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New build homes, flood resilience and environmental justice – current and future trends under climate change across England and Wales

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Abstract. Despite improvements in the management of flood risk and the introduction of new regulations, losses from flooding remain high. An important driver is the continuation of new assets being built in flood prone locations. Over the last decade over 120,000 new homes in England and Wales have been built in flood prone areas. While the yearly rates of new homes in flood risk areas have increased only moderately on the national level, significant differences between and within regions as well as between different flood types exist. Using property level data on new homes built over the last decade and information on the socio-economic development of neighbourhoods, we analyse spatial clusters of disproportional increase in exposure and investigate how these patterns evolve under different future climate scenarios. We find that a disproportionately higher number of homes built in struggling or declining neighbourhoods between 2008 and 2018 is expected to end up in high flood risk areas over their lifetime as a result of climate change. Based on these findings, we discuss several issues regarding future spending on flood defences and affordability of private level flood protection as well as flood insurance in the face of climate change.

1. Introduction

Flood risk is commonly understood as a function of hazard, exposure and vulnerability and can be altered through de- or increasing any of the three components. The largest share in increases in flood risk and subsequent losses over the last decades in many areas of the world including the UK can be attributed to an increase in exposure [1], but is likely to be dwarfed by the effects of climate change induced sea level rise and changes of precipitation patterns over the coming decades [2]. Therefore, managing the creation of new risk through spatial planning and other incentives that aim to reduce the amount of new assets in flood prone areas (including areas that are likely to become flood prone in the future) and in some cases retreat is seen as a key component of long-term flood risk management and adaption [3]. At the same time altering the flood vulnerability of communities by making people and assets more resilient to flooding both through ex-ante adaptation and efficient ex-post recovery is increasingly included in both national policies and local flood risk management practice [4]. Resilience in this context means the ability of communities or individuals to manage their flood risk in a way that it enables them to pursue there social, ecological and economic development objectives over time (also described as "bouncing forward")[5]. Together with a gradual shift of the responsibility towards private households and businesses to manage their own flood risk over the last decades, the question of an uneven distribution in the capacity of communities, neighbourhoods and individuals to respond to and recover from flooding in the context of environmental justice is emerging in both the academic literature and policy debate [6, 7]. Understanding differences in social vulnerability and flood resilience is therefore seen as key for a sustainable long-term management of flood risk. In this context, several studies linking local deprivation with flood exposure have been conducted in the UK [8, 9, 10, 11, 12, 13, 14], the US [15, 16] and elsewhere [17]. However, only few studies have analysed the long-term changes under the effects of climate change and no studies are available that provide an empirical analysis that captures the recent and dynamic changes of flood exposure as well as its role for social vulnerability and the wider development of a community in the context of climate change. Yet, understanding the long-term effects of new properties and their flood exposure on the wider socio-economic development of communities is essential to improve future planning decisions where both trade-offs exist between the anticipated stimulation of the local economy through investments in the property market and the long-term effects of an increase in the exposure to flooding in a community. Not taking these trade-offs into account and not planning new properties in a resilient and forward looking way, can jeopardise the long term sustainability of these property developments, especially in cases where the flood hazard is increasing as a result of climate change. This is especially important where the requirement to factor in flood resilience measures when building new homes increases the costs of the project and might be attenuated or waived to not threaten its viability and affordability [18]. We address this lack of evidence on the long-term effects of recent increases in flood exposure in this paper for the example of England and Wales by investigating 1) where new homes have been built over the last decade in England and Wales geographically and over time 2) how they are contributing to the current and future flood risk of their neighbourhoods, and 3) how the socio-economic development of the neighbourhoods they have been built in might affect their long-term flood resilience under changing flood hazards as a result of climate change. We further discuss how the findings of this study can support identifying neighbourhoods that might face socio-economic tipping points as a result of flooding which can lead for example to sudden large-scale out-migration [19] following a flood event, significant increases in mortgage defaults and foreclosures [20] or drop in insurability with implications for systemic risk [21, 22, 23].

2. Background

In the past, flood risk management has been seen as an isolated task with the single purpose to prevent harm to people and assets from flooding, mainly through structural defences that should keep the water out [24]. Devastating flood disasters over the last decades in the UK and elsewhere with structural flood defences failing or being overtopped was a reminder that there is no absolute protection from floods, which led to increasingly risk based approaches [25, 21]. One component to manage floods in an risk-based approach is to avoid increases in exposure by shifting development to areas with the lowest flood risk probability [26]. In this context the Planning Policy Guidance Note 25 (PPG25) was introduced in 2001 in England and Wales making the Environment Agency a statutory consultee on applications for planning permissions in flood risk areas [27]‡. It requires the local planning authorities, who are largely independent in setting their local development plans, to perform a so-called sequential test that aims to prevent new developments being permitted in areas known to be at risk from flooding . In case this is not possible an exception test can be applied which regulates development in areas with higher flood risk under the condition that the sustainable benefits should out weight the increase in flood risk and that the new development is both resilient and resistant to flooding [29]. However, faced with competing interests and institutional agendas such as constrains on building on protected land (e.g. the green belt around urban areas in England) and pressure to meet national housing targets, local authorities in the UK frequently permit new developments in flood zones. The Adaptation Committee of the UK's Committee on Climate Change estimated in 2019 that 54,500 new properties were built between 2014 and 2017 [30]. While the planning system stipulates that new buildings should only been built in accordance with requirements to ensure their current and future flood resilience, set by the Environment Agency, there are no nation-wide data sets available to monitor whether this is met. In addition, most of these requirements are based on current flood risks not taking into account a potential future increase in flood risk as a result of climate change [18]. At the same time, the effectiveness of other attempts to disincentivise new homes in flood risk areas such as the exclusion of homes build after 2009 from the national flood insurance pool FloodRE remains unclear [21]. While the academic and policy debate about acceptable levels of property development in flood risk areas and how new buildings can be made more resilient continues, there are significant gaps in the understanding on how new properties in or near flood risk areas affect the wider long-term future sustainable development in the neighbourhoods and communities they are built in. This concerns both the potential changes to the flood hazard as a result of climate change as well as local socio-economic changes over the lifetime of new property developments. Based on the theoretical framework of flood disadvantage outlined by [6], we analyse where new homes over the last decade have been built in flood risk areas in England and Wales and investigate the links between the

‡ The planning policies are likely to be superseded by new legislation currently discussed and outlined in the *Planning for the Future* White Paper [28]

socio-economic development trajectories of the neighbourhoods they have been built in. We also investigate how climate change might affect these new homes over their lifetime by applying three different climate change scenarios as used by the UK Committee on Climate Change. This information is urgently needed for the called shift from mainly risk based approaches to a holistic forward looking resilience strategy that allows for a more just flood risk management.

