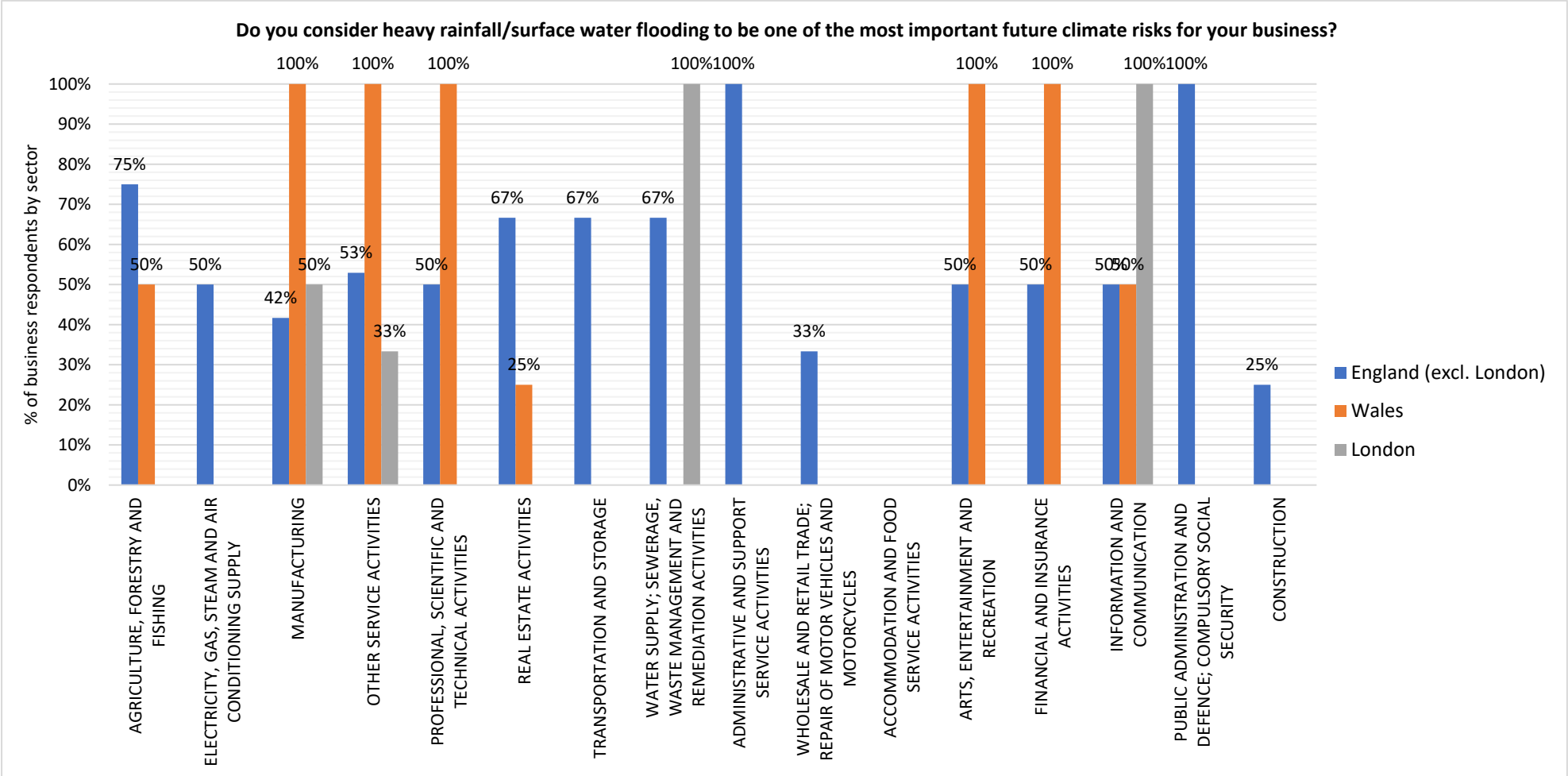


Figure C2. Perception of Surface water flooding by sector (GRI Survey, 2020)

