Integrated decision-making about housing, energy and wellbeing (HEW)

Report on the mapping work for stakeholders

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Summary

The Housing, Energy and Wellbeing (HEW) project is part of wider work about the unintended consequences of attempting to reduce carbon emissions from the built environment. We are using a collaborative mapping and simulation method (SDM: system dynamics modelling) with representatives from selected organisations involved in policies about housing (sectors of national and local government, non-government organisations, construction and housing industries, cross-disciplinary researchers). We will also be using a policy assessment tool (MCDA: multi-criteria decision-analysis) to consider policy options accounting for organisational priorities and values. The project involves in-depth interviews with stakeholders followed by a series of collaborative learning workshops to progress a shared understanding of housing, energy and wellbeing as a complex system (with many interacting variables in feedback relationships[1] which change over time). By doing so, we aim to support integrated decision-making so that co-benefits can be optimised and necessary trade-offs identified and made more explicit.

This report summarises the work so far to develop collaborative causal maps about housing, energy and wellbeing. The maps have been constructed from 35 in-depth interviews with stakeholders and a multi-disciplinary literature review. They were reviewed and adapted by 26 policy, NGO, industry and academic stakeholders in a workshop in June 2013. Thirty-five organisations are represented in the project by over 50 stakeholders. This second iteration extends the initial development of the maps through some further reference to research, particularly in the area of social connection and physical quality of neighbourhoods. It also reflects further feedback from individual stakeholders, from two community roots group workshops and a second all-stakeholder workshop.

The representatives who were interviewed connected housing to the following different specific aspects of what could be considered overall human wellbeing:

1. Social and cultural wellbeing and community connection
2. Physical health
3. Mental health, homeliness and happiness, stress
4. Local economic thriving, household income and employment, a stable economy
5. Adaptation and mitigation of climate change

[1] These are circular chains of cause and effect that can either amplify the original effect (positive or reinforcing feedback) or dampen the effect (negative or balancing feedback)

6. Sustainable resource use

In discussions, stakeholders also emphasised the need for fairer distribution of these aspects of wellbeing by income, ethnicity and gender. Specific considerations about the wellbeing of children and older people were also emphasised.

A complex map was constructed from the interviews and literature review. It has been divided into seven sections which are sets of deeply interconnected feedback loops:

1. Community connection and physical quality of neighbourhoods
2. Energy efficiency and climate change
3. Fuel poverty and indoor temperature
4. Household crowding
5. Housing affordability
6. Land ownership, value and development patterns
7. Ventilation

It is these feedbacks that are thought to be determining trends over time across different housing objectives. The aspects of wellbeing described above are woven through these different sections, taking part in some feedbacks, or as external outcomes of others.

Some initial insights can be drawn from these qualitative maps. Perhaps most importantly, the deep interconnections between sectors means that policy objectives cannot be considered in isolation. The energy efficiency map was striking in its lack of feedbacks, with many connections to other sectors. This may simply be because the process so far has failed to identify feedbacks which exist. Nevertheless, it also suggests that successful policies to reduce housing energy use and greenhouse gas emissions may require a more attention to addressing feedbacks in other sectors of the system. Ten early policy, research and process recommendations have emerged:

1. Successful decarbonisation of the UK housing stock requires the rapid establishment of a cross-government group to develop meaningful systems thinking capacity. This group would be supported by an advisory committee
2. The lack of feedback loops in the **energy efficiency** requires further investigation. There may well be detailed loops missing from this diagram
3. Development of widely agreed metrics to describe “quality” as it relates to both houses and neighbourhoods
4. Simulation of the **adaptation to climate change** feedback loops would allow policy makers to understand how important the reinforcing loops are in this diagram by demonstrating the energy and land costs of adaptation dynamically, compared with

expected energy savings from energy efficiency improvements

5. Simulation of the **fuel poverty and temperature optimisation** loops would demonstrate whether the balancing or reinforcing loops are most likely to dominate as a result of future climate change for the housing stock
6. The centrality of local social connection suggests policies should support the strengthening of community capacity to drive change
7. The assumption that mixed tenure types leads to greater community connection needs testing
8. A number of parts of the overall map suggest that improving tenure security in the private rental sector would strengthen a number of beneficial feedback loops for wellbeing and decarbonisation
9. Greater cross-government consensus about goals in the national property market would enable further work to understand effective policies that would have benefits across a range of wellbeing and energy outcomes
10. An existing energy or housing policy should be used to test the theoretical relationships developed here

The maps will continue to change as the project progresses. **Further feedback from stakeholders will improve their quality and usefulness**. Incorporating data into a simulation model based on the maps is a crucial step in understanding whether the loops described are active in reality, their relative strength for determining current trends, and initial policy directions for further simulation. Initial draft simulations will need to be followed by a continuing programme of research that continues to bring together policy, community and research representatives across a wide range of disciplines.

Background

The Housing, Energy and Wellbeing (HEW) project is part of wider work considering the unintended consequences of decarbonising the built environment. Our initial research in this area characterised many of these unintended consequences for the UK[2]. We found that current policies focusing on reducing carbon emissions from dwellings have a very large number of wide ranging other effects on health, society and the environment.

Housing design, availability and cost all are linked to human wellbeing outcomes. Although reducing carbon emissions is one major focus of policy about housing, separate policies aim to reduce fuel poverty and stimulate housing construction and property turnover as drivers of economic growth. A more comprehensive consideration of outcomes would integrate a wider range of relationships between dwelling changes and physical, social, economic and environmental wellbeing. These may include effects on household crowding and infectious disease; employment patterns; noise and sound; social connection and sense of security; and housing markets and affordability. It is therefore crucial to consider decarbonisation as just one objective in a wider system of housing, energy and well-being.

Achieving policies that optimise outcomes for health, equity and sustainability while minimising the unintended harms requires different decision-making processes, as well as methods that successfully support these processes. In complex systems like housing there are a range of places to intervene. These are summarised below, in order of increasing effectiveness for achieving transformational change[3]:

5. Numbers, constants and rates of flow
4. Feedback loops, time and information delays
3. The system rules
2. Capacity of actors to change and evolve
1. Ways of thinking and ideological/political constraints

In this project we aim to understand and encourage effective interventions to the system rules and feedback loops. Through the collaborative learning process we also aim to enhance the capacity of relevant stakeholders to evolve and create change, as well as support a shared understanding of housing, energy and wellbeing that crosses ideological boundaries.

[2]Shrubsole C, Macmillan A, Davies M, May N. 2014. 100 unintended consequences of policies to improve the energy efficiency of the UK housing stock. *Indoor and Built Environment* http://ibe.sagepub.com/content/early/2014/03/12/1420326X14524586

[3] Meadows D. 1999. *Leverage points: places to intervene in a system*. The Sustainability Institute. http://www.donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/

We are using a collaborative mapping and simulation method (SDM: system dynamics modelling) with representatives from organisations involved in policies about housing (sectors of national and local government, non-government organisations, construction and housing industries, cross-disciplinary researchers). We will also be using a policy assessment tool (MCDA: multi-criteria decision-analysis) to consider policy options accounting for organisational priorities and values. The project includes the following steps:

1. Identification of organisational representatives
2. In-depth interviews
3. Development of preliminary collaborative maps
4. **Workshop 1** to refine the maps
5. Further qualitative model refinement and exploratory simulation
6. **Workshop 2** to develop insights and identify possible fruitful policy directions
7. Further simulation modelling
8. **Future simulation and policy assessment workshop/s**

Representatives

Stakeholders were chosen to represent a diversity of organisations working with different objectives in the area of housing, energy and wellbeing. Thirty-seven agencies are represented by over 50 stakeholders. These include six national government departments; five representatives from local government; 14 non-government organisations; a group of six community housing activists; five industry organisations; and eight academic institutions. Some stakeholders represent more than one sector. We aim to continue strengthening relationships across ideological viewpoints and with other government departments with a stake in housing policy (such as Treasury). Currently represented organisations are listed below.

AECOM
Affinity Sutton
Age UK
Arup
Centre for Regional Economic and Social Research, Sheffield Hallam University

Centre for Sustainable Energy (CSE)
Centre for Sustainable Planning and Environments, University of the West of England

Chartered Institute of Building Services Engineers

Community Roots Group

Consumer Focus
Core Cities
Department for Business, Innovation and Skills
Department for Communities and Local Government

Department for Environment, Food and Rural Affairs

Department of Energy and Climate Change
Department of Health
EDF Energy
Environmental Change Institute and UKCIP, University of Oxford

English Heritage
Good Homes Alliance
Government Fuel Poverty Advisory Group
Greater London Authority
Homebuilders Federation
Leeds Sustainability Institute, Leeds Metropolitan University

New Economics Foundation
Parity Projects
Positive Money
Public Health England
Sheffield City Council
Shelter
Sustainable by Design
Sustainable Healthcare Network
Sustainable Development Foundation
University of the West of England
Usable Buildings Trust
Willmott Dixon
Zero Carbon Hub

Development and refinement of the collaborative causal maps

We interviewed 35 representatives of the above organisations, to capture their understanding of the relationships between housing, energy and "wellbeing". The notion of wellbeing was left open for the interpretation of stakeholders. A mapping method (cognitive mapping) was used to picture relationships. The initial interview diagrams were transferred into electronic cognitive maps and returned to people for review. They were revised in the light of further comments. An example is shown below (Figure 1).

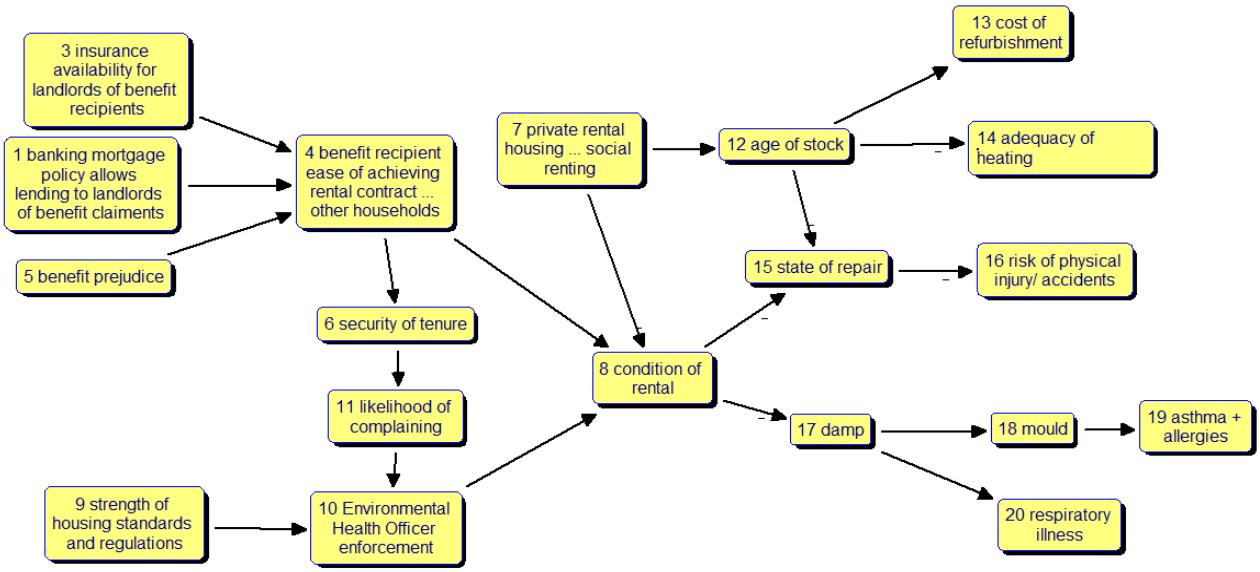


Figure 1 Example of an electronic cognitive map from the interviews

We combined all the individual cognitive maps to produce a preliminary shared set of causal maps, with some input from published research. Underlying the development of the shared causal diagrams are some principles about complex systems[4]:

1. Complex systems include many interacting variables that change over time
2. It is this pattern of interaction that determines system behaviour over time
3. Interaction between variables is characterised by feedback loops
4. Accumulation of "stocks" is important, including people, information, or resources
5. Time matters. The pattern of cause and effect may change over time.

The preliminary causal maps were reviewed, discussed and refined during the first workshop in June 2013, with 26 participants, a mixture of those interviewed and others. Additional individual and group feedback was incorporated, including from two community roots group workshops and a second all-stakeholder workshop in November 2013, again

[4]Adapted from Richardson GP. 2011. Reflections on the foundations of system dynamics. *System Dynamics Review* 27:219-243. http://dx.doi.org/10.1002/sdr.462

with 26 participants. Further analysis and revision has been undertaken reflecting feedback from stakeholders and triangulation with existing research, particularly the **community connection and the physical quality of neighbourhoods** map, which has been significantly revised following some initial simulation modelling.

Reading the causal maps

The causal maps represent interactions between variables (e.g. things, actions, feelings) that are likely to explain observed trends in the housing, energy and wellbeing "system". Some of these variables are levels that we are interested in measuring over time ("stocks"), while others are rates (or "flows") that affect these levels. The variables are connected by causal links (arrows), and together to form feedback loops – cycles of cause and effect that determine how a system behaves and changes over time. There are two kinds of feedback loop: reinforcing loops (R), so named because over time they reinforce patterns of system behaviour; and balancing loops (B) that dampen and limit trends over time. Figure 2 shows a reinforcing loop on the left and a balancing loop on the right, each with a single stock (money in the bank and tiredness). In the reinforcing loop, the more savings in the bank, the more interest is earned, reinforcing the growth in savings over time. The arrows both have +ve signs, because a change in the variable at the tail of the arrow leads to a change in the variable at the head in the same direction. In the balancing loop on the right, greater tiredness leads to more coffee drinking, which in turn leads to less tiredness. One of the arrows has a –ve sign because a change in the variable at the tail leads to a change in the variable at the head in the opposite direction. A delay between drinking coffee and feeling less tired is shown as a double line through the arrow. These delays can influence trends over time –feeling less tired may not occur immediately so that too much coffee may be drunk, overshooting the desired level of wakefulness. These are very simple examples. However, in real systems causal relationships may vary in strength or even change direction over time. Although the causal maps are static, computer simulation can assist with understanding these more dynamic relationships.

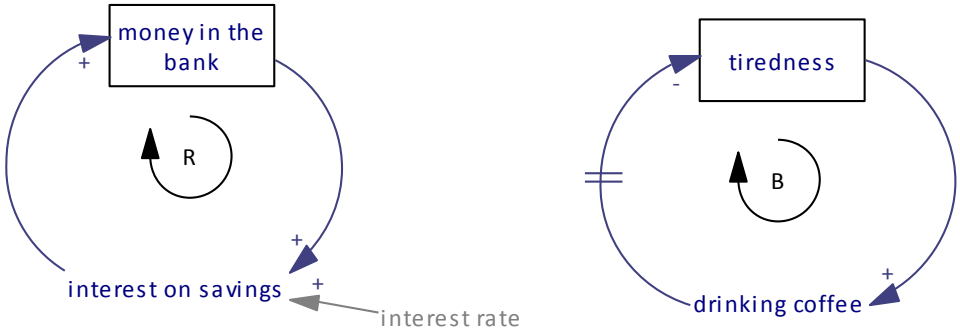


Figure 2 Examples of a reinforcing (R) and balancing (B) loop

Overview of the HEW causal maps

The 35 representatives who were interviewed made a wide range of connections between housing, energy and wellbeing. The following different specific aspects of what could be considered overall human wellbeing emerged from a thematic analysis of the interviews:

1. Social and cultural wellbeing and community connection
2. Physical health
3. Mental health, homeliness and happiness, stress
4. Local economic thriving, household income and employment, a stable economy
5. Adaptation and mitigation of climate change
6. Sustainable resource use

In describing the relationships between housing and wellbeing almost all the representatives implicitly held a view of wellbeing that privileged the wider structural influences (for example at a policy, economy, societal and built environment level) on people's lives rather than "lifestyle" or individual choices. On the other hand, there were discussions about how previous and current attempts to intervene (for example through the Code for Sustainable Homes, or other historical housing improvement programmes) had been less successful than hoped at improving people's lives or reducing energy use.

Almost all the representatives we interviewed emphasised the need for these aspects of wellbeing to be fairly distributed across different groups, including by income, ethnicity and generation (or life-stage), and that housing was an important contributor to existing wellbeing inequalities that could be modified.

By analysing the variables from the interviews, the maps were divided into seven themes (Figure 3 below), used to separate the causal maps. Although the themes have been mapped separately, Figure 3 demonstrates that they are very closely inter-connected.

The rest of this report describes the causal maps in detail. At this stage, they are presented in alphabetical order without prioritisation. In the main report, maps showing only the feedbacks are presented to support learning and understanding about these complex feedback structures, as well as to emphasise that it is these structures that are likely to determine trends over time. We have used the interviews and workshops to determine "stock" variables (in boxes). These are variables that the stakeholders were interested in measuring change in over time. Many of these stocks are included in the list

of criteria against which policies will be measured in preparing the policy assessment tool[5]. The description of the feedbacks is interspersed with quotations from the interviews. The reinforcing and balancing loops are labelled and numbered in the diagrams, for example *R1* and *B1*, in the order they are described in the text. A further version of each map is included in the Appendix. This has all the variables discussed that don't take part in the feedback loops, but which were considered important. These more comprehensive maps also highlight particular points where the themes connect with each other. Where there were conflicting theories about connections, we have included different possibilities, unless it was very clear from existing research or data that a connection worked one way and not another. Some connections were contested, made tentatively, or were considered to be very weak or not currently active. These are included as dashed arrows.