3. Materials and Methods

We combine property level information of new residential dwellings built between 2008 and 2018 in England and Wales from the AddressBase Premium dataset provided by Ordnance Survey (OS) with information on their current and future flood exposure under three different climate change scenarios as well as the socio-economic development trajectories of the neighbourhoods the new residential homes have been built in. The flood risk of a new home is determined by whether the geolocation of the property inside a flood risk area defined by the official risk maps for flooding from river and sea (RoFRS) as well as from surface water (RoFSW) available for England and Wales. The flood risk maps have national coverage, include local expertise, and take into account flood defences and their condition.

Homes are considered as being at a high to medium risk of flooding (HFR), when the property is in an area with a 1% (0.5% for sea) or higher annual chance of flooding. Properties are at a low risk of flooding (LFR) in case they are located in an area with a 1% (0.5% for sea) to 0.1% annual chance of getting flooded (for further details see Appendix A.1.1 and Appendix A.1.2).

The change in the flood risk by the 2050s as a result of climate change is estimated for the different flood types (sea, surface, river) across England and Wales based on three climate change scenarios as defined by the UK Climate Change Committee (CCC) [31]: a lower end scenario based on a 2° change in Global Mean Temperature (GMT) (2C), a 4°C change (4C) and a worst case scenario (H++) which does not refer to a specific GMT, but is considered a credible high end change scenario. A total of 11,908 local impact areas with sizes ranging from 3 to 23 km^2 are defined across England and Wales to capture the local and flood type specific changes to the flood risk for the different climate change scenarios. Following the approach from [32] we derive impact functions for each of the local impact areas and flood types by counting the number of new build properties that would get flooded for a 3%, 1% and 0.1% annual chance of flooding. Assuming no future changes in structural flood protection, we use the different regional scenarios for changes in the return period or standard of protection for river, sea and surface water flooding and the local impact functions to calculate the change in the number of properties built between 2008 and 2018 having a 1% or higher annual chance of flooding for each flood impact area by the 2050s for the three different CC scenarios (see Appendix A.1.4 for details).

The information of the recently built homes and their current and future flood risk under climate change is then combined with information on the socio-economic development of the neighbourhoods the homes have been built in. The neighbourhood development trajectory data set developed by [33] uses gridded information on demographic characteristics, socio-economic development and housing data of decadal censuses from 1971 to first create representative neighbourhood typologies for each census year and then use sequence analysis to derive seven representative trajectories characterising the wider socio-economic development of neighbourhoods from longitudinal transitions of these neighbourhood typologies over time (see Appendix A.1.3 for details). The data is available on a 1 km^2 grid for England and Wales.

In accordance with the three research questions outlined in section 1, we conduct three different analysis:

First, we analyse year to year changes in new homes in flood risk areas for the period between 2008 and 2018, both in total and by flood type. We use the non-parametric Mann-Kendall (MK) test to analyse trends in the absolute number and share of new homes in HFR and LFR. The non-parametric Theil–Sen estimator is used to estimate the magnitude and direction of both the national trend for England and Wales as well for each local authority (LA) district with a significant trend based on the MK test [34]. The difference in slope from the Theil-Sen estimator between the national trend and the trend in each LA district is used as a measure for the strength of the local deviation from the national trend.

Second, we analyse spatial trends in flood exposure of homes built between 2008 and 2018. For that we analyse the number of new homes in HFR both for the current and the future flood hazard for the 2050s for the three CC scenarios. Hot spots are assessed by using local spatial auto-correlation. We use the local $G_i(d)$ statistic (local Getis Ord) to identify clusters [35] of local flood impact areas. For each local flood impact area the local $G_i(d)$ statistic is estimated based on the distance between neighbouring flood impact areas and both the respective absolute number and share of homes in HFR. The threshold distance for neighbouring flood impact areas was set that each area has at least one neighbour (see Appendix A.2.1 for details).

Third, we analyse how the flood exposure of homes built between 2008 and 2018 is distributed among different socio-economic neighbourhood types. We calculate for each of the seven neighbourhood types the difference between the share of all new build homes and those in HFRs. This difference provides a measure whether the share of homes in high flood risk areas for a specific neighbourhood type is higher (positive values), or lower (negative values) compared to what would be expected based on the overall distribution of homes built between 2008 and 2018 in the respective neighbourhood type. The difference is calculated for current and future flood risks under different CC scenarios to analyse how future changes in the flood hazard is affecting the exposure to flooding of recently built homes over their lifetime in different socio-economic neighbourhood types (see Appendix A.2.2 for details).

4. Results

For the property data set, we find that for current hazard levels around 5% of the 1.3 million homes built between 2008 and 2018 in England and Wales are located in HFRs. Another 10% of new homes were built in LFRs. The majority of the 62,413 homes in HFRs are either affected by river (42%) or surface water flooding (41%). Full summary statistics are presented in Table B1 in the Appendix.

Time trends

We find significant trends for the year-to-year rate of new build homes in flood risk areas in some local authority (LA) districts. Of the 335 LA districts in which new homes have been built between 2008 and 2018, 29 show significant trends for HFR and 38 for LFR. Of those LA districts with significant trends 7 LA districts for HFR and 9 for LFR have trends below the national trend, while the majority of LA districts with significant increases have trends above the national trend. Only three out of the 335 LA districts have significantly declining trends in the ratio of new homes built in HFR and 8 LA districts in LFR. Figure B1 in the Appendix shows all LA districts with significant year to year trends in new build homes in flood risk areas including their deviation from the national trend. For the absolute number of new build homes in flood risk areas in England and Wales between 2008 and 2018 we find a significant increase in numbers in LFR and a non-significant increase in HFR (see Figure 1). Looking at the different flood types, we find that the rate of new homes built in areas at risk from surface water flooding has almost tripled between 2008 and 2012 and remains at a high level after reaching a peak in 2012, while the rate of new homes in areas at risk from river has decreased over time. Figure 2 shows the yearly rate of new build homes by flood type for HFR and LFR respectively. These findings can in part be explained by changes in the planning system, and also reflect the availability of flood risk maps: flood risk maps for river and sea were formally introduced in today's shape and form in 2004, while the surface water flood risk maps were introduced in 2013, around the time when the rate of new homes at risk from surface water flooding starts to stabilize.