Appendix D: GRI Survey: Flooding experience over the last year

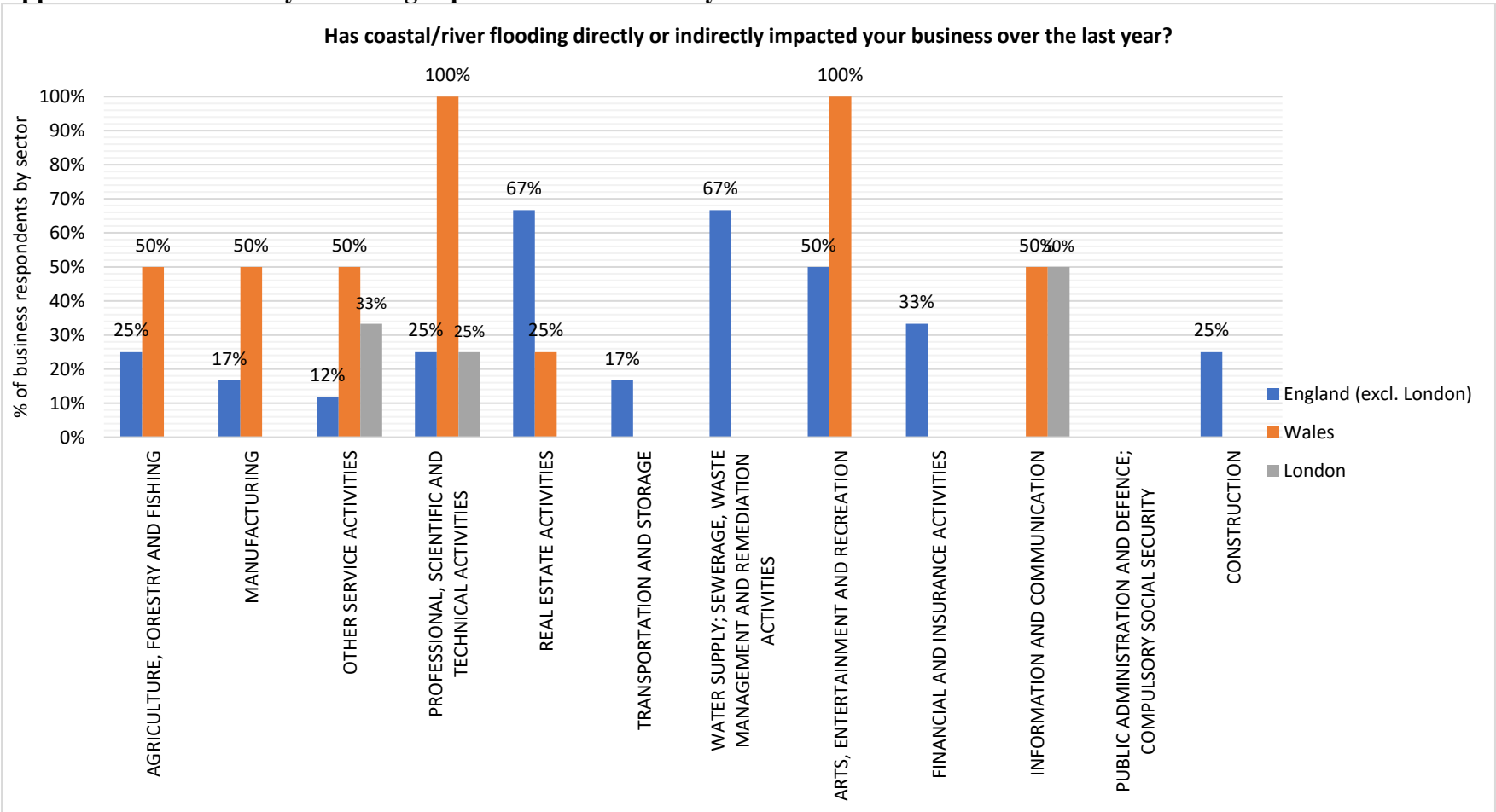


Figure D1. Coastal/river flooding experience over the last year (GRI Survey, 2020)