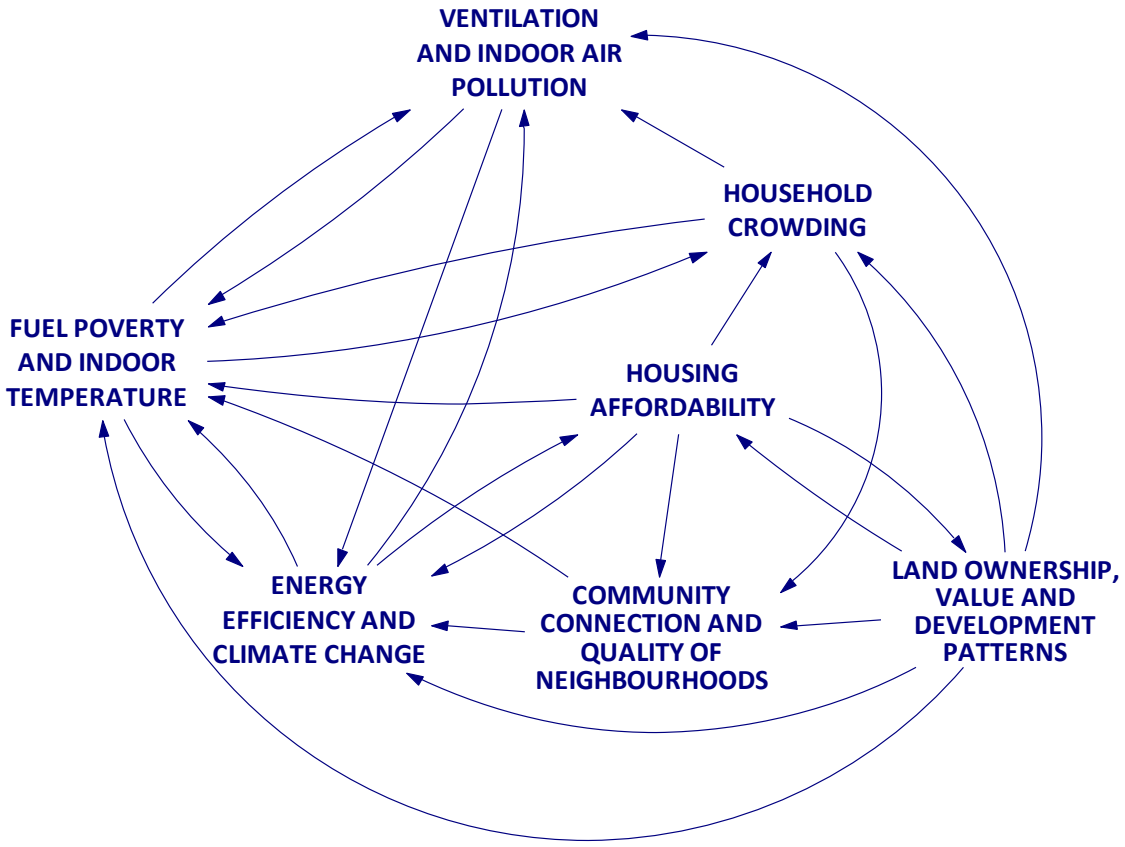


Figure 3 Overview of the themes for the causal maps and their close connections

The text accompanying each causal map includes a description of the feedbacks, views

[5] The agreed policy assessment criteria are as follows: carbon emissions from housing; community social connection; fuel poverty; housing adaptation to climate change; housing affordability; mental and emotional wellbeing; physical health; housing's contribution to social and income equity; and policy coherence

about the relative strength of the feedbacks and any unresolved disagreement.

The causal maps can be seen as a shared set of collective theory about the way the system works. Bringing in real world data to develop small pieces of computer simulation from the collaborative maps is an important next step to test these collective theories and support learning – about the maps themselves as well as about what they mean for trends over time. The maps represent a very aggregate view of housing, energy and wellbeing. Rather than attempting to capture the full detail of reality that would be required to operationalize policy, their purpose is to achieve a shared understanding of the most important feedback structures to support high level decision-making. While many variables could be divided up into more detailed parts (for example into different levels for different population groups), we have tried to develop a structure that is simple enough to be understood at a whole population level, while including feedbacks relevant for all groups. However, some variables will need to be broken up in the future, particularly to understand the effect of policies on inequalities.

Community connection and physical quality of neighbourhoods

Housing is closely related to neighbourhoods and community connection within those neighbourhoods. Stakeholders considered this relationship to be very important for wellbeing, but many were less clear about how they related to energy. Local social connection was considered to be one of the important positive outcomes of policies about housing and is therefore shown as a stock. Because stakeholders discussed this type of connection as contributing positively to wellbeing, it could be seen as equivalent to the *bridging* social connection described in the literature[6] – connections between people who aren't necessarily alike, to enable acting together for the common good. There was agreement among stakeholders that this stock had been declining over time. Furthermore, there was a shared desire to turn this trend around with beneficial effects for wellbeing (e.g. through social support, local physical activity and less crime) and energy use (e.g. through less travel for social connection, greater community capacity to support energy interventions). The relationships are considered to be currently dominated by reinforcing loops. While some are helpful for improving wellbeing and patterns of energy use, others serve to entrench poverty and poor social wellbeing. There are two separate sets of loops in this causal map, linked through "length of tenure". The first set links neighbourhood quality and local social connection, while the second set describes relationships related to tenure security, education and income. The concept of "quality" has not been clearly defined, although stakeholders tended to be describing physical aspects of the neighbourhoods and houses including well-kept, green and shared spaces; attractive local places for people to meet and safe places for children to play; well-maintained. Aspects of beauty were also discussed. On the other hand, litter, graffiti, neglected buildings and public spaces were all considered to detract from neighbourhood physical quality. It was considered important by some that quality was best defined by the residents of the neighbourhood.

> *"If you have let's say a block of flats or a row of terraces which are externally insulated…. people see somebody is showing we care about these properties and there is anecdotal evidence, but it's strong anecdotal evidence, that there is a reduction in graffiti and minor anti-social behaviour and it cements community bonds as there is a process of agreeing to it"*

This map has been revised following initial exploration of national data sources and published research. The revised version was presented at HEW Workshop 2.

[6] Kearns A. 2004. Social capital, regeneration and urban policy. (CNR Papers).ESRC Centre for Neighbourhood Research. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.198.1876&rep=rep1&type=pdf

Physical quality of houses and neighbourhoods

This section of the map reflects the collective theories of the stakeholders, triangulated with real world data and evidence, as well as some initial simulation modelling. The meaning of "quality" when it comes to housing and neighbourhoods varied across the representatives participating. High quality housing comprised sustainable, long-lasting materials; technology that didn't break down and was easily understood and used; energy efficient; well-designed and appropriate in size for its purpose; attractive to look at; thermally comfortable. In discussions about the quality of neighbourhoods, some stakeholders were clear that this meant adequate, safe and attractive green space, places for local people to come together (whether it was pubs, shops, community centres or churches), freedom from graffiti, rubbish and broken windows. Other stakeholders argued that what constitutes a high quality neighbourhood should be determined by the people who live there rather than top down social norms being imposed on diverse communities.

R1 physical qualities that make people want to stay: it was suggested that greater social connection and sense of security from crime leads to greater ownership, pride and sense of responsibility by residents. This leads to greater investment of resources by residents, landlords and local government into the physical aspects of houses and neighbourhoods. Improved houses and neighbourhoods (including amenities, green spaces and other places for locals to meet) makes people want to stay longer and increases social connection and sense of security. Existing research about social connection supports these links[7].

R2 connection and action: Stakeholders proposed that improving the physical quality of neighbourhoods (including quality of green space and "third spaces" or other places where locals could meet) leads to greater neighbourhood-level social connections – either directly or through longer tenure. In turn, these connections can enhance community capacity to take action in the neighbourhood by strengthening local organisations that act in the public interest. Stronger and truly representative organisations in turn further enhance neighbourhood social connection. There was some disagreement about whether the design of physical spaces could be used to influence social wellbeing in this way, for example:

> *"… you can't make people change their way of living by changing the road or the footpath or the parking space. You have to do it by other means… By building the community and dictating people's behaviour the result is that there has been a huge push back in those developments and prices have fallen because no-one wants to live like that."*

R3 community empowerment: the strengthening of local public interest organisations

[7] See for example: Livingston M, Bailey N, Kearns A. 2008. People's attachment to place - the influence of neighbourhood deprivation. University of Glasgow, Joseph Rowntree Foundation, Chartered Institute of Housing. http://www.jrf.org.uk/system/files/2200-neighbourhoods-attachment-deprivation.pdf

Pearson S, Lawless P. 2012. Population mobility in regeneration areas: Trends, drivers, and implications; evidence from England's New Deal For Communities programme. Environment and Planning A 44:2023-2039. http://www.envplan.com/abstract.cgi?id=a44679

through improvements to the physical quality of neighbourhoods was also considered to lead to greater ability of these organisations to attract external funding and other resources, enabling further improvements to the physical environment.
R4 housing improvements help people stay: as well as making residents want to stay in an area, improvements to houses (including energy efficiency improvements) may reduce household running costs and improve tenure security, allowing people to stay longer and further enhancing neighbourhood social connection.
There are two balancing loops that represent limits to the positive impacts of increasing social capital – in other words the potential negative effects of "too much" social capital, or when bonds between people who are very alike do not contribute positively to the public interest.
B1 unhelpful bonding: increasing social capital can lead to stronger bonds between people who are alike in ethnicity or socioeconomic status. In turn this can lead to territorial exclusion, prejudice and marginalisation of other groups. This can then undermine further improvements in local social connection and sense of security. Similarly, these patterns of exclusion and marginalisation can also undermine neighbourhood organisations (*B2*).

Neighbourhood social connection is considered to have varying importance by life stage, being particularly important for children and older people. It was argued though that neighbourhoods that successfully encouraged this kind of social connection would allow people to continue to live in neighbourhoods of their choice at different life stages. There was some debate about how community level income, ethnic and age mix fed into these community connection loops. While some argued that diversity would support community connection, resilience and positive action, others suggested that "super-diversity", particularly when accompanied by short tenures and in the absence of resources, was not conducive to positive local community connection.

Tenure security

Two patterns of reinforcement are possible – one reinforcing improvements in material circumstances through movement and others entrenching intergenerational poverty. Central to both is the differential quality of schools between localities, in itself reinforcing (*R5 differential in school quality*). The mutually reinforcing links between employment and income security are shown in *R6 housing and job security*, while tenure security also means greater income to pay the mortgage, as frequent house moves incur letting fees, bonds and removal costs (*R7 less moves save money*). Low tenure security leads to households being moved within low income neighbourhoods, increasing the number of school changes, but also directly reducing the quality of children's education. Lower

educational attainment leads to intergeneration entrenchment in poor neighbourhoods (*R8 downward social spiral* and *R9 instability entrenches poor education*). Greater student turnover also has a detrimental effect on school quality (*R10*). On the other hand, higher income and employment security means greater resources to make house moves on the basis of school quality, leading to reinforcement of improved education, employment and housing prospects (*R11 moving up the social ladder*). However, school moves can still be detrimental to children's educational outcomes (*B3 moving up has its drawbacks*).

The **local** and **national housing affordability** maps connect closely to the feedbacks about tenure security. Quality of houses and neighbourhoods connects closely to **land ownership, value and development patterns**. Local geographical social connection was considered an important influence on **energy efficiency and climate change** through community capacity, knowledge and leadership about energy efficiency, as well as resilience and adaptability to expected climate change.

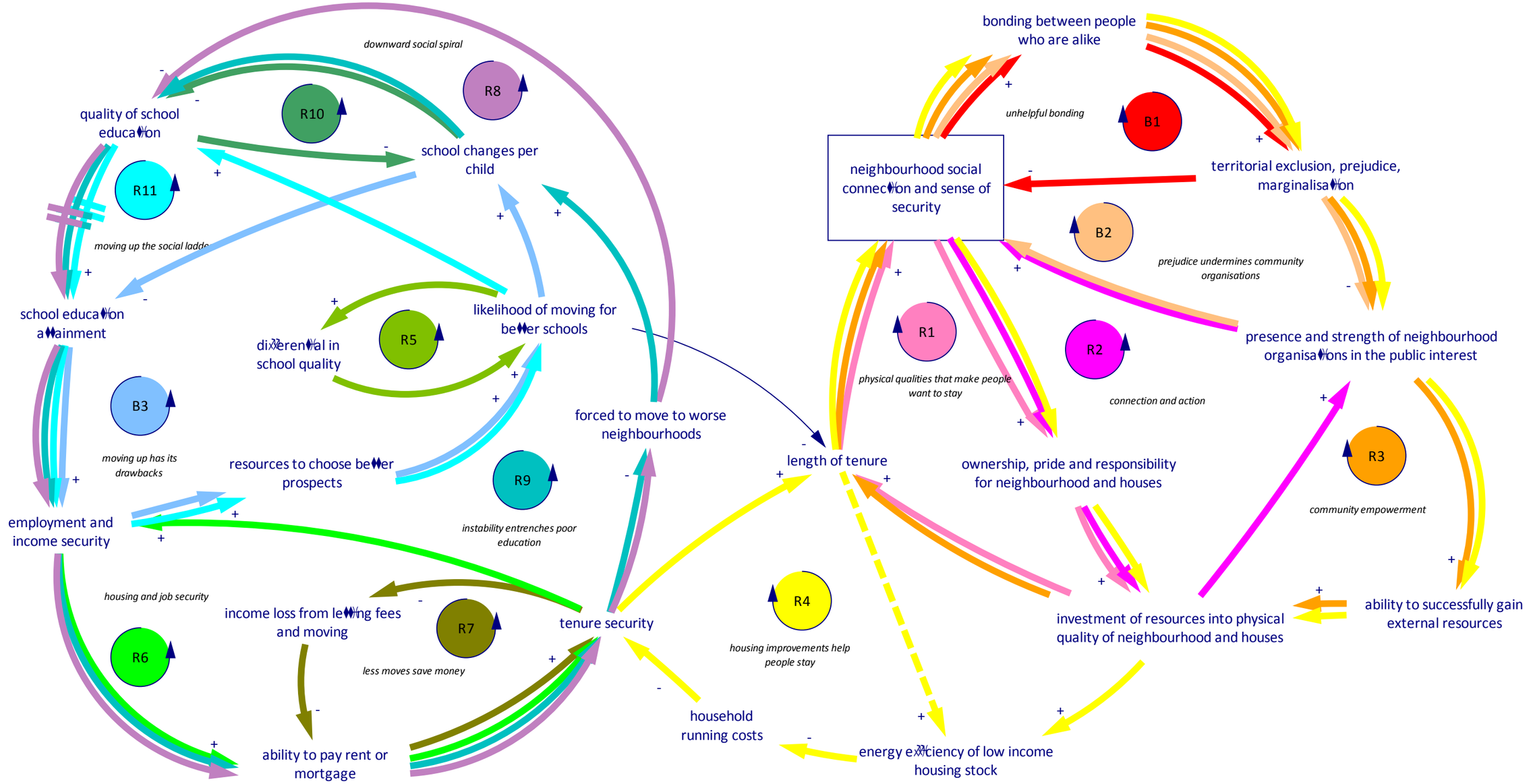


Figure 4 Community connection and quality of neighbourhoods

Energy efficiency and climate change

There are three causal maps relating to **energy efficiency and climate change**: adaptation of the housing stock to expected climate change effects; influences on energy efficiency of the housing stock; and energy cost inequities

Adaptation of housing stock to expected climate change effects

This causal map highlights the need for policies about housing to consider the expected (and already occurring) effects of climate change for Britain's housing stock. In addition, that adapting the housing stock to climate change has its own set of implications for wellbeing and energy use. The map is dominated by problematic reinforcing loops that tend to undermine efforts to reduce energy or improve wellbeing by intervening in housing. Area of green space and lifecycle housing sector energy use are stocks stakeholders considered important to be measuring over time.

The links between greenhouse gas emissions from Britain's housing sector and the world's ability to limit climate change is not just about the contribution of the emissions themselves, but Britain's ability to lead and influence in a global governance setting, and for large developed countries to show that it is possible to reduce emissions to levels required to limit climate change.

R1 energy costs of pre-emptive adaptation of stock: Adapting Britain's housing stock to a warmer climate overall involves significant resource and energy use in itself. Although for each house this may be a one-off energy and resource investment, it will nevertheless, to some extent, undermine emissions reductions in the short to medium term.