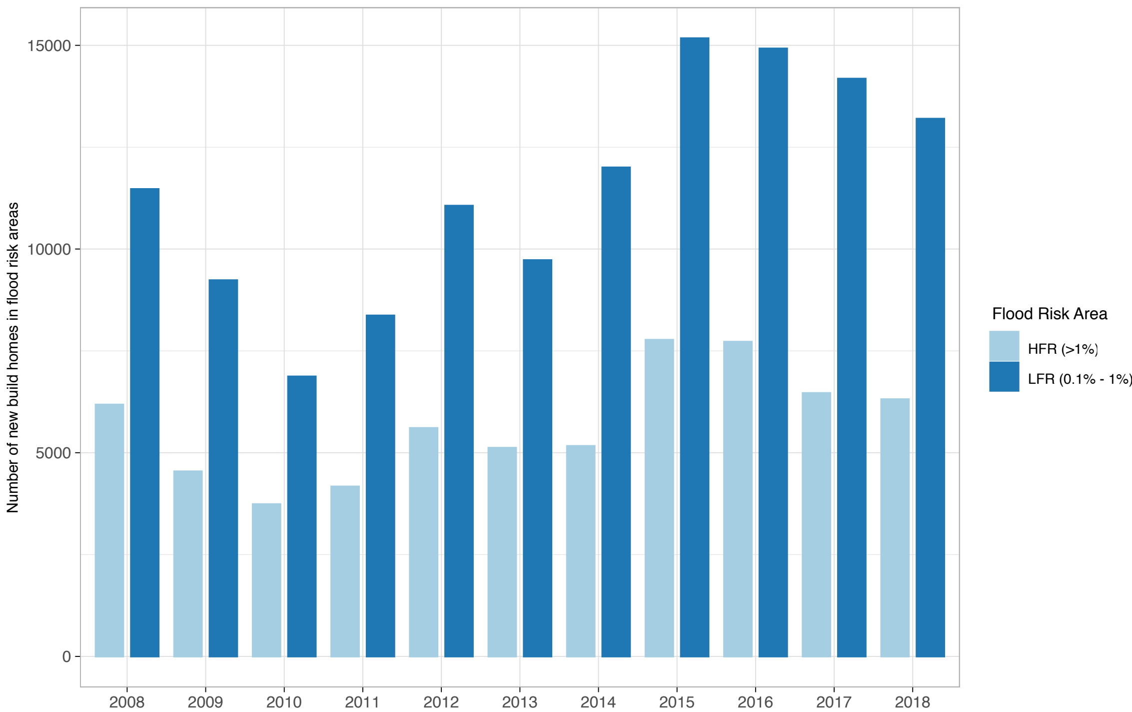

Figure 1. Number of new homes build per year in high/medium (HFR; >1%) and low (LFR, 1% - 0.1%) flood risk zones between 2008 and 2018.

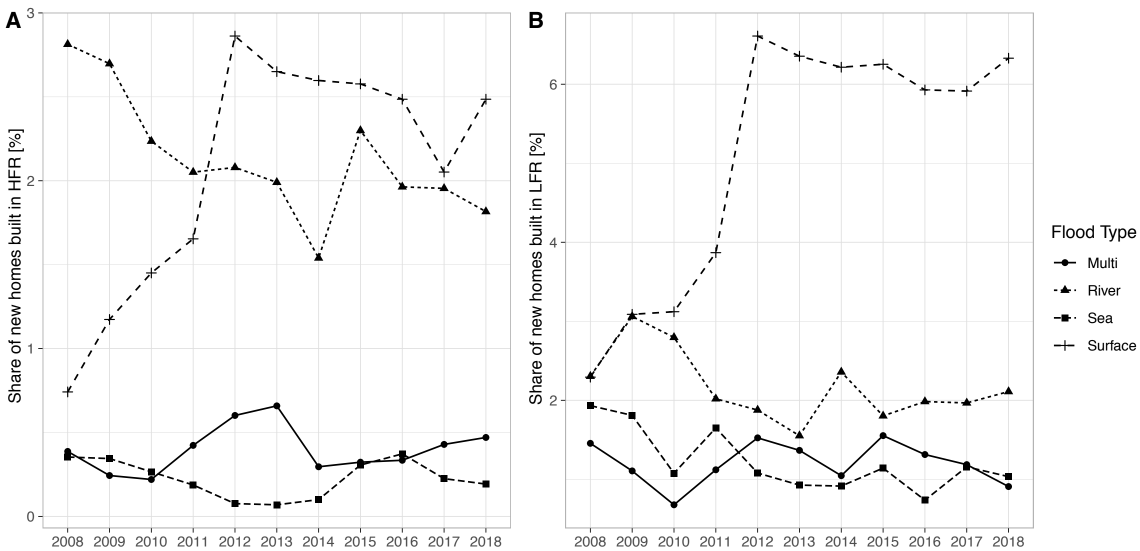

Figure 2. Year to year change in the share of new homes built in flood risk areas as percentage of all new build homes for different types of flooding. A shows results for high/medium flood risk (HFR; >1%) areas. B shows results for low flood risk areas (LFR, 1% - 0.1%).

Spatial trends and hot spots

We find a high total number of new build homes in HFR in parts of London and in the Thames Valley for current hazard levels. Other clusters include urban areas in estuaries such as in Liverpool, Hull or Bristol as well as smaller areas along rivers in the East Midlands or Yorkshire and the Humber (see Figure 3).

Looking at the share of new build homes in HFR as a proportion of all buildings built in the respective area during the same period, a strong clustering with high shares appear mainly in estuaries on the border between the East of England and the East Midlands as well as along the river Trent in Yorkshire and the Humber (Figure 4 - top left). This is also confirmed by the hot spot analysis based on local spatial auto-correlation (Figure 5): we find two significant local clusters with high shares of new build homes in HFR in estuaries on the border between the East of England and the East Midlands and along parts of the river Trent. The latter was also severely affected during the 2019/2020 winter flood season [36].

For the different climate change scenarios we find that existing hot spots are expected to be further amplified with more homes built between 2008 and 2018 expected to fall into HFRs by the 2050s without further action. But also new hot spots are expected to emerge without further intervention for these homes, especially along lower lying coastal areas in the South East of England, along the Thames river banks in London and along the Ouse in Yorkshire and the Humber (Figure 4). We find the highest expected shift in the share of homes built between 2008 and 2018 in HFR by 2050 as a result of climate change to range from 2%-points for the 2C scenario to 35% for the high-end scenario (H++). Here, the largest changes are expected along coastal areas and estuaries in the East of England and in Yorkshire and the Humber, but also in smaller areas in the South East and the North West of England. Results of the local hot spot analysis for different climate change scenarios are shown in Figure B2 in the Appendix.