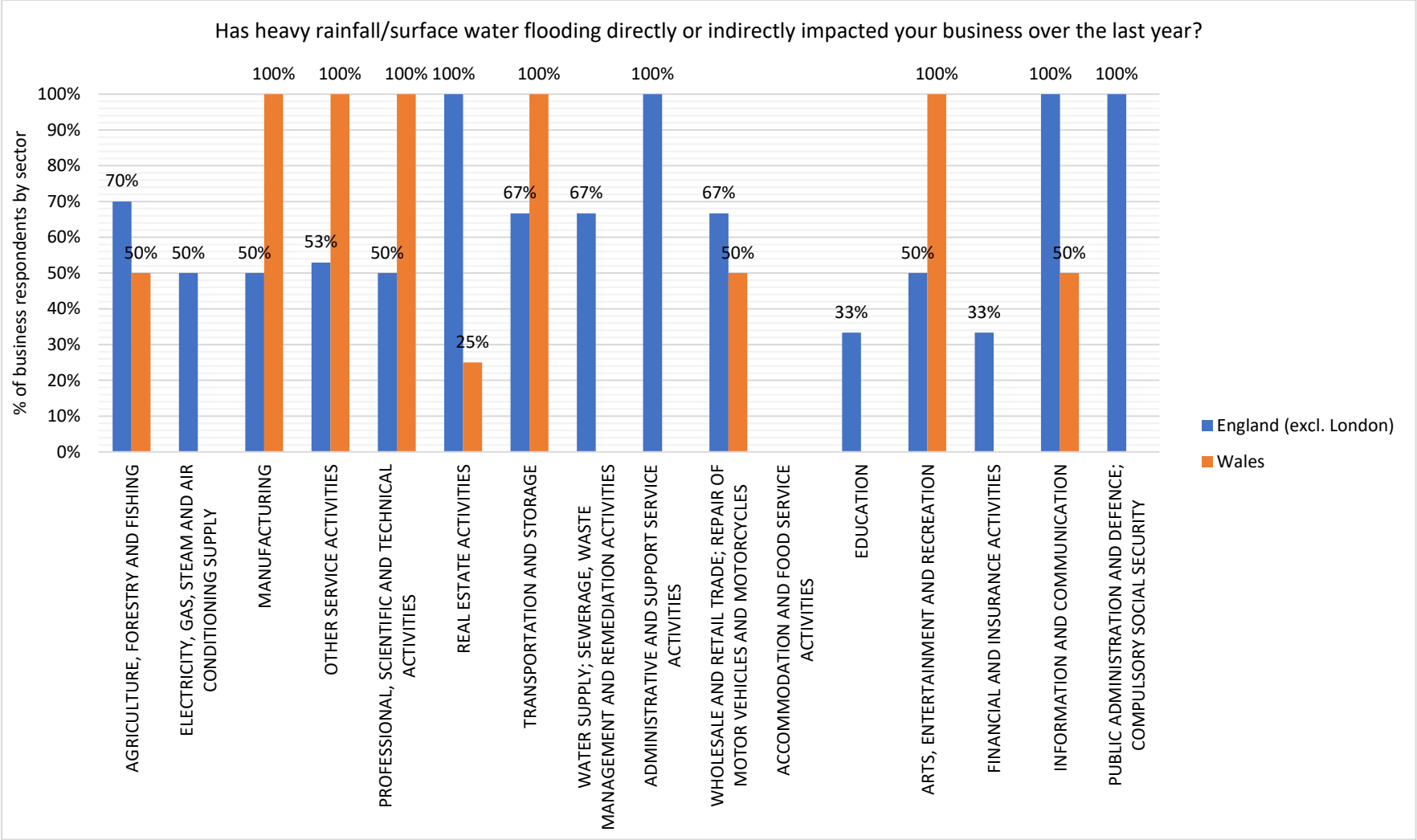


Figure D2. Surface water/fluvial flooding experience over the last year (GRI Survey, 2020)