R2 energy costs of extreme temperatures: Greater extremes of heat are expected (and probably already occurring) in Britain. Although milder winters are expected, there is a higher likelihood of extreme cold events as well in the medium term. Energy costs are incurred by responding to these, by the disruption they cause, as well as the need to recover from them. The increased frequency of extreme rainfall and inundation events also comes with a significant response and recovery energy cost (*R3 flooding, energy cost and climate change; R4 inundation, energy cost and climate change*), as well as significant negative social impacts which are outside these feedbacks. Stakeholders considered the costs of extreme weather events likely to be much greater in the future than the likely costs of inundation and erosion from storm surges and sea level rise.

The other reinforcing loops in this map relate to the way pressure for new housing interacts with our ability to adapt the housing stock to climate change. Firstly, increasing numbers of flood vulnerable houses, and societal experiences of severe flooding, lead to

governance decisions to abandon vulnerable houses and communities. Relocation, as well as having significant wellbeing implications (see Appendix for the full map) and energy costs (*R5 energy costs of relocation*), puts pressure on the housing stock. This can lead to new housing being built on flood vulnerable land (*R6 relocation and housing pressure*). More likely, it was argued, the pressure to provide new housing is likely to encroach on green space which is crucial for protecting households from flooding as well as extreme temperatures (*R7 pressure on green space*). In what was considered a weaker relationship, sea level rise, erosion and storm surges also put similar pressures on the land available for housing (*R8*). Finally, the global effects of climate change may well be already contributing to immigration from low income countries. This is likely to create further pressure for new housing in the UK (*R9 climatic immigration requires new housing*).

In the context of inadequate climate change mitigation, it was considered likely that very significant disruptions in energy supply would occur in the long term, to a degree that would severely limit people's ability to use energy to support their lives in ways that are currently the norm (*B1 severe energy discontinuities*).

This causal map relates closely to the **community connection and quality of neighbourhoods** map, **housing affordability** maps and **household crowding**.

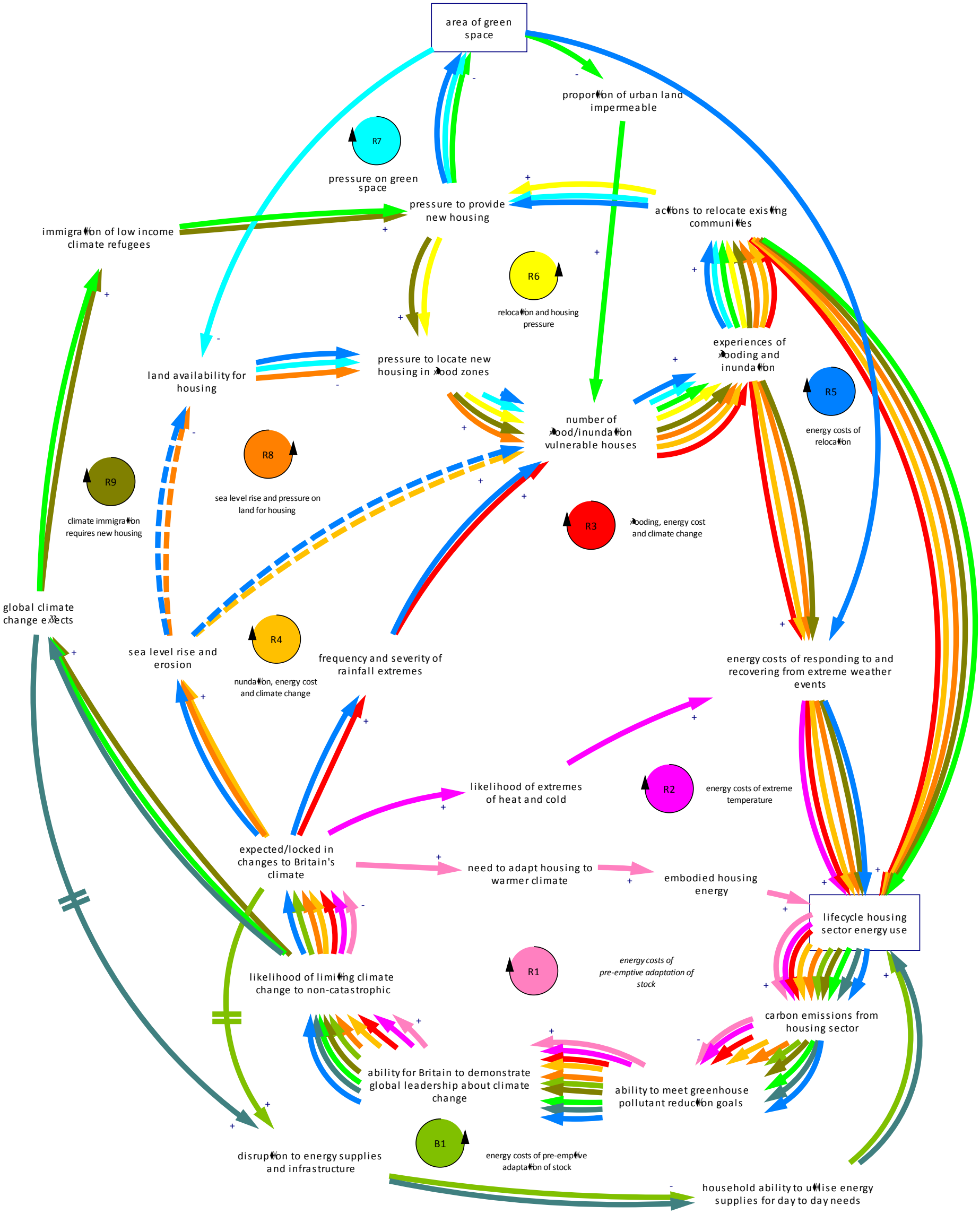


Figure 5 Adaptation of housing stock to expected climate change effects

Influences on energy efficiency of the housing stock

There are few feedbacks in this map and the diagram shown in Figure 6 (two reinforcing and one balancing loop). The figure therefore also includes all the variables that do not take part in the feedbacks. Two stocks take part in the feedbacks: energy efficiency of the housing stock and household energy use. The map demonstrates that the influences on housing energy efficiency, at least those identified by stakeholders thus far, come mainly from other causal maps. Policies aiming to improve the energy efficiency of housing and reduce housing sector greenhouse gas emissions will therefore need to understand effective intervention in the other causal maps.

R1 experience and salience of cost savings: Firstly, it was suggested that the more households who invest in energy efficiency improvements to dwellings, the more people who experience energy cost savings, and the greater the salience of these cost savings in further investments for the same people and their networks. However, many considered this loop not to be particularly strong as an influence on investment, perhaps because of the variables feeding into the salience of cost savings. There are also limits to the potential growth in investment as a result of this loop (*B1 diminishing returns*), since each further investment in a dwelling becomes more costly with less energy cost savings. The resources to invest in energy efficiency and other influences on the proportion of households investing in interventions were considered to be more important than the potential cost savings currently.

A further reinforcing loop was suggested that may be increasing the salience of environmental sustainability in decisions to invest in energy efficiency. *R2 local aggregation of environmental awareness*: it was considered that that environmentally aware households were attracted to areas where local government was actively engaged in sustainability. In turn this increases local government action through the voting and advocacy of constituents, again making the region more attractive to households interested in sustainability.

This causal map has dense connections with many of the other causal maps, in particular **community connection and quality of neighbourhoods** (both tenure security and community connection); **housing affordability**; and **land ownership, value and development patterns**.

> *"If you have a technological approach to policy; whether you are deriving all the benefits from your home, I guess it's the sense of control and therefore security and people's ability to cope may be compromised. Environmentally, there is an issue in relation to the new technology and using that and behavioural issues…the amount of*

people that struggle with their heating controls, they don't know how a smart meter works"

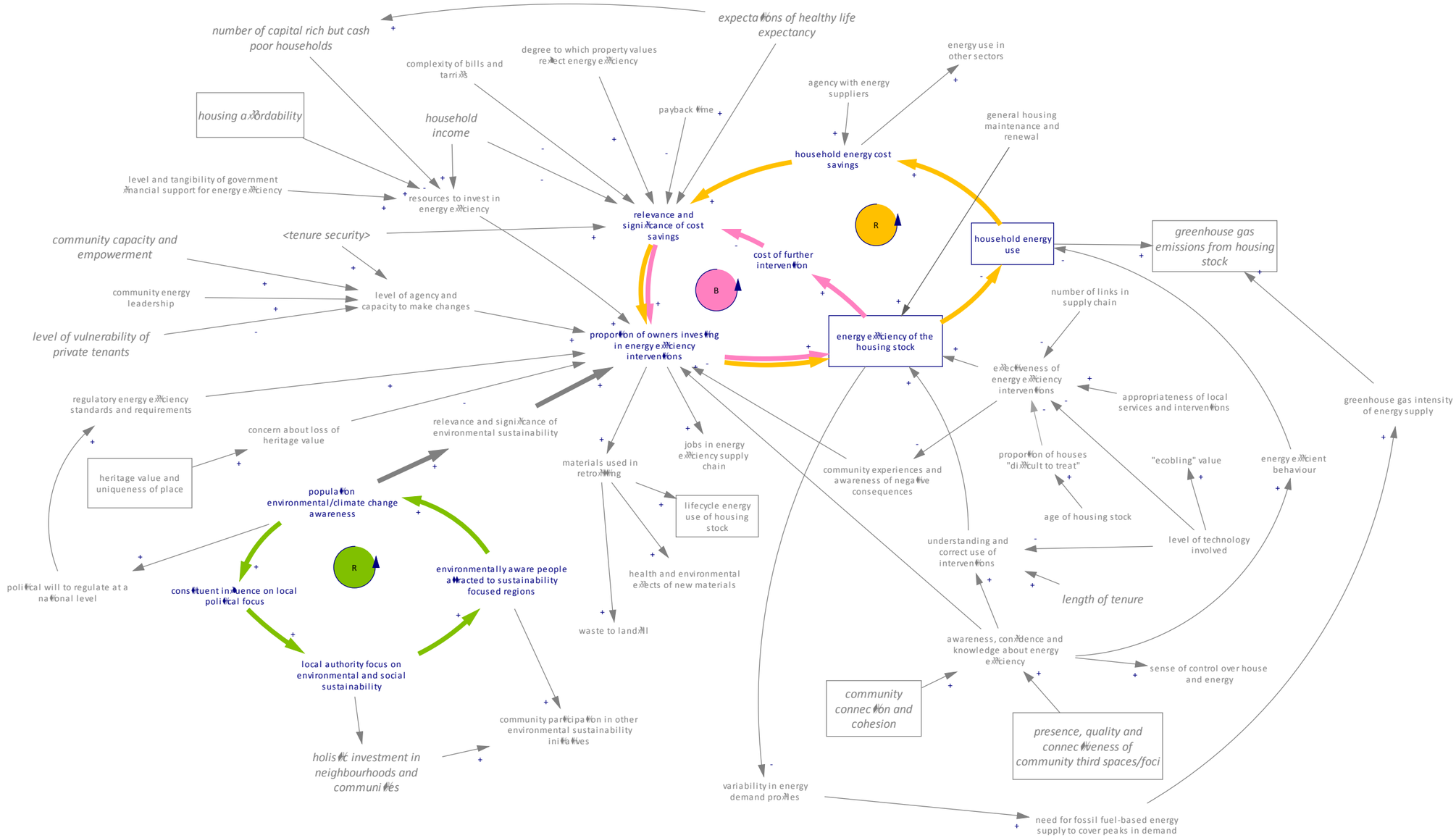


Figure 6 influences on energy efficiency of the housing stock

Energy cost inequities

Similar to the influences on energy efficiency, there are just two reinforcing feedbacks in this causal map, describing vicious cycles that help maintain income inequities[8] in the cost of household energy. Energy cost inequity was considered very important by stakeholders in linking housing, energy and wellbeing and is shown as a stock in Figure 7. All the variables influencing this stock are included in the diagram, which links to the **housing affordability** and **energy efficiency and climate change** causal maps.

> *"The price of energy is one of the biggest problems of them all. We have got issues being loaded onto electricity bills that should be met through taxation and not regressively funded by energy bills. In some instances, everybody pays, but not everybody benefits".*

R1 effects of housing inequities on work and income: A widening income gradient in the state of repair of rental housing would also widen the income gradient in health outcomes related to housing. In turn, this would worsen the income gradient in fitness for work and increase the number of low income houses requiring benefit support, reinforcing the income gradient in the quality of private rental housing. This entrenchment of poor quality housing occurs in the context of the second reinforcing loop (*R2 benefit vulnerability*) where the current system means that households receiving benefit support have lower tenure security and poorer quality rental housing because of barriers for benefit recipients to renting privately owned houses.

> *"The thing that I care about in this context of energy prices and decarbonising the supply is that by creating schemes to improve energy efficiency, are we directly increasing costs to poor people? The renewables obligation, by forcing companies to source energy from somewhere other than the cheapest source must increase costs".*

[8] Where inequity is taken to mean an unjust, systematic and preventable disparity between groups with different levels of social advantage and power (Braveman and Gruskin 2003)

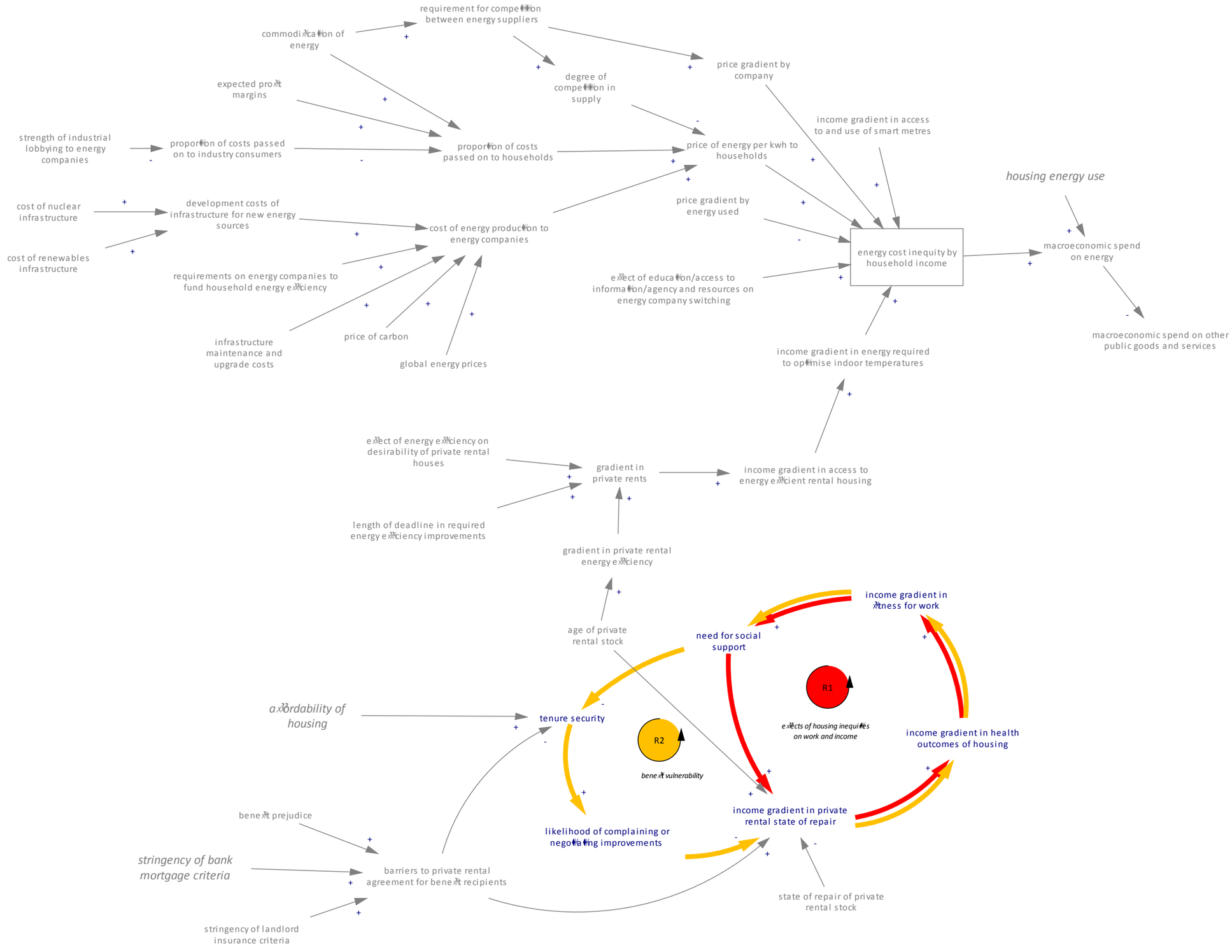


Figure 7 energy cost inequities

Fuel poverty and indoor temperature

The relationship between indoor temperatures, wellbeing and fuel poverty are described here, with identified stocks: housing-related greenhouse gas emissions; physical health and fitness; and the affordability of indoor temperature optimisation. The combination of reinforcing and balancing loops make the relative strength of loops important for understanding expected patterns of behaviour over time.