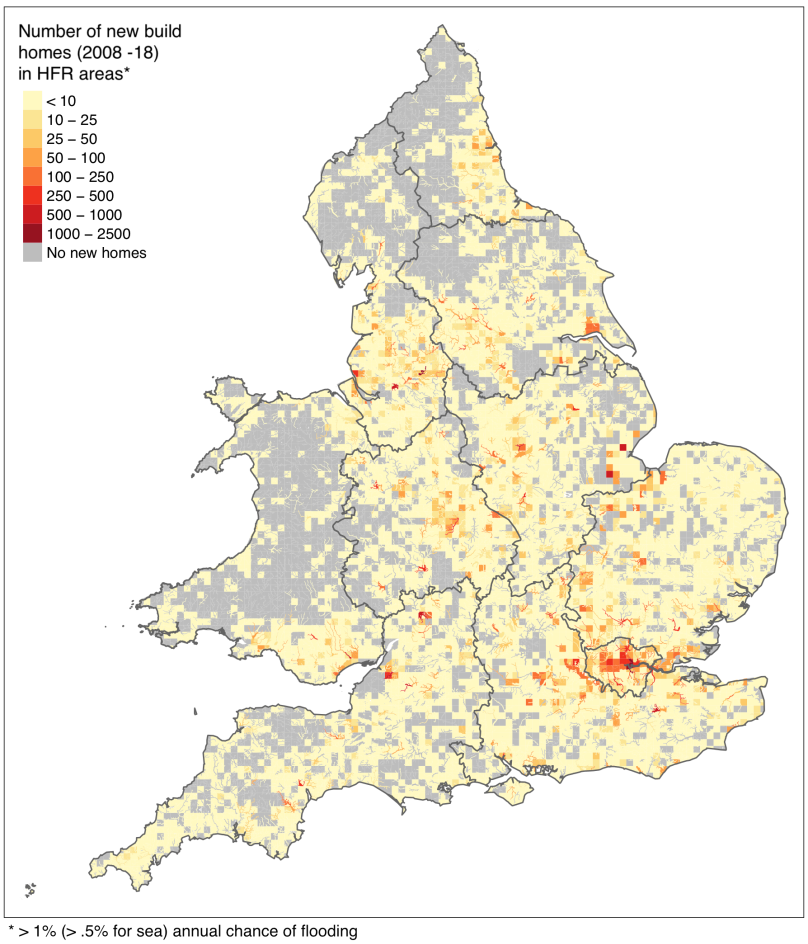

Figure 3. Spatial distribution of the total number of homes built between 2008 and 2018 in high/medium flood risk (HFR; >1%) areas across England and Wales.

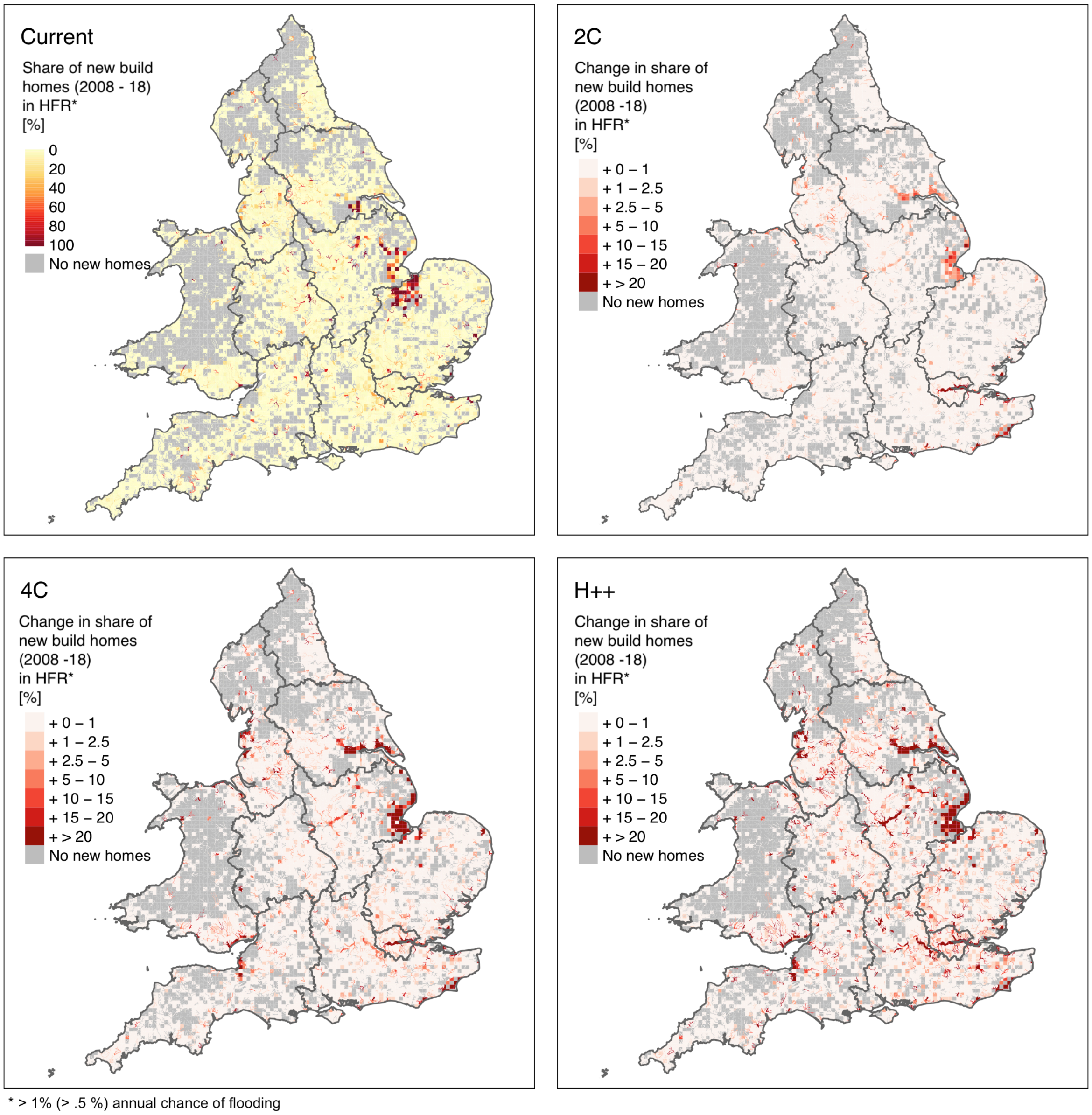

Figure 4. Top left: Share of homes built between 2008 and 2018 in high/medium flood risk (HFR; >1%) areas as percentage of the total number of homes built in the same time period for local impact areas across England and Wales. Top right - bottom left: Change in share of homes built between 2008 and 2018 in HFR areas by the 2050s as a result of changing flood hazard levels for three different climate change scenarios (2C: 2 degree warming by 2100, 4C: 4 degree warming by 2100 and H++: credible high end warming scenario)