Appendix E: AddressBase: Percentage of business premises facing flooding risk

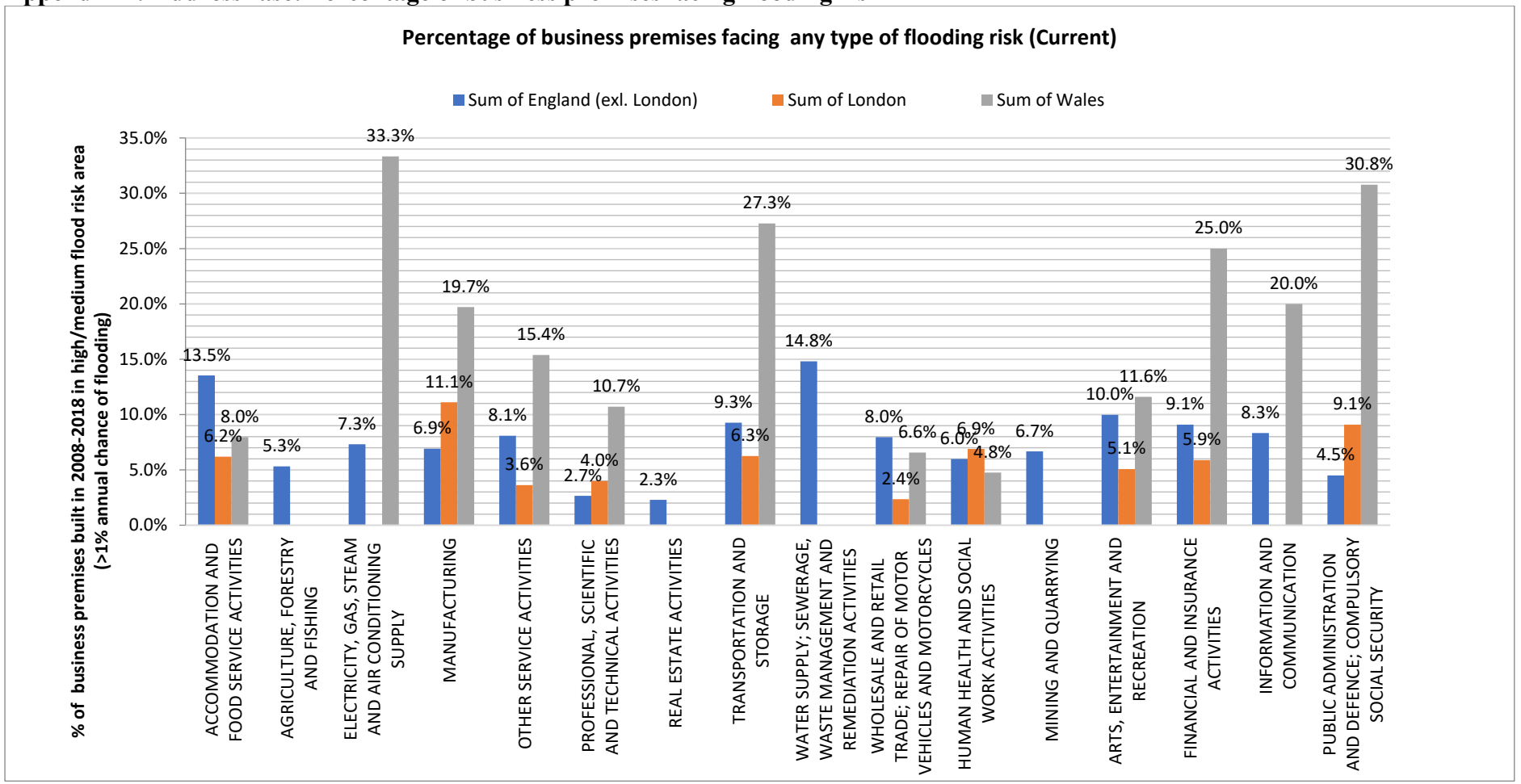


Figure E1. Percentage of business premises in HFR areas (surface water, fluvial and coastal flooding) by sector and region (OS data, 2020)