Current and expected future effects of climate change on external temperature distributions in the UK are crucial to these loops. The total energy used by households to optimise indoor temperatures for overall wellbeing contributes to housing greenhouse gas emissions (depending on the greenhouse intensity of the energy supply). In turn, these emissions contribute to increasing climate change. The effects of climate change on the distribution of temperatures are expected to be an early flattening of the distribution (with more extreme temperatures at both ends), followed by a shifting of the whole distribution to the right (less cold and more warm temperatures). This will occur unevenly and also be affected by other feedbacks (for example the melting of ice sheets and shifting of ocean currents). By the 2080s, climate projections suggest that all seasons will be warmer, but that summer temperatures will increase substantially more than winter temperatures.

> *"We are getting something wrong in super-insulating homes to reduce carbon emissions. All we have done is turn the winter under-heating problem into a summer overheating problem. So, we just shift where the problem occurs rather than solving anything."*

However, future climate scenario and energy use analysis of non-residential buildings suggests a possible 40% reduction in energy use for space heating by the 2080s, accompanied by a doubling of cooling energy use by 2050[9].The causal map therefore includes a reinforcing and balancing loop in uncertain competition - *R1 (climate change and need for summer cooling*), where increasing ambient summer temperatures lead to greater energy required (and used) to cool houses, generating further greenhouse gas emissions and *B1* (*climate change and winter heating*), where over time the need for winter heating is expected to significantly

[9] The COPSE project analyses modelled building performance for non-residential buildings in response to several future climate scenarios. Analyses suggest a possible doubling of the need for cooling energy and up to a 40% reduction in space heating energy use by the 2080s. Comparative magnitudes of energy use for heating and cooling for the whole building stock were not provided. Levermore, G.J., Courtney, R., Watkins, R., Cheung, H., Parkinson, J.B., Laycock, P., Natarajan, S., Nikolopoulou, M., McGilligan, C., Muneer, T., Tham, Y., Underwood, C.P., Edge, J.S., Du, H., Sharples, S., Kang, J., Barclay, M. and Sanderson, M. 2012. Deriving and using future weather data for building design from UK climate change projections – an overview of the COPSE Project. Manchester University, UK.

reduce. The overall dynamic effect of these loops on the total energy required and used to optimise indoor temperature is therefore difficult to predict, with shifting dominance likely as climate change progresses.

Total energy used to heat and cool homes also contributes to the urban heat island (UHI) effect in cities (as one contributor among many). In turn, the UHI creates similar reinforcement and balancing (increased energy use in summer and reduced need for heating in winter – *R2* and *B2*). In the absence of adequate climate change mitigation, more extreme effects may cause infrastructure failures. On the one hand, this could keep people at home and increase household energy requirements (*R3*). On the other hand, disruption may mean that households are not able to access energy for their needs (*B3*).

To some extent (and depending very much on age and physical fitness) people are able to physically adapt to a range of temperatures. However, it was argued that increasing energy use for heating and cooling does not allow this adaptation to happen (*R4*). It's not yet clear how the combination of population aging and improving health will combine to alter the potential for physiological adaptation.

R5 fuel poverty: The more energy needed to achieve optimal household temperatures (for wellbeing), the less affordable temperature optimisation becomes (the energy efficiency of dwellings influences this). Rising costs of fuel and therefore temperature optimisation increases morbidity from extremes of heat and cold indoors. In turn, this burden of illness reduces household employment and income, again reducing the affordability of temperature optimisation. Related to this, the burden of illness from extremes of temperature also increases the time people spend in their homes (*R6 people who are unwell spend more time at home*) as well as reducing people's ability to go out to work (*R7 people out of work spend more time at home*).

> *"The rise in winter deaths is associated with fuel poverty, poor heating and an inability to pay bills. Now, as of the last 10 years the opposite problem is starting to emerge, with summertime overheating increasingly causing health stresses"*

Three kinds of behavioural adaption to changing household energy circumstances were also proposed to be occurring. Firstly, it is argued; as heating and cooling becomes more affordable, people do more of it (*rebound effects of affordability*). These rebound effects potentiate the effects of climate change and the UHI. In a further rebound loop, it was proposed that with cheaper heating and cooling,

households have been shifting their patterns of heating and cooling from only living areas to all the rooms in the house, as part of changing societal expectations (*R8*). In addition, with increasingly available heating and cooling people's expectation of indoor temperature **variability** was considered to reduce (*R9*), enhanced by other factors, such as patterns of heating and cooling in workplaces. There was some disagreement among stakeholders about whether this last loop was active.

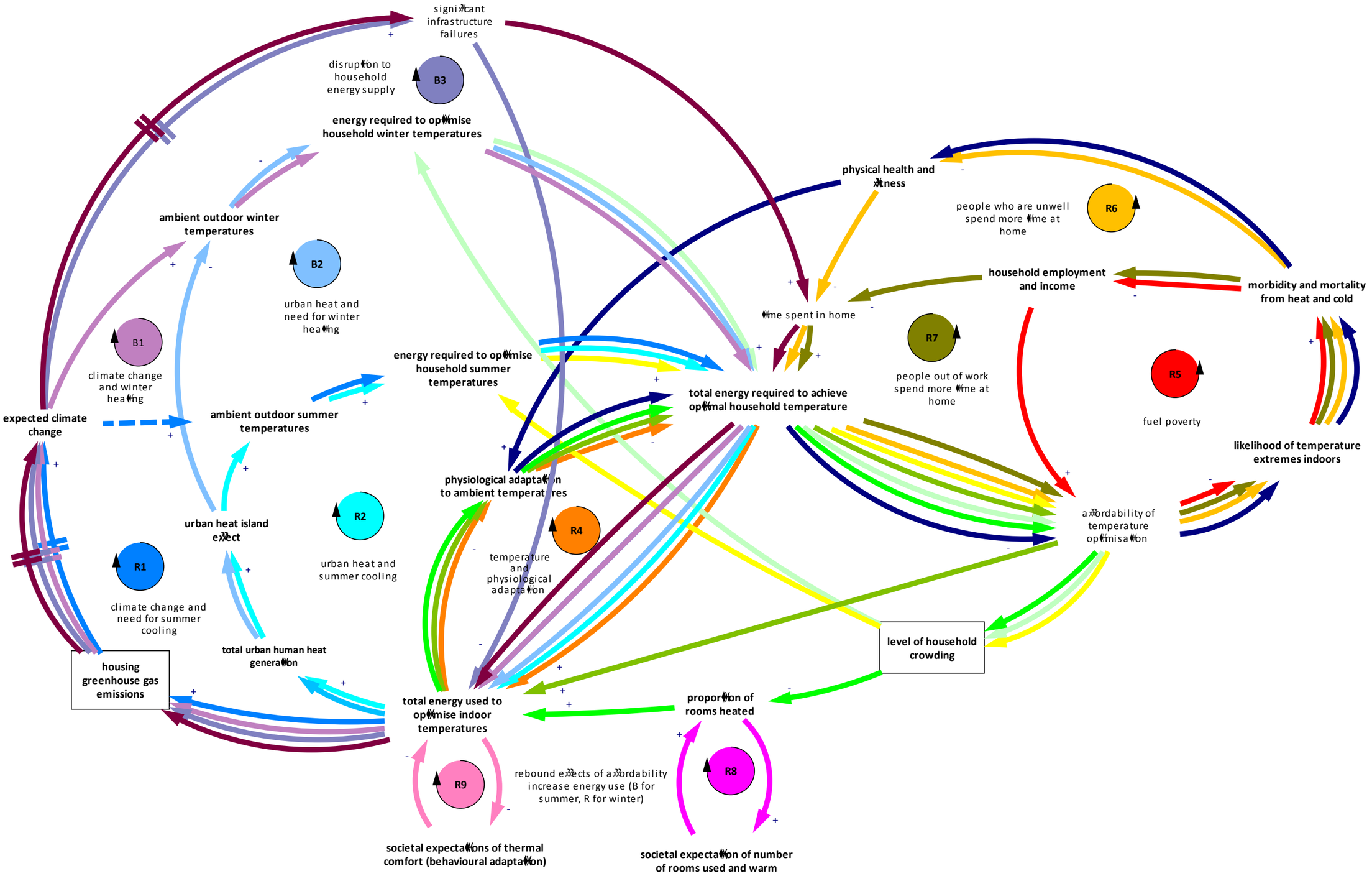


Figure 8 fuel poverty and indoor temperature

Household crowding

Stakeholders considered overcrowded households to be an important stock and overcrowding to be increasing, particularly in London and for minority groups. There was a widely articulated desire for this trend to be reversed. The sector is dominated by reinforcing loops, potentially trapping generations of families in crowded houses.

R1 crowding, ill health and work: the burden of illness from overcrowded households reduces employment, keeping adults at home, reinforcing overcrowding and reducing housing affordability. This directly effects crowding by forcing households to live in smaller (lower cost houses), as well as limiting room use, particularly in winter (*R2 forced to stay in one room to keep warm*). The burden of illness from crowding is exacerbated by more washing, cooking and drying clothes (*R3 crowding and moisture)*. The direct effect of overcrowding on children (through having limited places to do activities) is coupled with the indirect effects of family conflicts and breakdowns. Both impact children's education and social wellbeing, leading to an intergenerational vicious cycle (*R4*).

> *"Children crammed into inappropriate spaces stops young children thriving and getting out of the treadmill of poverty. Where are the role models? How do you even get up to go to school?"*

Poor education outcomes and lower social wellbeing were considered to reduce young people's ability to leave home, reinforcing overcrowding (*R5*). Higher housing costs also lead to households amalgamating (*R6 households join together to afford housing costs*). The feedbacks associated with family break-ups were less certain. While some stakeholders suggested that families breaking up would increase the number of households requiring family houses (*R7*), others considered that family break-ups would reduce the pressure on family housing by reducing family size (*B1*). However, in the longer term, shifting relationships and family combinations might tend to negate both these loops. There were also disputed theories about the interplay between household crowding, housing affordability and population fertility. Two balancing loops were proposed. In *B2 crowding, education and fertility*, the curtailment of children's ability to leave home and form new households could limit growth in overcrowding. Similarly, in *B3 housing affordability limits childbirth*, as housing costs rise households may choose to have fewer children to fit into smaller, cheaper houses.

The full causal map in the Appendix shows some other important demographic variables, the links between ethnicity, location and overcrowding, as well as the connections between this sector and **housing affordability**, **temperature optimisation**, **ventilation**, **community connection** and **land ownership, value and development patterns**.

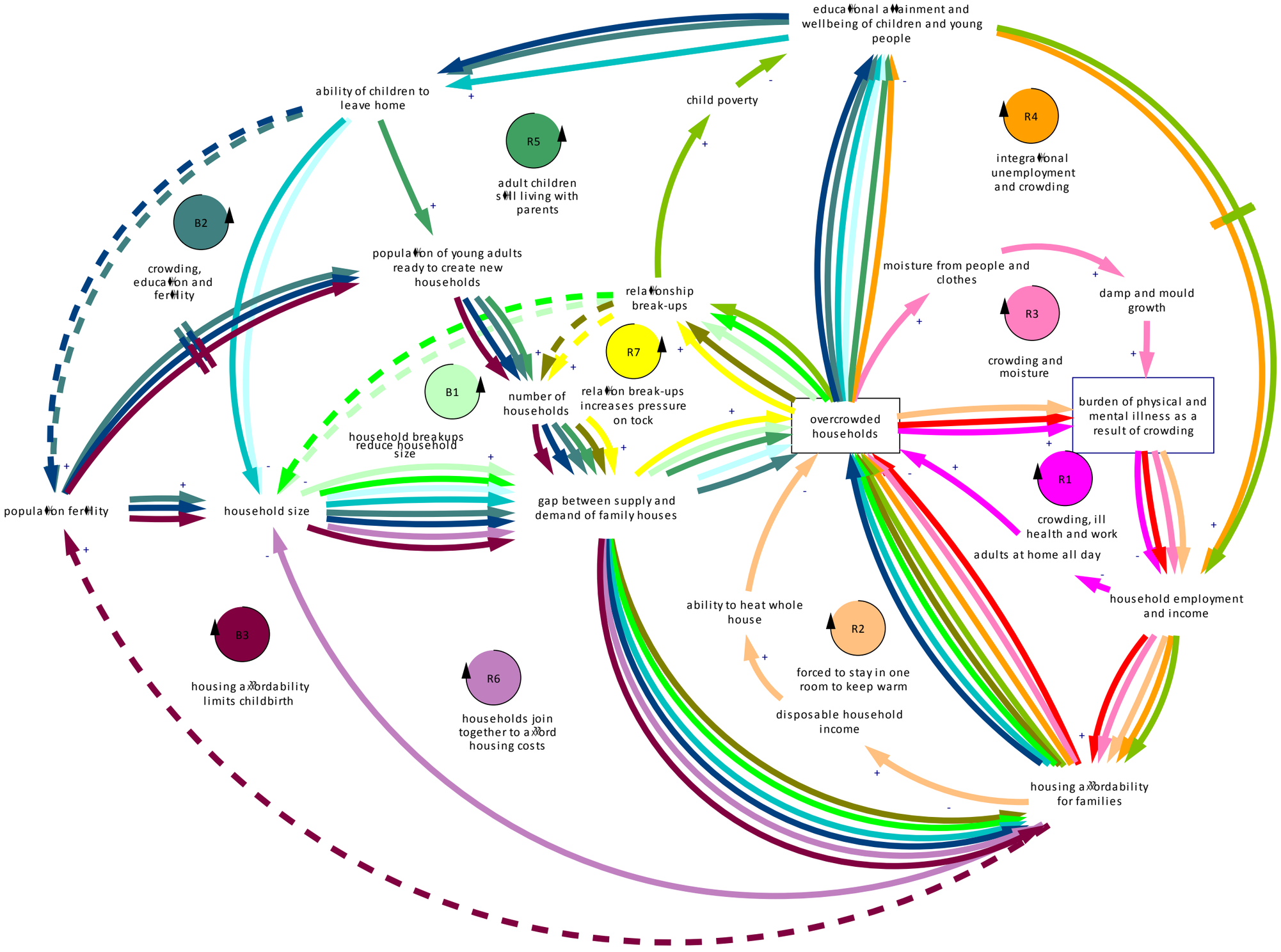


Figure 9 household crowding

Housing affordability

There are three causal maps relating to **housing affordability**. Quite different, but closely interlinked, processes are considered to be occurring at different geographical scales: the national property market; regional housing affordability; and local gentrification[10].

"You can't look at wellbeing if you don't look at the affordability of housing"

National Property Market

The national property market was considered by stakeholders to be an important influence on housing affordability more generally. National median house prices, the proportion of households able to afford to buy a house and rate of home ownership are all stocks considered to contribute to overall housing affordability. There were opposing desires among stakeholders for the future of these stocks. While improving housing affordability remains one long-term goal, a current economic aim is to keep house prices rising and property turnover high. As well as being measures of economic growth in their own right, property turnover also fuel other kinds of consumption. The map includes some potential limits to growth, but currently the reinforcing loops that keep house prices rising are dominant.

B1 and B2 limits to growth through affordability: in a self-limiting market, as prices rise, the number of people who can afford to buy a house who don't already own one will fall, reducing demand and limiting growth in house prices. A further limit to growth is *B3 limits to growth through wages:* as prices rise and property becomes more profitable, banks may increase lending in the property market, while decreasing it in other portfolios. Less lending to businesses and industry may lead to a reduction in employment and wages, limiting the number of households who can afford a mortgage.

B4 limits to growth through lending: if banks have a property lending target based on number of mortgages, then rising demand for property helps them meet this target. As this target is approached, banks reduce their risk by tightening up lending criteria, reducing demand and balancing out prices. *B5 limit to growth through meeting bank targets:* On the other hand, if banks have a property lending target based on total lending rather than mortgage numbers, house price rises increase the total value of mortgages lent, also helping them meet their target and tighten lending criteria. **However, this loop then feeds into B1 and B2 creating counterintuitive reinforcement of rising prices over time:** If rising prices help banks meet lending targets, followed by tightened lending criteria, this leads to a drop in demand, slowing the growth in prices. However, this in

[10] This was the term used by most representatives to describe a movement of wealthier people into a low income locality, neighbourhood or suburb with the consequent changes to the character of the area

turn will stimulate further demand as asset affordability increases.

A number of reinforcing loops expand the market. *R1 and R2 current owners buy more*: rising prices increase property asset wealth for households already in the property market, allowing them to buy more expensive properties (*R1*), or to buy a private rental property or second home (*R2*).

> *"For banks one of the sure fire bets you've got… is increasing land and property values and is much less risky than investing in a company making a new widget. So essentially there is a mechanism… for the banking system to make properties more expensive (and by inference land values) and look like they are increasing growth in society…"*

The attractiveness of investment in private rental properties is also enhanced by *R3 price rises push people into private rental*: as home ownership becomes less affordable, demand for private rental housing grows, driving up rents and enhancing the attractiveness of private rental investment. On the other hand, as private rental investment increases, the increasing supply of private rental housing will tend to balance out rent levels and therefore the attractiveness of investment (*B6 limit to rental investment*).

R4 expanding demand through easier mortgages: as house prices rise, the property market becomes more attractive to banks and they may increase their property lending targets, then expand their lending market by relaxing criteria so that households with lower income and less savings are able to secure a mortgage.

R5 property speculation: rising property prices also make property investment an attractive proposition for wealthy investors, including from overseas. This accelerates rising prices, as many of these investors have budgets many times the size of the median household income.