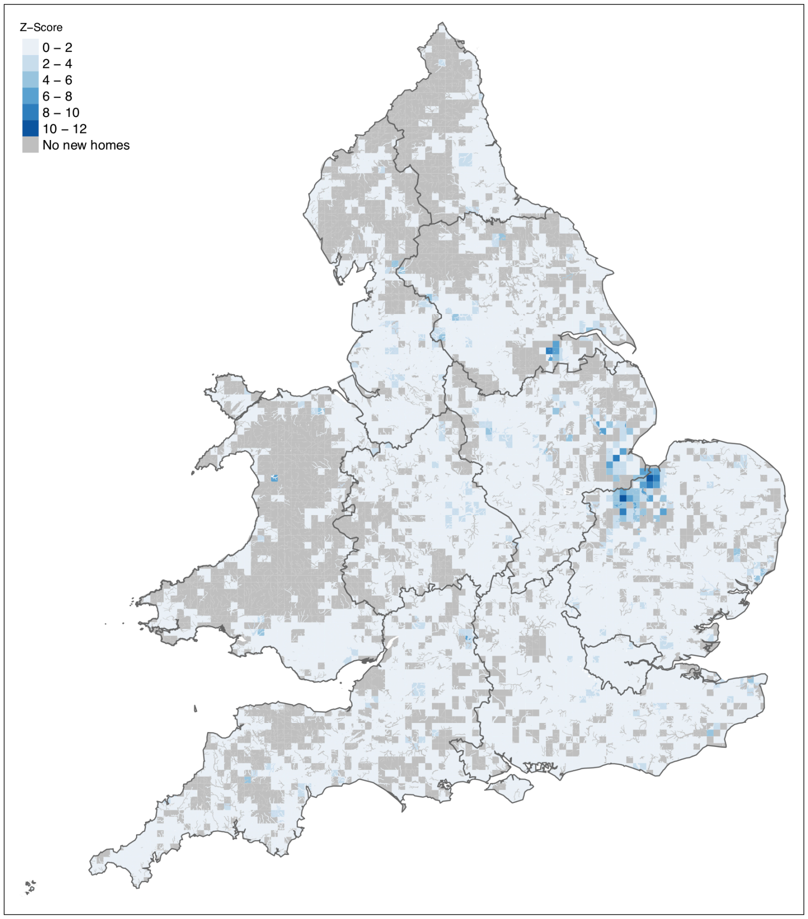

Figure 5. Spatial clusters (hot spots) with high shares of new build homes in high/medium flood risk (HFR; >1%) areas, 2008–2018. High positive Z-score values indicate hot-spots with a high number of neighbouring impact areas with a high share of new build homes in flood zones.

Current and future flood exposure by neighbourhood type

Figure 6 shows the distribution of homes in HFR built between 2008 and 2018 by the different socio-economic development trajectories of the neighbourhoods they have been built in. When comparing to the overall number of homes built in the different neighbourhood trajectory types in the same period, we find that under current flood hazard conditions a disproportionately lower share of new homes in HFR in England and Wales were built in areas with *Increasing struggling homes-owners*, characterised by [33] as areas transitioning from a "families in council rent type to a struggling [home-owner] type" as well as in *Upwarding thriving neighbourhoods*, described as neighbourhoods that have persistently been thriving over the last four decades. A disproportionately higher share of new homes in HFR were built in the *Ageing manual labour* (describing neighbourhoods transitioning from blue collar families to an ageing demographics type) and *Stable affluent* (describing neighbourhoods that have persistently remained affluent over the last four decades) neighbourhood types. For other neighbourhood types the share of new homes in HFR is nearly proportionate to all new homes built between 2008 and 2018 in those respective areas. Under the assumption that neighbourhoods across England and Wales remain on their current socio-economic development trajectories over the coming decades, we find that the susceptibility to changes in the flood hazard as a result of climate changes of homes built between 2008 and 2018 differs depending on the neighbourhood type they are located in. The results show a socio-economic polarisation in flood exposure for homes built between 2008 and 2018 over their lifetimes as a result of climate change with increasing deviations in the share of homes located in HFR in three of the eight neighbourhood types (Figure 6). Most noticeably in the *Increasing struggling homes-owners* neighbourhood type, where a climate change induced change of the flood hazard is expected to lead to a disproportionately larger share of homes built between 2008 and 2018 ending up in a HFR by the 2050s for all CC scenarios, while the share under current hazard levels is disproportionately lower.

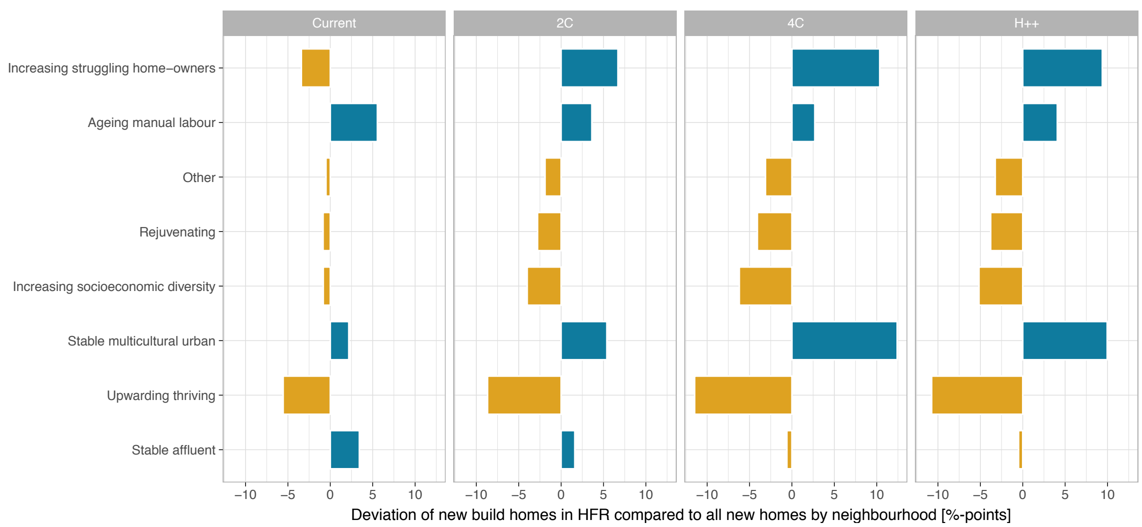

Figure 6. Deviation of the share of new-build homes (2008 - 2018) in high/medium flood risk (HFR) areas from the share of all homes built in the respective neighbourhood types based on [33] in percent points. Positive values indicate a disproportionately higher, negative values a disproportionately lower share of homes in HFR areas relative to the share of all homes in a specific neighbourhood type. The deviations are shown for the seven different neighbourhood types and for current flood hazard conditions as well as for flood hazard conditions by the 2050s for the 2C, 4C and H++ climate change scenarios.

5. Discussion and Conclusion

Our study extends previous research on flood exposure, spatial planning and environmental justice [6, 7, 8, 9, 10, 11, 13, 14] by including the effect of recently built homes on the flood exposure of different socio-economic neighbourhood types and how changes in the hazard due to climate change is affecting these homes in neighbourhoods they were built in over the homes' lifetime.

Our analysis shows that the around 17,000 new homes that have been built in HFR and LFR areas in England and Wales on average each year over the last decade, are not only highly spatially concentrated with 34 local authority districts (10% of all local authority districts where new homes have been built) being responsible for 90% of all new homes built in flood risk areas, but also unevenly distributed between different socio-economic neighbourhood types. Our results indicate that a spatial shift in flood risk areas as a result of climate change is expected to result in more homes built over the last decade to end up in HFR areas over their lifetime without further action; disproportionately higher in multi-cultural urban neighbourhoods and areas dominated by increasingly struggling home-owners.