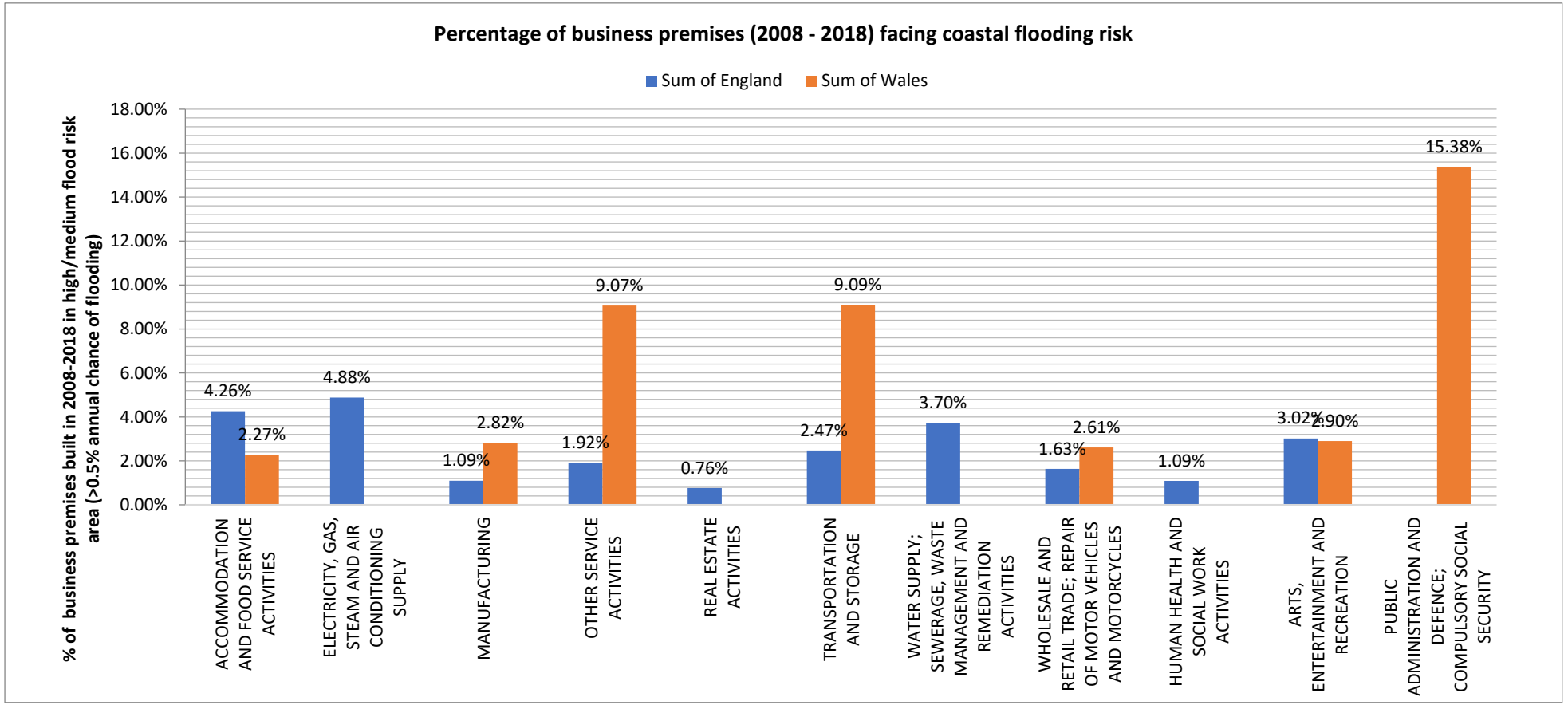


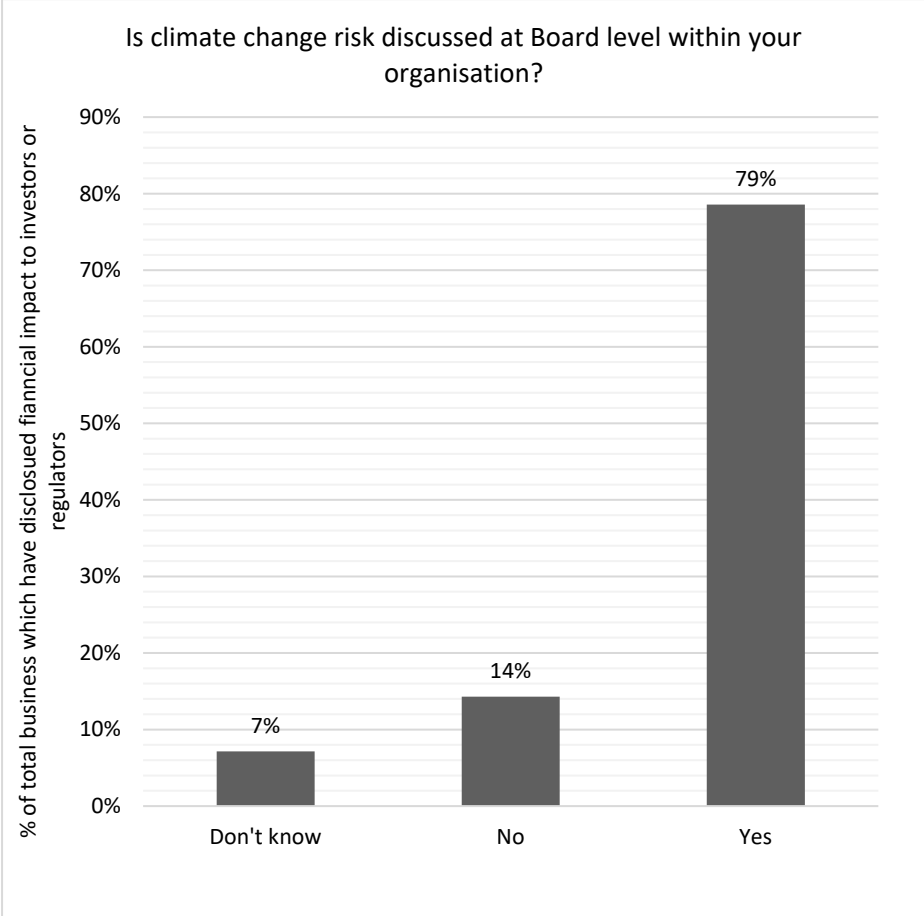
Figure E2. Percentage of business premises (2008 - 2018) facing coastal flooding risk by sector and region (OS data, 2020)