R6 focus on mortgages harms construction: if banks focus heavily on lending into the property market at the expense of business and production, it is possible that this reduces lending to housing construction. This limits the supply of housing, reinforcing price rises.

R7 price rises increase construction costs: in areas where prices are high, land values for development also increase, making new development more expensive (but also possibly more lucrative). Attracting construction workers in areas where property prices are high may also be difficult, further increasing the cost of construction.

The full causal map in the Appendix demonstrates how this sector is related to other aspects of **housing affordability**, as well as **energy efficiency and climate change** and **land ownership, value and development patterns**.

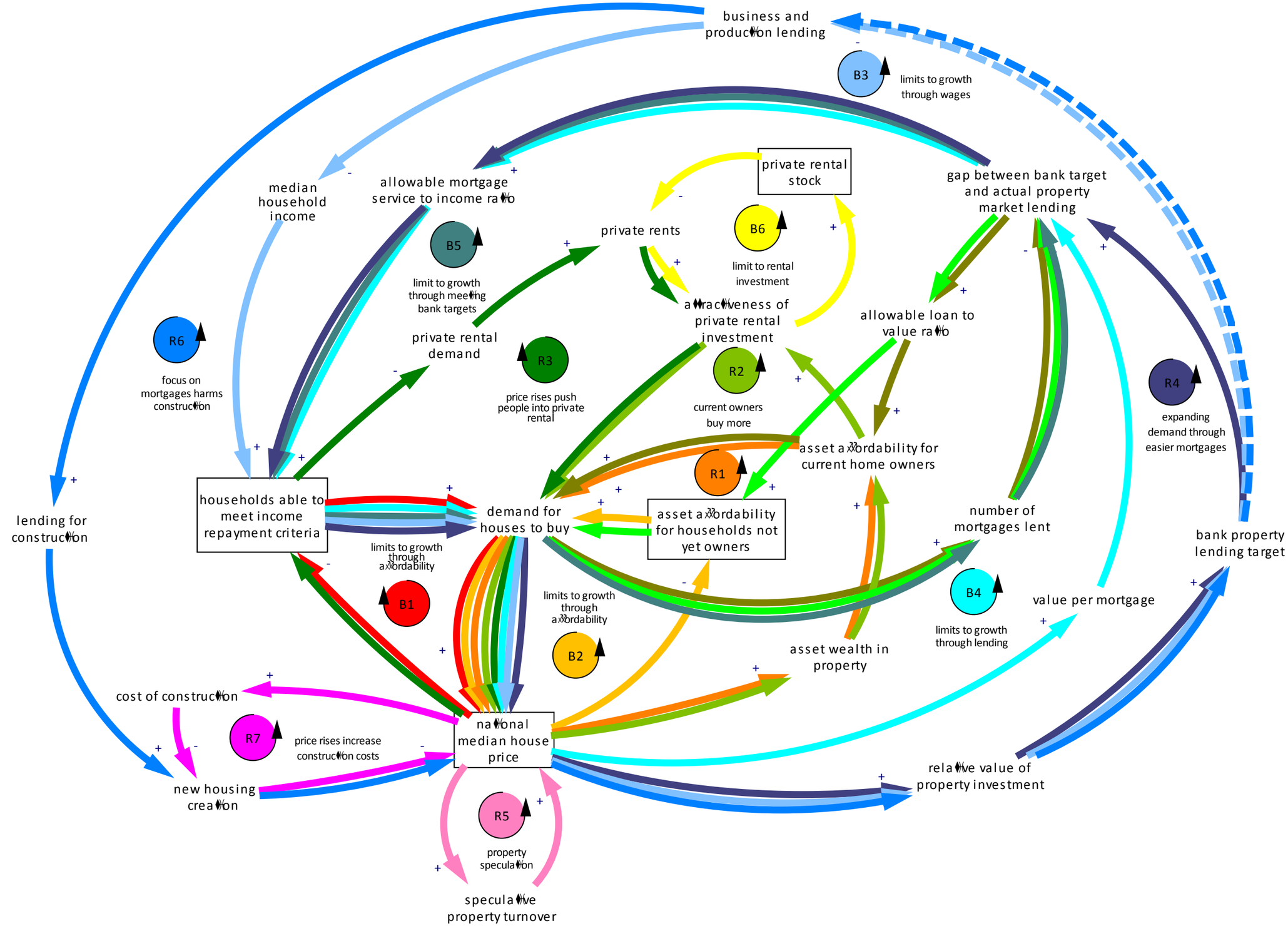


Figure 10 National property market

Regional housing affordability

This map describes theories of regional difference in housing affordability and the relative attractiveness of a region. There are three stocks: regional median house price, regional private rent affordability, and regional housing affordability. The loops are strongly influenced by the **national property market loops** above. Many of the theoretical connections were contested and uncertain.

R1 regional private market puts pressure on social housing: many considered the reinforcing interplay between regional property demand and social housing supply to be important. As regional private rents rise, demand for social housing also rises, placing further pressure on the private rental market. However, some considered the separation between social and private rental stocks to be increasingly false.

Although the availability of jobs was considered the main influence on the attractiveness of a region (see full map in the Appendix), the quality of education and services, housing affordability were also considered important, forming two balancing loops. *B1 property and rental prices limit regional attractiveness*: as regional attractiveness rises, demand for housing rises and housing affordability declines, dampening attractiveness. Private rental affordability was considered particularly important for attracting "key workers" (e.g. teachers, police, nurses). As attractiveness increases and rental affordability reduces, a region becomes less attractive to key workers, reducing the quality of education and services, limiting attractiveness (*B2*).

> *"By having pupil choice the local school is no longer representative of the locality it serves. Teachers (certainly in London) can't afford to live nearby and essentially what could be a hub for the community is abandoned."*

R2 increasing social welfare increases rent: in the current context, with increasing reliance on a minimally regulated private rental market, it was considered that as private rent levels become less affordable for low income families, there is greater pressure to increase government housing support. However, this was considered a fix that fails, since private landlords can respond to increased support by raising rents.

B3 housing improvements: there was debate about how private rent levels influence housing improvements (for example to improve energy efficiency). It was initially suggested that as private rent levels rise, landlords have more income to spend on improvements, the opposite was argued by most representatives: rising rental demand provides less incentive for landlords to make improvements, and it is at times of low demand, when rental properties are vacant, that owners are motivated to make improvements to attract new tenants.

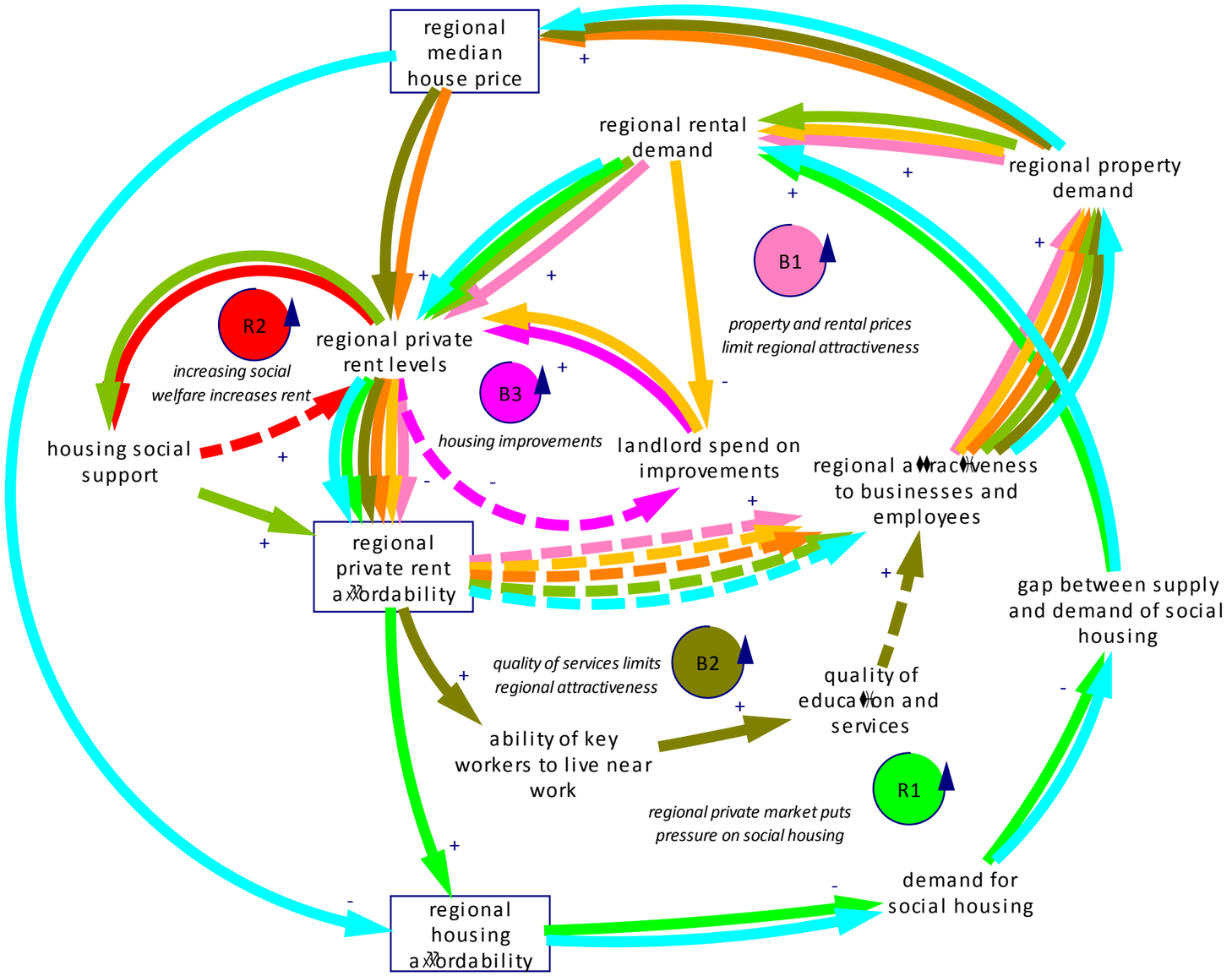


Figure 11 regional housing affordability

Local housing affordability and gentrification

Processes of gentrification at a local scale were considered important for explaining differences in housing affordability. These processes were strongly related to community social mix, through the availability of mixed tenure types. A single stock was considered important in this map – community social mix by income and ethnicity. Waves of gentrification were suggested, with some loops being active earlier in the process and others strengthening later. Some representatives suggested that processes of gentrification also occur regionally, influenced by council housing allocation policies.
R1 differential services drive desirability: it was suggested that differential property prices are driven by the differential quality of schools, services and infrastructure (e.g. public transport). Price differentials in turn tend to increase tenure and social segregation by locality, and this reinforces the differential quality of schools and services particularly.
B1 early gentrification increases social mix: the early stages of gentrification were described as positive for community social mix, as some young families, or "trail-blazing" house buyers become attracted to areas where property prices are cheaper (perhaps in particular where there is perceived to be underlying architectural heritage), increasing the range of different tenures and incomes in the area and balancing out the differential quality of schools and services. Similarly, over time, shops, services and schools in the area begin also to be gentrified and differences in quality between localities reduces (*B2 gentrification could equalise service quality*).

> *"…the arcade used to be a drug dealing place, half of the shops were closed, you know, while now it's more diverse. So yes I do like the fact that the rich people [have] come … and in a way yes I might lose a little bit but I do like the fact that it is a better place to live, there is better quality services, schools will hopefully improve and it will be safer…"*

However, unhelpful reinforcing loops were thought to follow closely behind – some argued these processes occur so quickly that the balancing described above does not occur. In *R2* (*social housing and landlords respond to the market*), early gentrification leads to rising property prices, encouraging speculative investment, and the sale of more affordable houses by social and private landlords. This reduces tenure and social mix, counteracting any early reduction in differential service and school quality.

> *"Any attempt to improve housing conditions has got to … have improved the conditions of the people who were originally living there. If it's just a case of this house has got better insulation and heating, but actually in the process… the original resident has been displaced and a more affluent household has moved in, that's not helping."*

In *R3* (*gentrification reduces affordability*), changes to shops and services to attract wealthier customers make them less affordable to low income families, who then move or travel further to purchase affordable goods and services. It was noted that this loop is

important in some rural communities where large numbers of second homes stand empty, reducing both affordability and viability of local goods and services.

> *"…where there is all this gentrification, new shops, we got a new champagne and fromage shop now. You name it, it's in Brixton. What you see is the people around it have to go further away to even entertain themselves because they cannot afford the entertainment in there."*

Finally, in *R4 racism undermines ethnic mix*, the potentially positive aspects of local gentrification were further undermined by experiences of racism by longstanding residents belonging to minority ethnic groups, who then move elsewhere to escape these experiences.

The map relates closely to **community connection and quality of neighbourhoods**, other aspects of **housing affordability** and **land ownership, value and development patterns**.

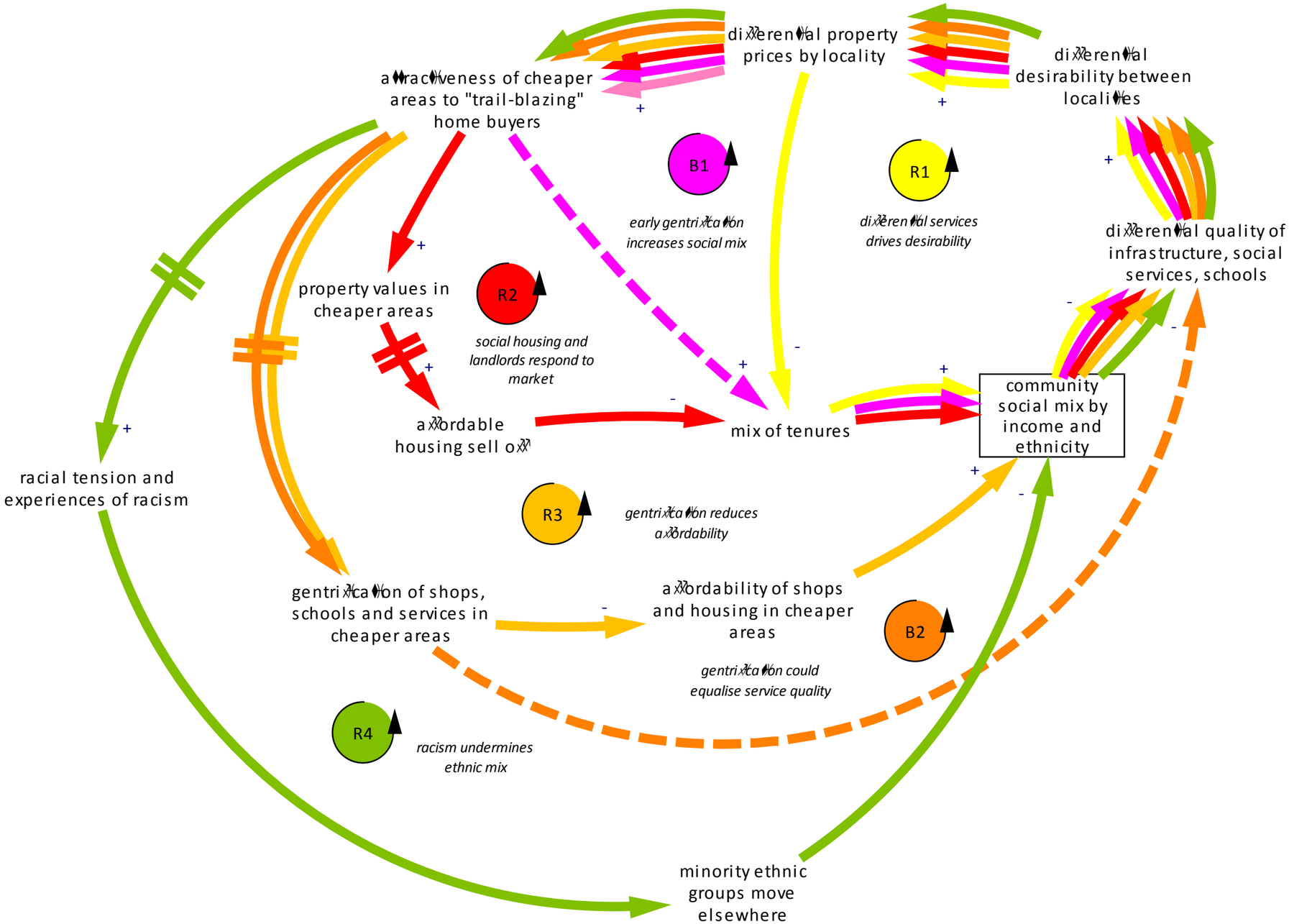


Figure 12 local housing affordability and gentrification

Land ownership, value and development patterns

The physical quality, density and availability of housing were considered by stakeholders to be strongly dependent on the way that land is valued, owned and developed. Although some of the loops proposed could be helpful for improving wellbeing and possibly patterns of energy use, others were thought to currently undermine housing quality and affordability. The number of affordable and social houses was considered by stakeholders to be one of the important outcomes of housing policies and is therefore shown as a stock. Three parts to this map can be distinguished. The first relates to quality of housing[11], the second to local business viability, and the third to housing affordability and development patterns. One reinforcing and one balancing loop on the left of the map describe relations affecting quality of houses and neighbourhoods. *R1 low quality houses leave no resource for improvement*: there was an assumption that the quality of houses and neighbourhoods is influenced by the amount of resources to improve quality. It was argued that low quality houses and neighbourhoods eventually leads to increased cost of insurance, maintenance and repairs, which leaves no resources to invest in housing and neighbourhood quality. *B1 loss of profit could drive future quality*: Stakeholders argued that if developers, investors and owners more clearly felt the increased burden of maintenance costs due to low housing quality this would eventually increase developers' commitment to housing quality. That could also result from harm to reputation as a result of producing low quality housing. There was some debate about whether different types of investors (owner occupied, social, private rental) have different priorities and, therefore, are influenced by different motives. Many argued that maintenance and repairs costs are not currently well connected to the original investors and developers despite the increase in insurance premiums that accompanies claims against builders and developers.