It is difficult to consider all dynamic and mutually influencing processes when analysing the interplay between new build homes, current and future flood exposure and socio-economic development in the context of climate change. Many aspects especially in a forward looking analysis are difficult to include without introducing large uncertainties such as where new homes will be built in the coming decades and how they might further shape the socio-economic development of the neighbourhoods they will be built in. While we specifically analyse where new homes have been built between 2008 and 2018 and what happens to those homes and in their respective neighbourhoods over the coming decades, it is possible that neighbourhoods might leave their identified socio-economic development trajectory in the future in case of significant disruptions such as through changes of investment flows into a neighbourhood (e.g. when a council decides it can no longer defend a neighbourhood from increasing flood hazards) or simply a change in preferences or demand (e.g. raise in attractiveness of suburban or countryside homes). We partly address this issue by using a new data set of neighbourhood classifications from long-term longitudinal data [33]. This data set takes into account a larger set of variables characterising the longitudinal socio-economic development of different neighbourhood types over the last four decades and by that increases the robustness of development trajectories. Other approaches use either proxy variables that are very sensitive to the overall economic development such as real estate prices or use relative measures such as the frequently used index of multiple deprivation, which does not allow longitudinal analysis over time.

Another source of uncertainty regards future changes in the flood risk as a result of climate change which is both affected by uncertainties in the link between changes in the GMT and the resulting changes in the frequency and intensity floods (e.g. through rising sea levels and changes in rainfall patterns). Future investments in structural flood defences could offset some of the identified increase in risk levels but it is uncertain where and to what degree this will be done. However, as the current spatial planning regime works under the assumption that new homes in flood risk areas are built in a resilient way, our analysis assumes there will be no future changes in structural flood defences to specifically protect these homes.

However, lacking property level information on the actual flood resilience of the buildings in our study allows only for crude estimates to what degree this assumption is met and therefore it is unclear how the expected increase in exposure will also lead to an increase in flood risk. While assumptions on the rate and effectiveness of for example private level adaptation have been made in previous studies they generally rely on very limited evidence and it remains unclear to what extent they reflect reality [37].

Therefore further research and the development of data sets on the level of adaptation of buildings are necessary as it not only supports an improved spatial planning system to maximise flood risk reduction in the face of climate change and newly created exposure as requested by the CCC [38] but would also allow to take environmental justice issues around the affordability of flood resilience measures into account. Our analysis shows how this could be done in a forward looking way taking into account the current and future flood hazards together with socio-economic characteristics of neighbourhoods. This can also support the already existing Long-term investment scenarios (LTIS) for flood and coastal erosion risk management published by the Environment Agency which currently lacks both the necessary level of detail to guide local planning decisions.

The current blind spots regarding the actual level of adaptation of new build homes both for current and future flood hazards additionally carries the risk that especially in deprived and declining neighbourhoods, where the need for property development as part of a local regeneration strategy clashes with limited financial resources and the demand for affordable housing, an increase in flood risks (both through newly created exposure and increasing hazard) might not only lead to not meeting expectations for economic growth and prosperity but could even exacerbate issues of decline and deprivation in cases where long-term flood resilience cannot be ensured. To avoid a vicious cycle of creating new risks as a strategy for economic regeneration, the long-term flood resilience of new properties not only needs to be considered as a requirement in the planning process, but needs to be embraced as part of regeneration strategies that include future changes in flood hazards and the local socio-economic context that might affect the ability to ensure long-term flood resilience.

However, the interactions between future flood resilience, exposure and scocio-economic development of neighbourhoods go beyond the already discussed implications of flood protection measures and adaptation: The largest share of the homes in our analysis is not covered through the subsidised insurance pool FloodRE, due to the exemptions of homes built after 2009 and insurance cover may be unavailable or not affordable. Owners of these homes might therefore face a difficult dilemma, in which they either need to accept that flood damages to their home might increase and are likely to negatively affect the value of their property or will have to accept increasing insurance premiums and/or invest in retro-fitting their buildings to mitigate damages where possible and economically viable. Our results show that already struggling neighbourhoods will face this issue more likely than other types of neighbourhoods. This can lead to knock-on effects where a low or lacking ability to cope with increasing flood risks of even a small number of individual homes or properties can decrease both the attractiveness and property value of a larger area in case full recovery after flood events is unlikely and community development is impaired. In these case larger disruptions such as sudden out-migration [19] or an increase in mortgage defaults and foreclosures [20] after flood events due to a combination of dropping real estate prices and lacking financial resources for recovery become more likely.

Appendix A. Material and Methods

Appendix A.1. Data

Appendix A.1.1. New build properties 2008 - 2018 We construct a property level data-set of newly build dwellings between 2008 and 2018 in England and Wales by combining information on the dwelling type, location, occupancy and postcode from the AddressBase Premium product provided by Ordenance Survey [39] with postcode information from the publicly available postcode directory from the Office of National Statistics (ONS) [40] through their unique post code. AddressBase Premium contains detailed information on address and types of assets for every property in the UK. By filtering the dataset by the property type and the introduction year of a new postcode from the ONS postcode directory, we are able to identify new residential homes and the year of their completion (i.e. the year the address has been activated). The resulting data set comprises of around 1.3 mio data points representing new homes in England and Wales built between 2008 and 2018, their year of completion, their location and the dwelling type (flat, detached, semi-detached, terraced, other). This approach is different from previous approaches such as by [41], which compared reversed versions of the AddressBase data base for specific snapshots in time, to allow for a higher temporal resolution.

The constructed data set contains both new developments on green- and brown fields associated with land-use change as well as conversions or redevelopments in existing urban structures. Individual homes are defined as self-contained units with their own registered address. The data set has been validated by comparing historic high-resolution satellite imagery from GoogleEarth from a year before and after the stated year of construction for 50 random addresses.

Appendix A.1.2. Flood hazard maps The flood hazard maps used in this study are the publicly available flood maps provided by the Environment Agency for England and by Natural Resources Wales for Wales. For the flood hazard from river and sea the "Risk of Flooding from Rivers and Sea (RoFRS)" flood maps are used [42, 43]. For surface water flooding the extent maps from the Risk of Flooding from Surface Water (RoFSW) are used [44, 45]. The flood maps have nation-wide coverage, are available as GIS shapefiles and shows the chance of flooding as one of four flood risk categories, taking into account flood defences and their condition.

In this study we consider homes being at a high/medium risk of flooding, when the property is in an area with a 1% or higher annual chance of flooding from river and surface water and a 0.5% or higher annual chance of flooding from sea. We consider areas with a low risk of flooding in case they have between a 1% (0.5% for sea) and 0.1% annual chance of getting flooded. Whether a home is at risk from flooding is determined by its location within or outside the respective flood risk area.