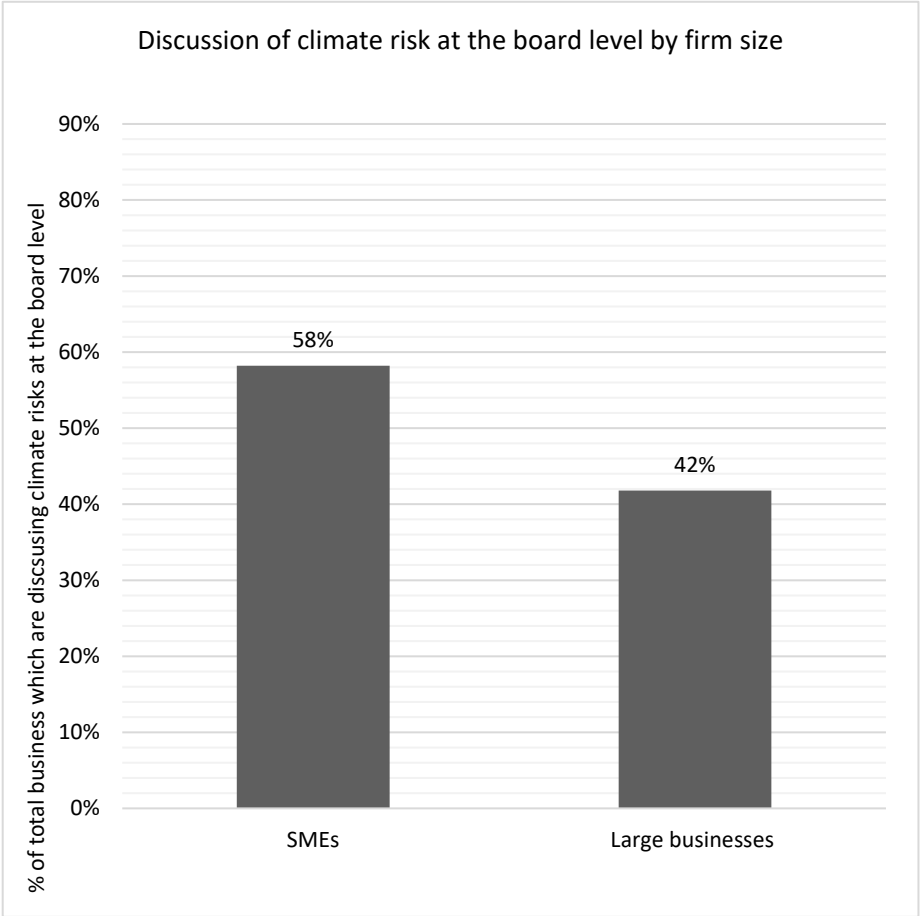
Appendix F: Business sector mapping AddressBase v CCRA

AddressBase	**CCRA**
Agricultural-All	AGRICULTURE, FORESTRY AND FISHING
Utility-Other	ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY
Industrial - Factory Manufacturing	MANUFACTURING
Office -Work/Studio; Retail - Licenced Vendor	OTHER SERVICE ACTIVITIES
Education-All	PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES
Retail - Retail Service Agent	REAL ESTATE ACTIVITIES
Transport-All	TRANSPORTATION AND STORAGE
Industrial - Incinerator/Waste Transfer Station; Utility - Waste Management; Utility - Water Waste Water Sewage Treatment Works; Utility - Landfill	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES
Retail - Market Indoor/Outdoor; Retail - Petrol; Retail - Shop/Showroom; Retail - Shop/Showroom; Industial - Light Industrial; Industial - Storage; Industial - Light Industrial; Industial - Wholesale; Industial - Recycling; Industial - Maintenance	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES
Hotel; Retail - Pub; Retail - Restaurant; Retail - Fastfood; Retail - ATM	ACCOMMODATION AND FOOD SERVICE ACTIVITIES
Medical-All	HUMAN HEALTH AND SOCIAL WORK ACTIVITIES
Industrial - Mineral Ore Working Quary Mine	MINING AND QUARRYING
Leisure-All	ARTS, ENTERTAINMENT AND RECREATION
Retail - Bank Financial Services	FINANCIAL AND INSURANCE ACTIVITIES
Office-Broadcasting	INFORMATION AND COMMUNICATION
Office-Other	PUBLIC ADMINISTRATION AND DEFENCE; COMPULSORY SOCIAL SECURITY