> *"Private sector developers don't have a long-term interest in the properties they build. They sell the house and they are gone. Any failures are covered by warrantees and insurance."*

On the lower part of the map two reinforcing loops describe influences on local business. *R2 local businesses provide locally appropriate and successful services*: it was proposed that increasing the viability of locally-owned businesses (contrasted with businesses unwilling or unable to change to support the particular wellbeing needs of the local community) will lead to local services and interventions (including housing and energy interventions) being more appropriate to the local context. This may enhance their use and support by local community. Depending on local street connectivity, local community support would lead to increase in walking to local high street, further enhancing viability

[11] Refer to previous discussion about the meaning of this term on p.11

of local business (*R3 walking and business viability*).
In the centre of the map increased strength of the regional economy will eventually make more capital available to develop land (*R4 affordable proximity to jobs stimulates the economy*). Depending on local authority requirements, this can lead to more affordable and social houses, stimulating the regional employment rate. More affordable housing also reduces the regional gap between supply and demand for housing, reducing pressure on local authorities to accept low quality housing developments, and continuing to improve the quality and attractiveness of the region (*R5 Continuing quality supply*). On the other hand, as regional employment increases, it can tend to balance quality by increasing demand on housing (*B2 Pressure on councils to accept poor quality backfires*).
There were competing theories about the relationships between land availability, the market value of land and the likelihood of land being (re)developed for housing. *B3 limits to growth in land development*: As land is developed and becomes scarcer, opportunities for further development are reduced. It was suggested that this scarcity increases land values, making the land more attractive to development (*R6 scarcity stimulates development)*. It was also suggested that in times where the market value of land is lower, developers may bank land to reduce its availability and hold onto it until its market value rises (*B4 speculative land market*). Stakeholders argued that developers will not develop a site that is not viable even if land is available and cheap.
It was further argued that higher market land values increase the ratio of developer profits that are derived from the value of the land compared with from the houses, creating a disincentive for investment in quality and encouraging developers to build a larger number of smaller dwellings (*B5 Quality, development and profits*). A number of stakeholders argued that the strength of this loop varies by region.
R7 density stimulates the high street economy: In a situation when less land is available, there is greater pressure to increase building density. If done well, this can enhance walking to local businesses, improving their viability and feeding back into the regional economy. The quality of intensification was considered crucial to this loop.

The **land value ownership, value and development** maps are closely related to **quality of neighbourhoods and community connection**, as well **as housing affordability**. If development patterns compromise housing affordability, it could eventually lead to increase in **household crowding**. At the same time, if development patterns lead to quality housing, gains in **energy efficiency** and effective **adaptation to climate change** cannot be achieved. The full model in the appendix also demonstrates how this causal map is linked closely to aspects of transport and transport energy use.

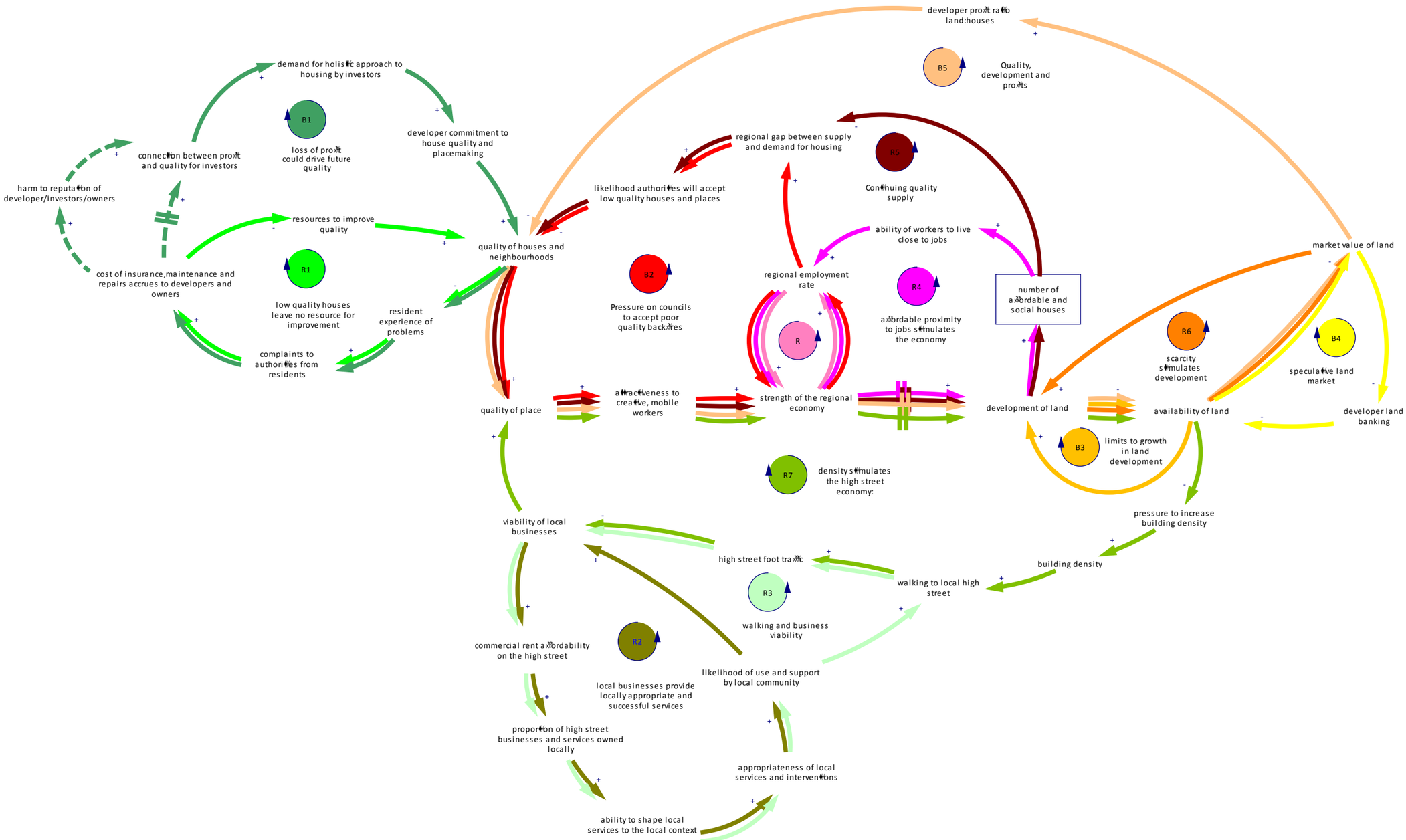


Figure 13 land ownership, value and development patterns

Ventilation and indoor air pollution

The indoor air quality of dwellings contributes significantly to physical and psychological wellbeing. The relationship between sources of air pollution (indoor and outdoor) and air change rates in dwelling are therefore important for housing-related wellbeing. Morbidity and mortality from indoor exposure to air pollution was considered an important stock. There was a shared desire among stakeholders for mortality and morbidity from indoor air pollution stock to decline (e.g. through improved indoor air quality conditions), but disagreement regarding the current trend. The causal map is dominated by unhelpful reinforcing loops. All the loops in the map rest on the effect of indoor air pollution on household employment and income. The strength of this relationship was debated. There are three types of air change rate differentiated in the map: infiltration from the "draughtiness" of houses; window opening; and other kinds of purpose provided ventilation such as mechanical ventilation systems.

It was argued by some that households with lower income tend to live in less airtight houses, with therefore greater movement of indoor air pollution outside affording some balancing protection from air pollution morbidity and mortality (*B1*). On the other hand, less airtight houses also allow outdoor pollutants to infiltrate, increasing morbidity and mortality from this source (*R1*). Income was also argued by some to increase the air change rate through the installation, use and maintenance of purpose provided ventilation systems. If effectively designed, installed, maintained and used (perhaps rarely), these systems could potentially reduce indoor source air pollution exposure (*R2*), as well as outdoor source pollution if they include effective filtration (*R3*).

> *"95% of all ventilation systems in new low energy dwellings built to 2010 standards or better; don't deliver the ventilation rates that the regulations require"*

A more tenuous balancing loop was also proposed – *B2 draughtiness and mould*, whereby the illness and costs associated with excess moisture and mould might keep low income households in draughty dwellings, which has the potential to reduce the risk of moisture and mould (depending on temperatures).

B3 humidity and fresh air: this loop describes how decreasing the air change rate increases indoor relative humidity and the risk of excess moisture and mould. It was argued that many households actively manage this risk by opening windows to increase ventilation (with an associated increase in energy used to optimise indoor temperature). Lower household income is one risk factor for household crowding. This has two implications for indoor air quality. Firstly, it was proposed that more people per house increases indoor air pollution and therefore morbidity (*R4 people produce pollution*). Secondly, more people per house increases the relative humidity through breathing and

use of water, increasing morbidity as a result of moisture and mould (*R5 people produce moisture*). Stakeholders also proposed that greater household employment and income could contribute to increased indoor air pollution through greater consumption of new materials (B4).

There is also an income gradient in smoking prevalence, making low income households more likely to be exposed to tobacco smoke as an indoor air pollutant (*R6 income reduces smoking*) and more susceptible to the negative impacts of air pollution (*R7 income and susceptibility*).

The **Indoor air quality** maps are most closely related **to indoor temperature and fuel poverty, energy efficiency and climate change** and **housing quality**, **development patterns.** As the full map demonstrates, these loops are also influenced by transport energy use which is a major contributor to outdoor air pollution levels.

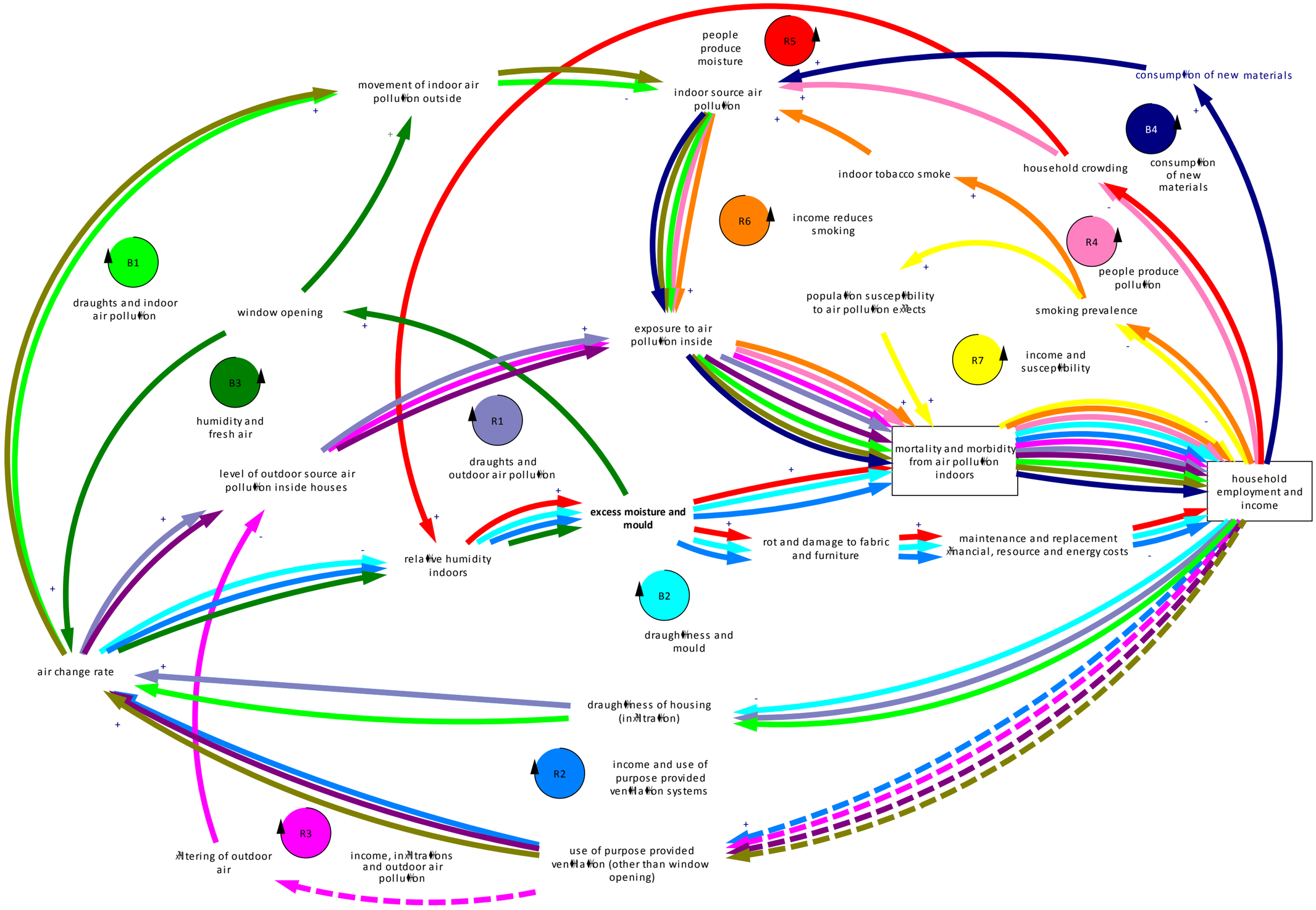


Figure 14 ventilation

Insights and early recommendations from the causal maps

Some initial new policy-relevant insights about housing, energy and wellbeing can be drawn from these qualitative maps. Perhaps most importantly, the deep interconnections between sectors means that policy objectives cannot be considered in isolation. The energy efficiency map was striking in its lack of feedbacks, with many connections to other sectors. This suggests strongly that successful policies to reduce housing energy use and greenhouse gas emissions may require greater attention to addressing feedbacks in other sectors of the system. A number of specific recommendations have emerged from the participatory development and exploration of the maps so far. In describing these we differentiate between process, policy and research recommendations, and refer back to the *places to intervene in a system* described on page 3.

1. Successful decarbonisation of the UK housing stock requires the rapid establishment of a cross-government group (including at least DECC, DCLG, BIS and Treasury) to develop meaningful systems thinking capacity. This group would be supported by an advisory committee (process recommendation to increase the capacity of policy actors to evolve)
2. The lack of feedback loops in the **energy efficiency** requires further investigation. There may well be detailed loops missing from this diagram (research recommendation for industry, DECC, researchers to understand and intervene in feedback loops)
3. Development of widely agreed metrics to describe "quality" as it relates to both houses and neighbourhoods (policy recommendation to understand and change the system rules)
4. Simulation of the **adaptation to climate change** feedback loops would allow policy makers to understand how important the reinforcing loops are in this diagram by demonstrating the energy and land costs of adaptation dynamically, compared with expected energy savings from energy efficiency improvements (research recommendation to understand and intervene in feedback loops)
5. Simulation of the **fuel poverty and temperature optimisation** loops would demonstrate whether the balancing or reinforcing loops are most likely to dominate as a result of future climate change for the housing stock (research recommendation to understand and intervene in feedback loops)
6. The centrality of local social connection suggests policies should support the strengthening of community capacity to drive change (policy recommendation to increase the capacity of communities to change and evolve)

7. The assumption that mixed tenure types leads to greater community connection needs testing (research recommendation to understand feedback loops and delays)
8. A number of parts of the overall map suggest that improving tenure security in the private rental sector would strengthen a number of beneficial feedback loops for wellbeing and decarbonisation (policy recommendation to change the system rules)
9. Greater cross-government consensus about goals in the national property market would enable further work to understand effective policies that would have benefits across a range of wellbeing and energy outcomes (process recommendation to change the system rules)
10. An existing energy or housing policy should be used to test the theoretical relationships developed here (research recommendation to understand the feedback loops)

Using these collaborative maps as the basis for small strategic simulations will be crucial for understanding which feedbacks are dominant in influencing trends, which can be refuted or supported by existing research, and which need to direct future data collection and research.