Appendix A.1.3. Neighbourhood development To identify the development trajectories of neighbourhoods in combination with their flood exposure, we use a gridded, spatio-temporal consistent neighbourhood trajectory data set developed by [33]. The data is available on a 1 km^2 grid for England and Wales. The approach uses neighbourhood-level information of the four decadal censuses between 1971 and 2011 to create neighbourhood typologies for each census year. The neighbourhood typologies are based on in total 21 variables on demographic (age, place of birth), socio-economic (socio-economic group, occupation, proportion of students, unemployment, mode of travel to work) and housing data (ownership, social housing, vacancy rate) (a full list and of all variables considered in the analysis is shown in [33]). Sequence analysis was used to derive seven representative trajectories of neighbourhood development from longitudinal transitions of these neighbourhood typologies over time. The names and descriptions of the seven trajectories are shown in Table A1. This approach allows for a spatially and temporally consistent and representative classification of development paths of neighbourhoods in a community, identifying neighbourhoods with stable, upward and downward socioeconomic development pathways. Compared to the widely used English and Welsh indices of multiple deprivation (IMD), which only allow to analyse changes in deprivation between two snap-shots in time relative to other neighbourhoods, sequence analysis allows to capture the evolution of neighbourhoods transitioning through phases of development, growth, stability and decline over time. More details on the methodology that was used to derive the representative trajectories can be found in [33]. For the analysis in this study, the neighbourhood a new home was built in is determined by its geographical location. In cases where new developments are not in a neighbourhood trajectory grid cell (either through small inaccuracies caused by the grid approach or through greenfield developments that have not been considered as part of the neighbourhood before) we apply a nearest neighbour approach to link the new build homes to the nearest neighbourhood. This is only done in cases where the new build home is less than 1 km (or 1 grid cell) away from the closest neighbourhood, based on the assumption that developments further away need to be considered as independent new neighbourhoods which are likely to have their own development trajectories.

Table A1. Names and key features of the seven main neighbourhood trajectories as described in [33]

Neighbourhood trajectory name	Description
Stable affluent	Areas remaining persistently affluent over 1971 and 2011.
Ageing manual	Areas transitioning from being dominated by blue collar families to an older striving neighborhood type.
Increasingly socio-economically diverse	Areas transitioning from a struggling or blue collar families type to a mixed workers suburban type.
Increasingly struggling home-owners	Areas transitioning from a families in council rent type to a struggling type.
Stable multicultural urban	Areas remaining multicultural in urban locations.
Rejuvenating	Areas transitioning from an older striving type to a mixed workers suburban type.
Up-warding thriving	Areas transitioning from an older striving type to, or remaining in, a thriving suburban type.

Appendix A.1.4. Climate change scenarios For this study the future flood hazard projections for three climate change scenarios for the 2050s as defined by the UK Climate Change Committee (CCC) are considered [31]: a lower end scenario based on a 2° change in Global Mean Temperature (GMT) (2C), a 4°C change (4C) and a worst case scenario (H++) which does not refer to a specific GMT, but is considered a credible high end change scenario. All changes in GMT are expressed for the year 2100 relative to the 1961-90 baseline as by the UK Climate Change Projections (UKCP09) provided by the Met Office. Based on these climate projections [32] developed future flood hazard projections for the UK including relative sea level rise around the English and Welsh coastline, changes in peak river flows for the 12 major catchment areas in England and Wales as well as changes in storm rainfall depth and intensity influencing the surface water flood risk. Using the same approach and assumptions as in [32] for the UK Climate Change Risk Assessment the relative changes in sea level rise, peak river flow and storm rainfall depth and intensity are translated into changes in the annual chance of flooding/changes in the level of protection for different hydrological regions, land use types (i.e. urban and not urban) and coastal regions and features (i.e. beaches, cliffs, levees etc.). Change parameters for all flood types, different return periods and the different scenarios used in this study can be found in [46]. Table A2 gives an overview of the regional differences and differences in the susceptibility for the different flood types considered in this study. To analyse the potential local effect of climate change on the future exposure to floods of new build properties, we create local impact areas based on a 5 by 5km grid across England and Wales for surface water flooding. For sea and river flooding, we use the same grid to split areas potentially affected by flooding from river or sea (based on current shapefiles of flood risk areas from the RoFRS). This allows us to define a total of 11,908 local flood impact areas across England and Wales with sizes ranging from 3 to 23 km^2, that are spatially consistent in regard to their flood risk. Based on the mentioned regional CC parameters we derive impact functions for each flood type and for each of 11,908 local impact areas. The impact functions describe the functional relationship between the current annual chance of flooding (i.e. 3%, 1% and 0.1%) and the respective number of homes built between 2008 and 2018 at risk from flooding. The impact functions are then used to translate the change in the flood hazard for the three different CC scenarios into the change in the number of homes that are expected to have 1% or higher annual chance of flooding by the 2050s under the 2C, 4C and H++ scenarios.

Table A2. Regional differences and differences in susceptibility considered in the three different climate change scenarios.

Flood type	Change indicator	Regional differences	Susceptibility differences
Sea	Relative sea level rise	5 coastal regions (E, SE, SW, MW, NW)	3 coastal defence types (sea wall, embankment, beach)
River	Peak river flow	12 hydrometric regions	-
Surface	Storm rainfall depth & intensity	-	2 runoff types (rural, urban)

Appendix A.2. Methods

Appendix A.2.1. Spatial trends We calculate for each local flood impact area i across England and Wales the share of homes in high/medium flood risk areas (HFR; >1% annual chance of flooding for river and surface, >0.5% for sea) P_{fl} by taking the ratio between the number of homes that have been built in HFR areas from 2008 to 2018 $N_{i_{HFR}}$ and the total amount of homes built in the respective flood impact area $N_{i_{total}}$:

$$P_{i_{fl}} = \frac{N_{i_{HFR}}}{N_{i_{total}}}$$

$P_{i_{fl}}$ is calculated for the current climate, as well as for the 2C, 4C and H++ climate change scenarios. To estimate the potential change in the spatial distribution of the share of recently built homes in flood risk areas by the 2050s, we calculate the difference in percent points between the current share and the share for the three different CC scenarios:

$$P_{fl,diff} = P_{fl,CC} - P_{fl,current}$$

Hot spots and spatial trends are assessed by using local spatial auto-correlation. We use the local $G_i(d)$ statistic (local Getis Ord) to identify clusters [35]. For each local flood impact area the local Getis Ord statistic is estimated based on the distance between neighbouring flood impact areas and both the respective absolute number and share of homes in HFR areas. The threshold distance for neighbouring flood impact areas was set that each area has at least one neighbour.