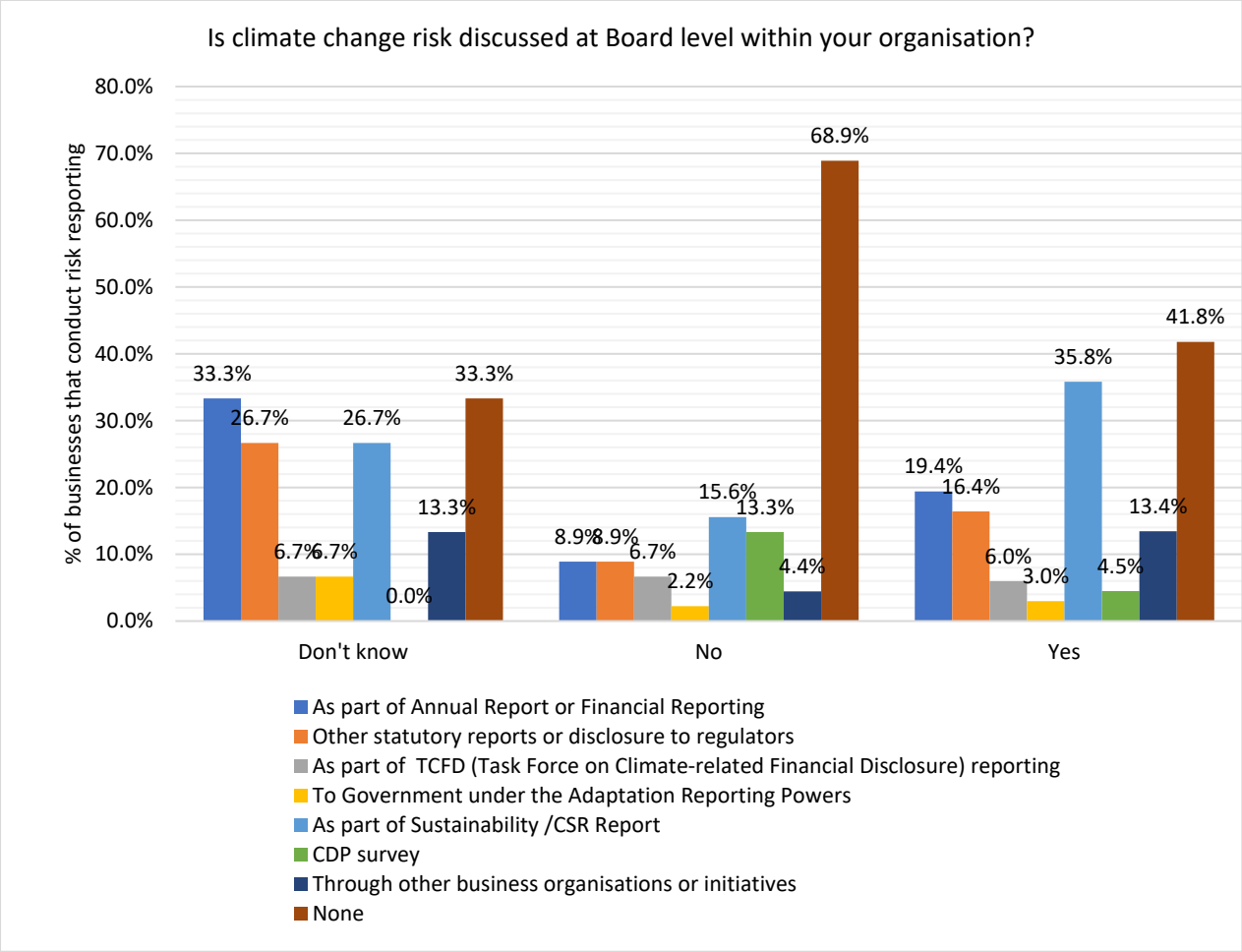
Appendix G: Board engagement v financial impact disclosure

In organisations where climate risk is discussed at the board level, financial impacts are most likely to be disclosed to regulators/investors.





Appendix H: Corporate climate risk governance and reporting (GRI Survey, 2020)



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