Next steps

The next steps for the project are as follows:

1. The group of participating organisations will continue to be reassessed in the light of the collaborative maps to try and ensure expertise covering all the emergent themes
2. We are in the process of recruiting a senior researcher to continue the work on developing policy relevant pieces of strategic simulation
3. We have also applied for specific funding to further the simulation work about community social connection, tenure security and energy efficiency
4. As suggested during Workshop 2, we will use an existing policy to test the current set of maps – could they have assisted with identifying the "unintended consequences" of existing policies?
5. A third workshop is tentatively planned for late 2014 to combine the maps with some simulation modelling to assess some realistic policy options
6. We plan to develop a programme of research involving multidisciplinary teams to further develop the simulations

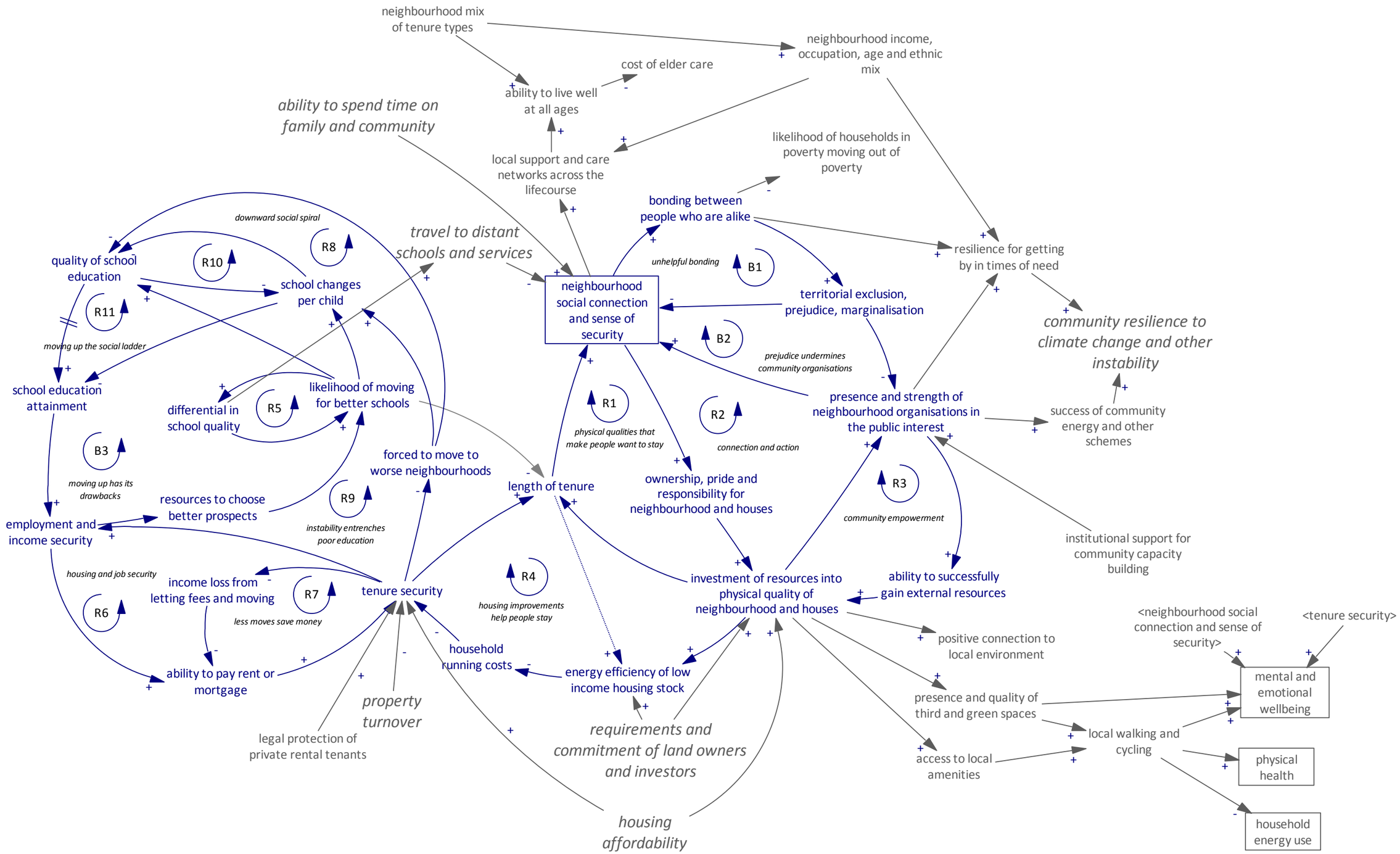
Appendix A: Causal maps including all variables

The causal maps are presented here including all the variables (in grey) that are not part of the feedback loops. In addition, connections between the causal maps are made clear, through the variables in larger grey italics.

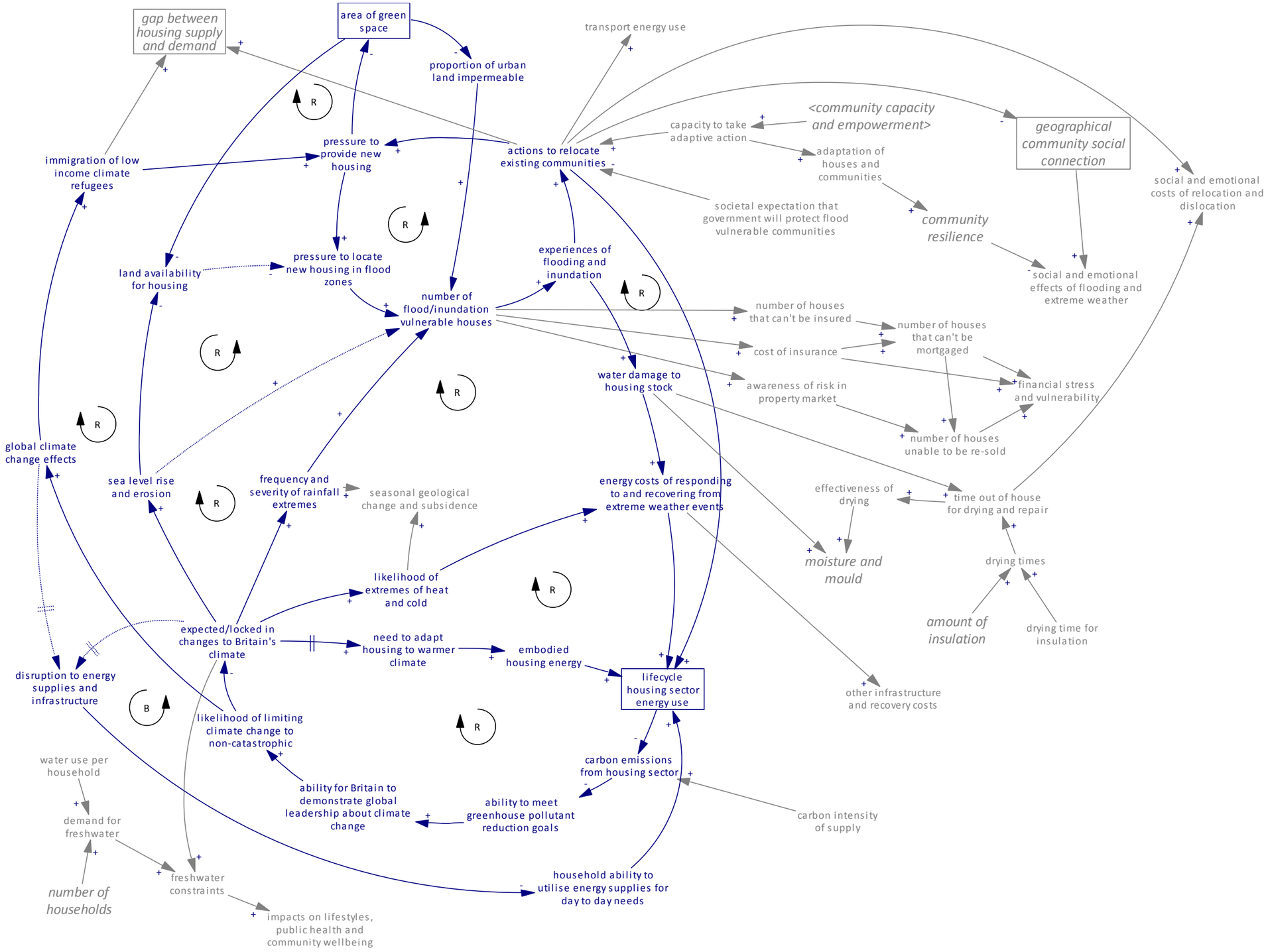
The maps are presented again in the following order:

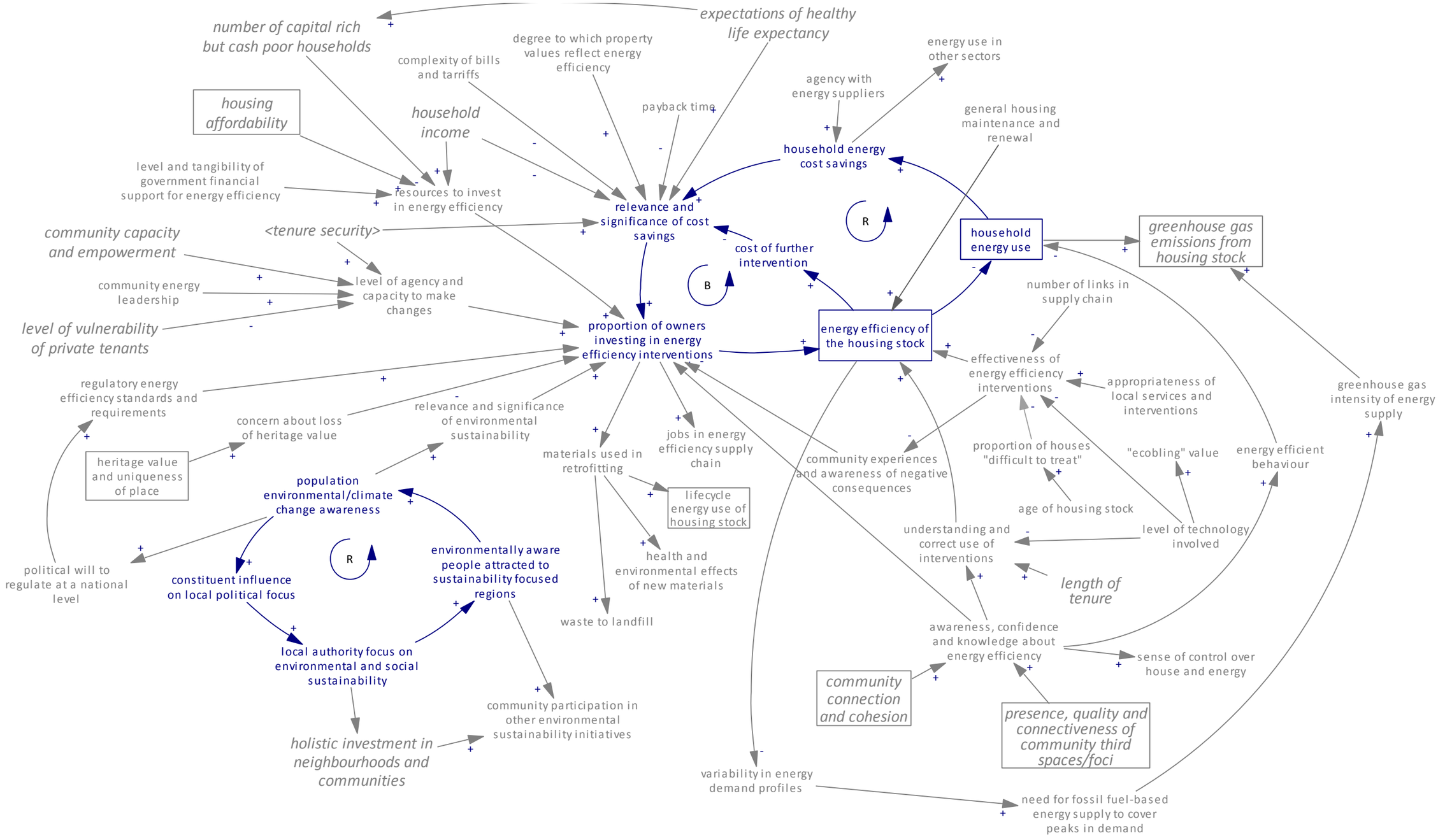
1. Community connection and quality of neighbourhoods
2. Energy efficiency and climate change
3. Fuel poverty and indoor temperature
4. Household crowding
5. Housing affordability
6. Land ownership, value and development patterns
7. Ventilation and indoor air quality

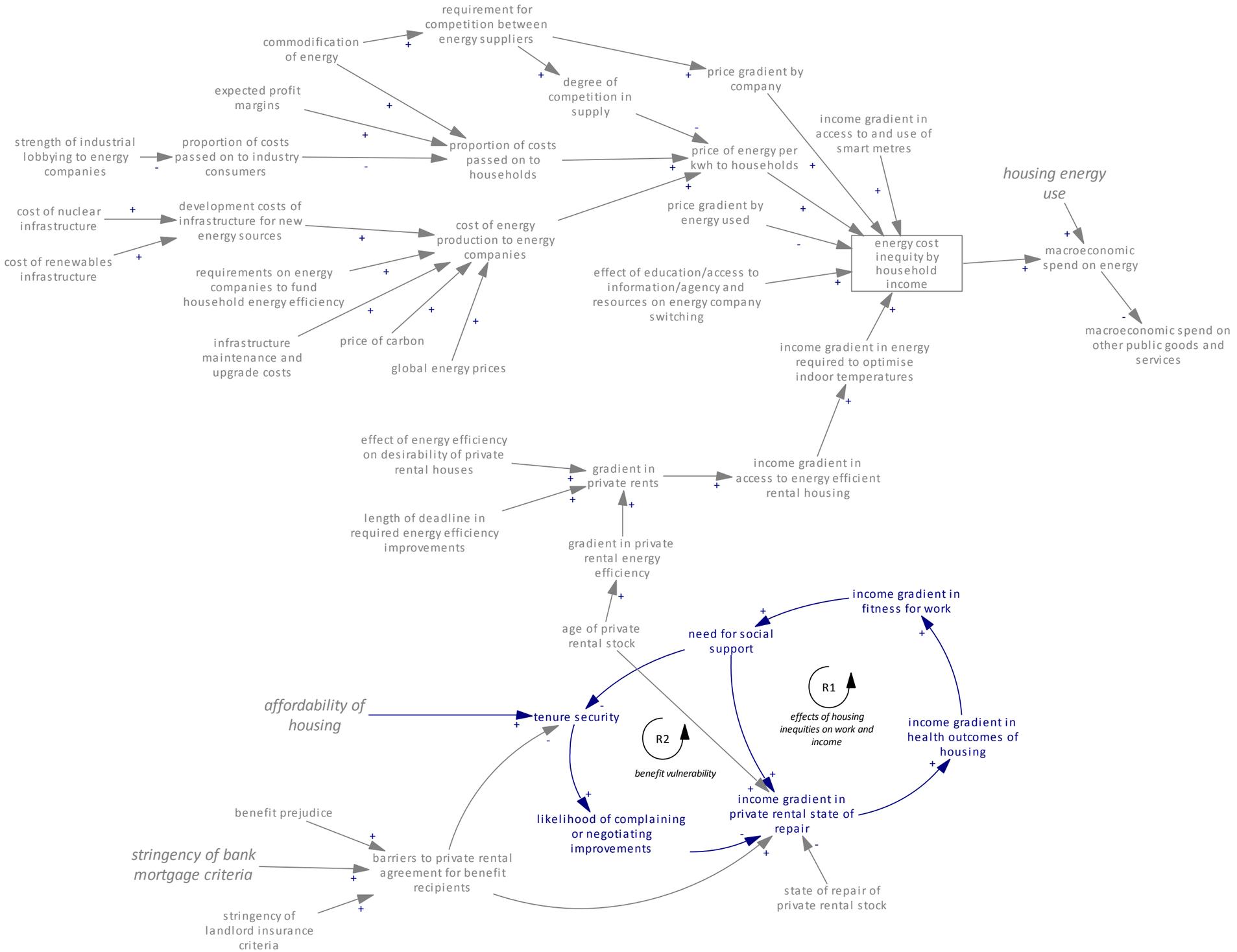
Community connection and quality of neighbourhoods