Appendix A.2.2. Flood exposure and neighbourhood development For each of the seven neighbourhood development trajectories across England and Wales, we calculate the deviation between the proportion of homes built in HFR areas with the overall proportion of homes build in each neighbourhood type:

$$Diff_{per,nbh} = P_{HFR,nbh} - P_{total,nbh} = \frac{N_{HFR,nbh}}{N_{HFR,total}} - \frac{N_{total,nbh}}{N_{total}}$$

with $Diff_{per,nbh}$ representing the difference in percent points between the share of new build homes in HFR areas for a specific neighbourhood type $P_{HFR,nbh}$ and the total share of homes for this neighbourhood type $P_{total,nbh}$. $Diff_{per,nbh}$ provides a measure whether the share of homes in flood risk areas for a specific neighbourhood type is higher (positive values), on par (around 0), or lower (negative values) compared to what would be expected based on the overall distribution of new homes between the different neighbourhood types. We calculate $Diff_{per,nbh}$ both for the current state as well as for the 2C, 4C and H++ climate change scenarios to be able to estimate how the distribution of recently built homes in HFR areas is expected to shift between the different neighbourhood development trajectories with climate change.

Appendix B. Results

Appendix B.1. Summary results

Table B1. Summary statistics showing all homes build in high/medium flood risk areas (1% or greater annual chance of flooding from rivers and surface water and 0.5% or greater annual chance of flooding from sea) and low flood risk areas (between 0.1 and 1% annual chance of flooding from rivers and surface water and between 0.1 and 0.5% annual chance of flooding from sea) by country, dwelling type and flood type.

High/medium flood risk area	England				Wales				Total
	River	Sea	Surface	Multiple	River	Sea	Surface	Multiple	
Houses (detached, semi-detached, terrace)	9850	935	12483	2126	1120	40	513	224	27291
Flats (self-contained)	15403	1841	12459	2335	289	171	223	54	32775
Other	1035	95	1116	16	13	-	72	-	2347
Total	26288	2871	26058	4477	1422	211	808	278	62413
Low flood risk area	**England**				**Wales**				**Total**
	River	Sea	Surface	Multiple	River	Sea	Surface	Multiple	
Houses (detached, semi-detached, terrace)	8515	5391	31406	7175	1189	1938	1339	777	57730
Flats (self-contained)	16227	5011	30452	6732	697	3112	500	746	63477
Other	1221	198	2889	453	6	171	75	4	5017
Total	25963	10600	64747	14360	1892	5221	1914	1527	126224

Appendix B.2. Time trends

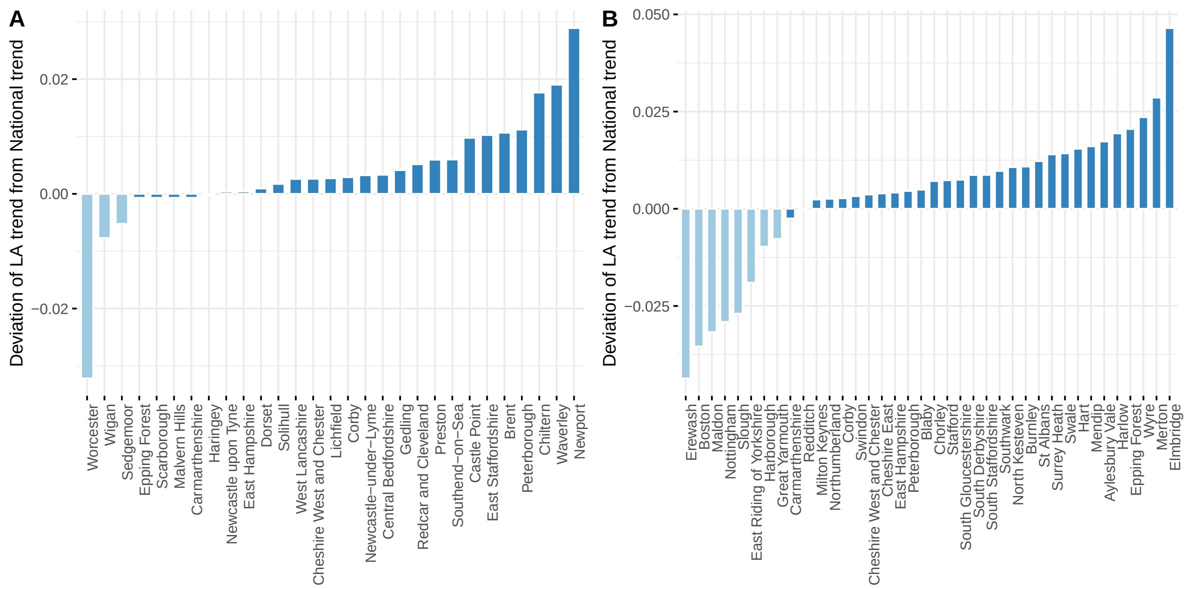

Figure B1. Local authority districts (LA) with significantly increasing or decreasing trend in year-to-year ratios of new build homes in flood risk areas over time (2008 - 2018) based on the Mann-Kendall trend test with .05 significance level. Deviation on y-axis shows the difference in slope between each LA and the national trend. Slope is calculated based on the non-parametric Sen's slope. Bars in light-blue show decreasing trends (negative slope); bars in dark-blue show increasing trends (positive slope). A shows results for high/medium flood risk areas (1% (0.5% for sea flooding) or higher annual chance of flooding). B shows results for low flood risk areas (between 1% (0.5% for sea flooding) and 0.1% annual chance of flooding).

Appendix B.3. Spatial trends and hot spots

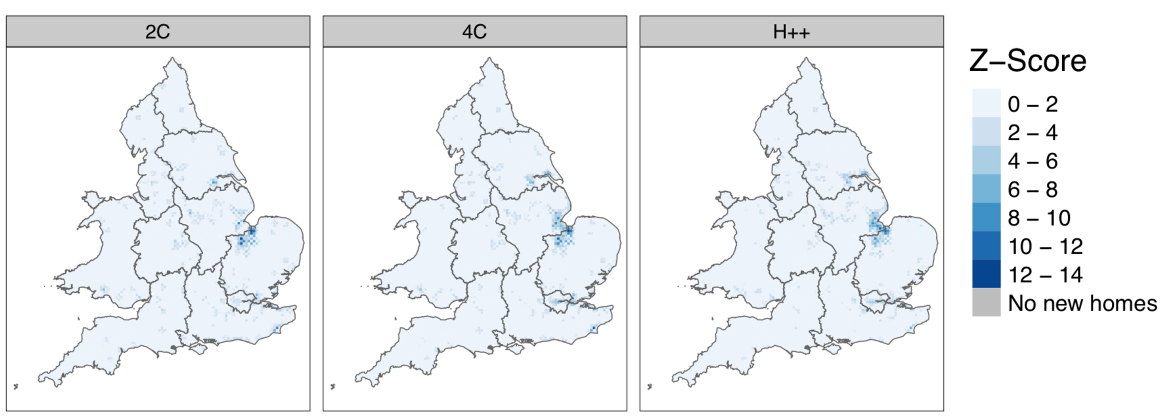

Figure B2. Spatial clusters (hot spots) with high shares of new build homes in flood risk areas, 2008–2018 for 2C, 4C and H++ climate change scenarios. High positive Z-score values indicate hot-spots with a high number of neighbouring impact areas with a high share of new build homes in flood risk areas.

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