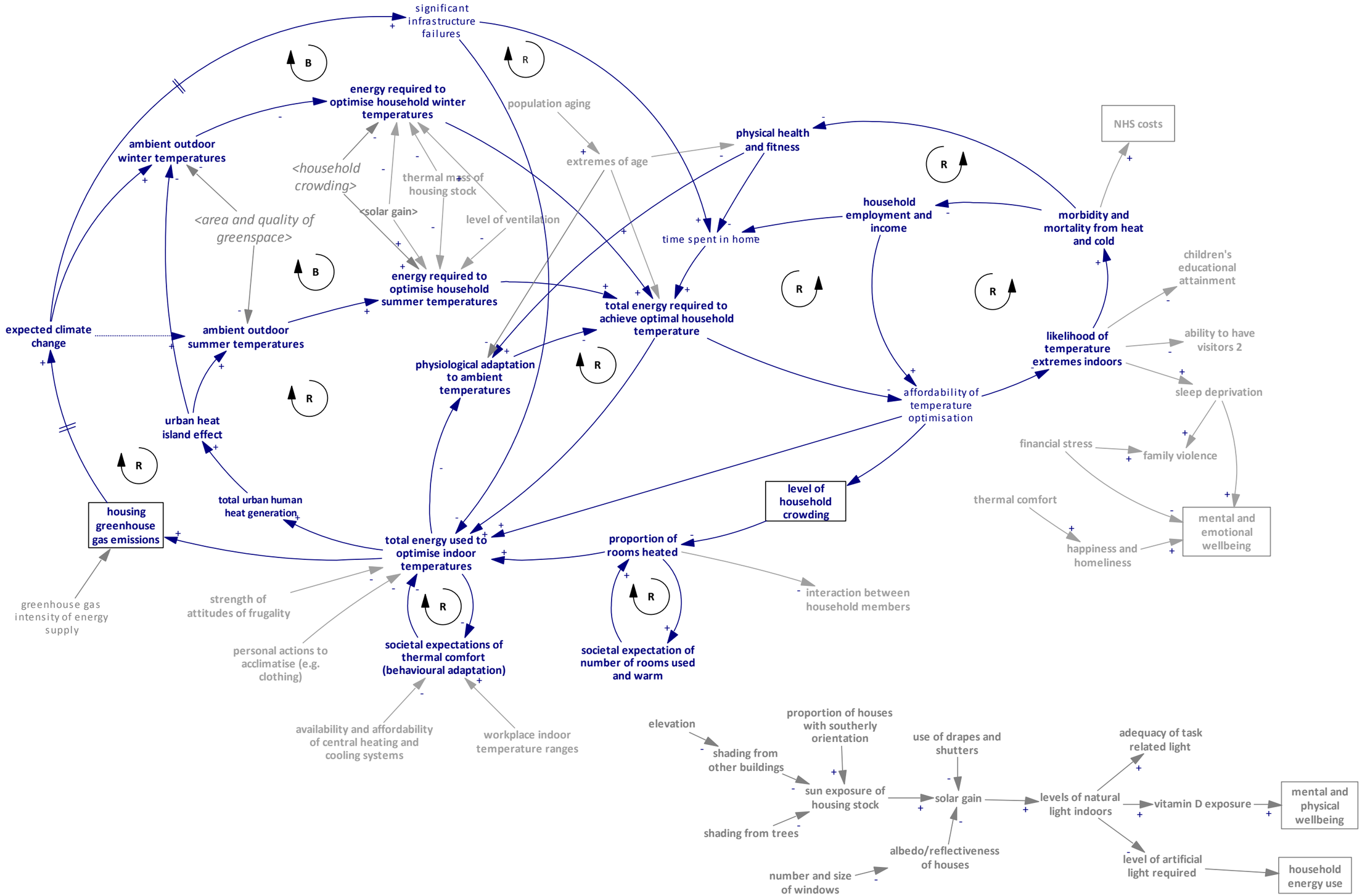
Energy efficiency and climate change



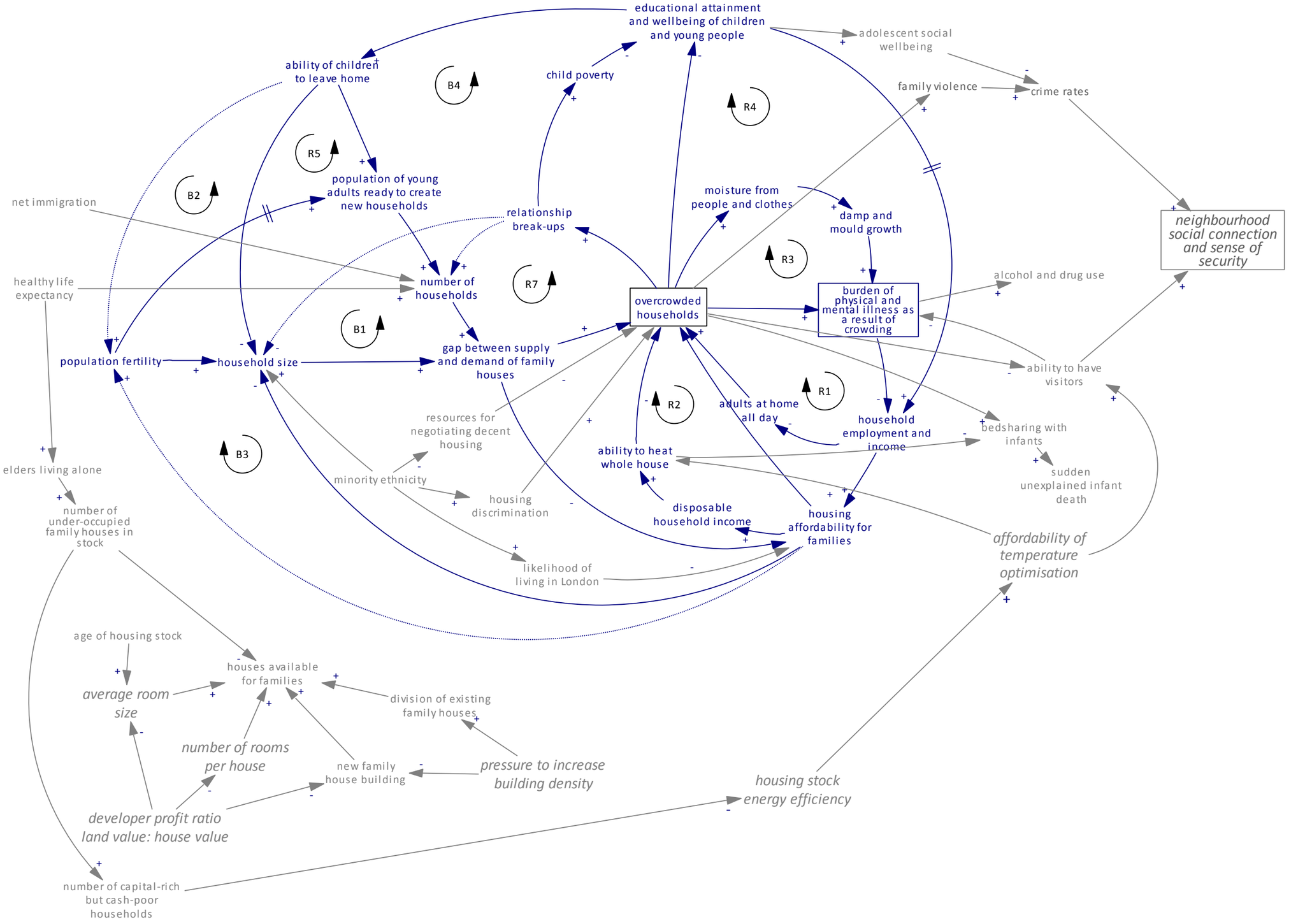

number of capital rich but cash poor households
expectations of healthy life expectancy
degree to which property values reflect energy efficiency
complexity of bills and tarriffs
energy use in other sectors
agency with energy suppliers
payback time
housing affordability
household income
general housing maintenance and renewal
household energy cost savings
level and tangibility of government financial support for energy efficiency
resources to invest in energy efficiency
relevance and significance of cost savings
R
household energy use
greenhouse gas emissions from housing stock
community capacity and empowerment
<tenure security>
cost of further intervention
B
community energy leadership
level of agency and capacity to make changes
number of links in supply chain
level of vulnerability of private tenants
proportion of owners investing in energy efficiency interventions
energy efficiency of the housing stock
effectiveness of energy efficiency interventions
appropriateness of local services and interventions
greenhouse gas intensity of energy supply
regulatory energy efficiency standards and requirements
concern about loss of heritage value
relevance and significance of environmental sustainability
materials used in retrofitting
jobs in energy efficiency supply chain
community experiences and awareness of negative consequences
proportion of houses "difficult to treat"
"ecobling" value
energy efficient behaviour
heritage value and uniqueness of place
population environmental/climate change awareness
lifecycle energy use of housing stock
age of housing stock
political will to regulate at a national level
constituent influence on local political focus
R
environmentally aware people attracted to sustainability focused regions
health and environmental effects of new materials
understanding and correct use of interventions
level of technology involved
length of tenure
waste to landfill
awareness, confidence and knowledge about energy efficiency
sense of control over house and energy
local authority focus on environmental and social sustainability
community connection and cohesion
presence, quality and connectiveness of community third spaces/foci
community participation in other environmental sustainability initiatives
holistic investment in neighbourhoods and communities
variability in energy demand profiles
need for fossil fuel-based energy supply to cover peaks in demand


requirement for competition between energy suppliers
commodification of energy
degree of competition in supply
price gradient by company
expected profit margins
strength of industrial lobbying to energy companies
proportion of costs passed on to industry consumers
proportion of costs passed on to households
price of energy per kwh to households
income gradient in access to and use of smart metres
housing energy use
cost of nuclear infrastructure
development costs of infrastructure for new energy sources
cost of energy production to energy companies
price gradient by energy used
cost of renewables infrastructure
requirements on energy companies to fund household energy efficiency
energy cost inequity by household income
macroeconomic spend on energy
effect of education/access to information/agency and resources on energy company switching
infrastructure maintenance and upgrade costs
price of carbon
global energy prices
income gradient in energy required to optimise indoor temperatures
macroeconomic spend on other public goods and services
effect of energy efficiency on desirability of private rental houses
gradient in private rents
income gradient in access to energy efficient rental housing
length of deadline in required energy efficiency improvements
gradient in private rental energy efficiency
age of private rental stock
income gradient in fitness for work
need for social support
affordability of housing
tenure security
R1
effects of housing inequities on work and income
R2
benefit vulnerability
income gradient in health outcomes of housing
likelihood of complaining or negotiating improvements
income gradient in private rental state of repair
benefit prejudice
stringency of bank mortgage criteria
barriers to private rental agreement for benefit recipients
state of repair of private rental stock
stringency of landlord insurance criteria

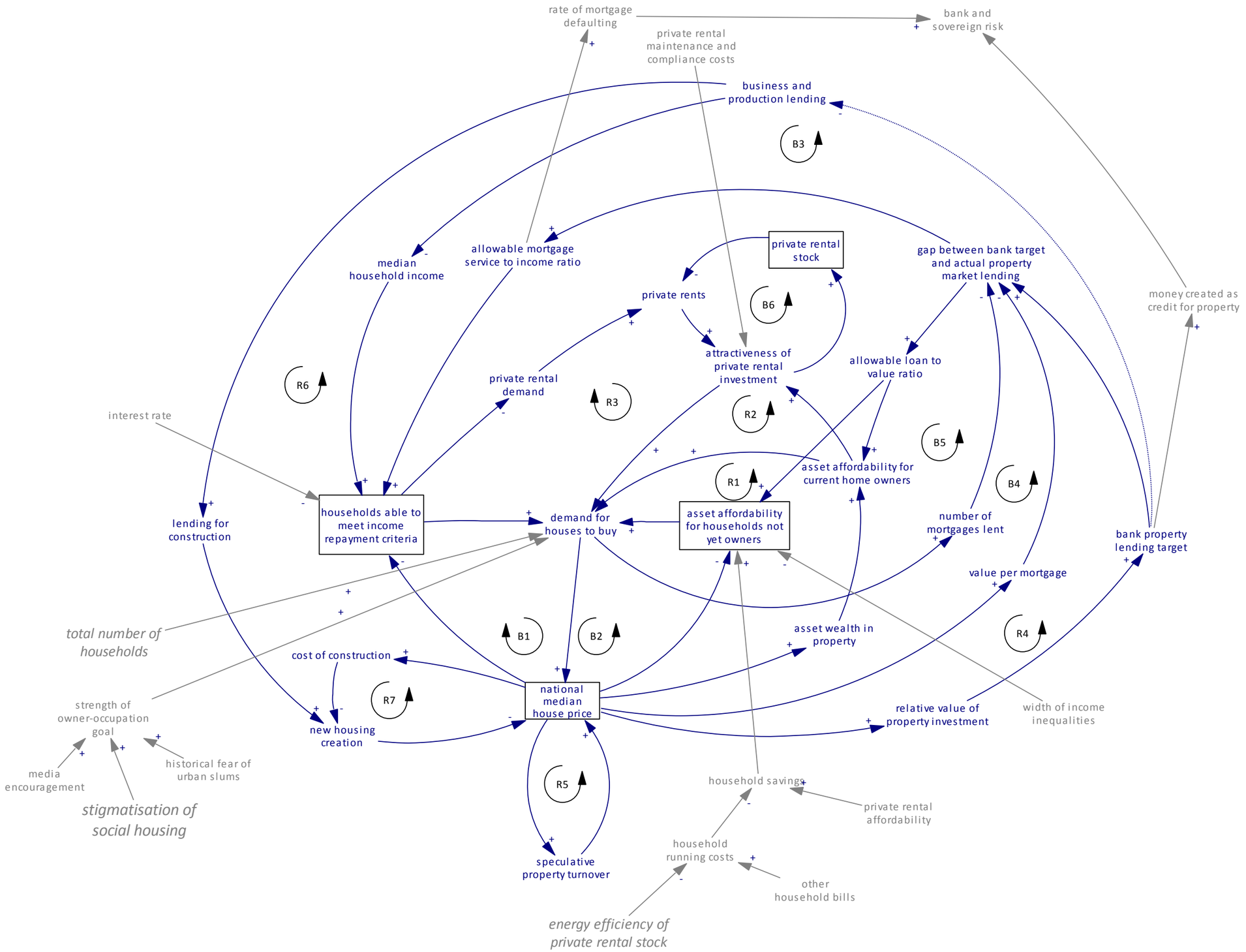
Fuel poverty and indoor temperature

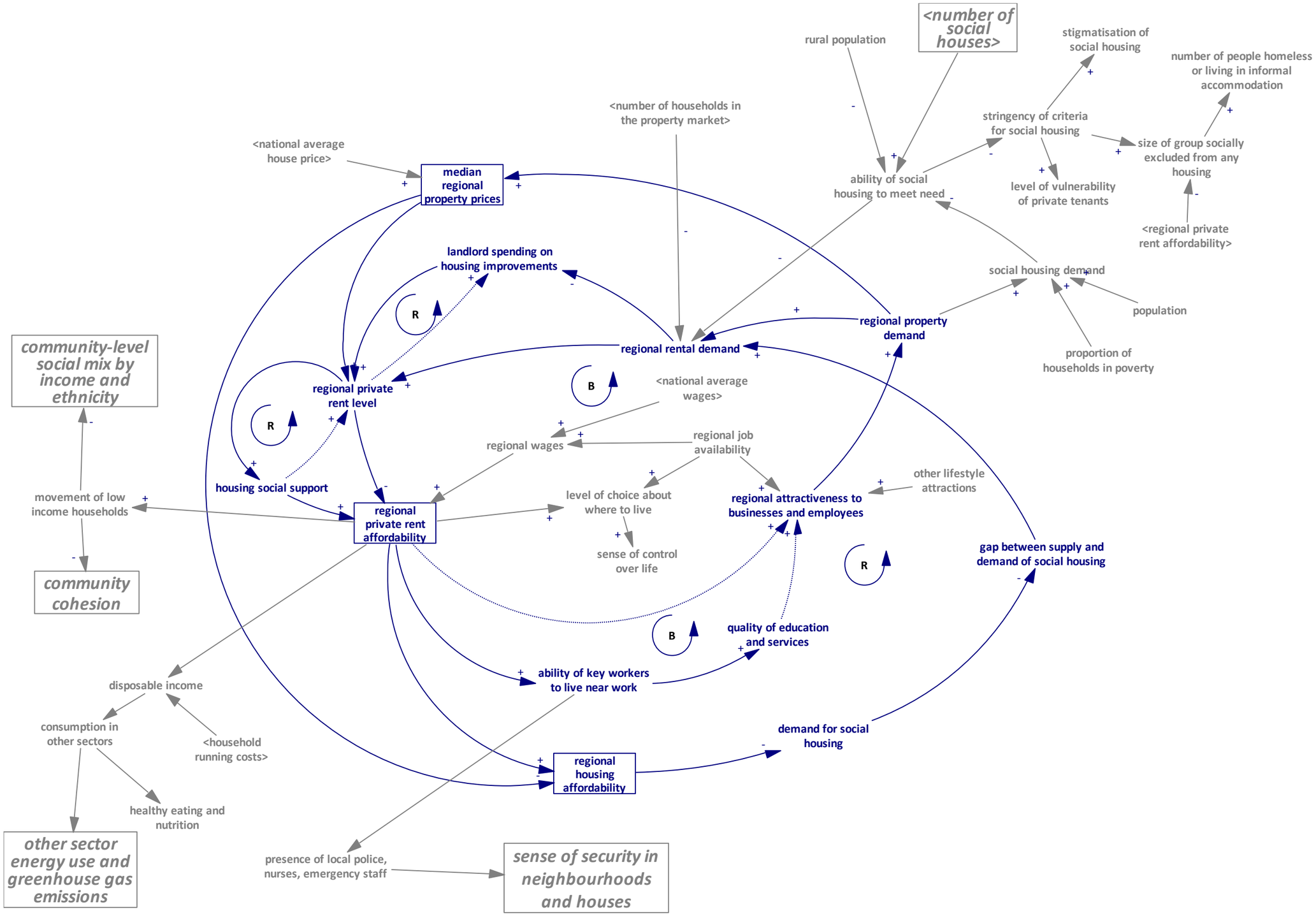


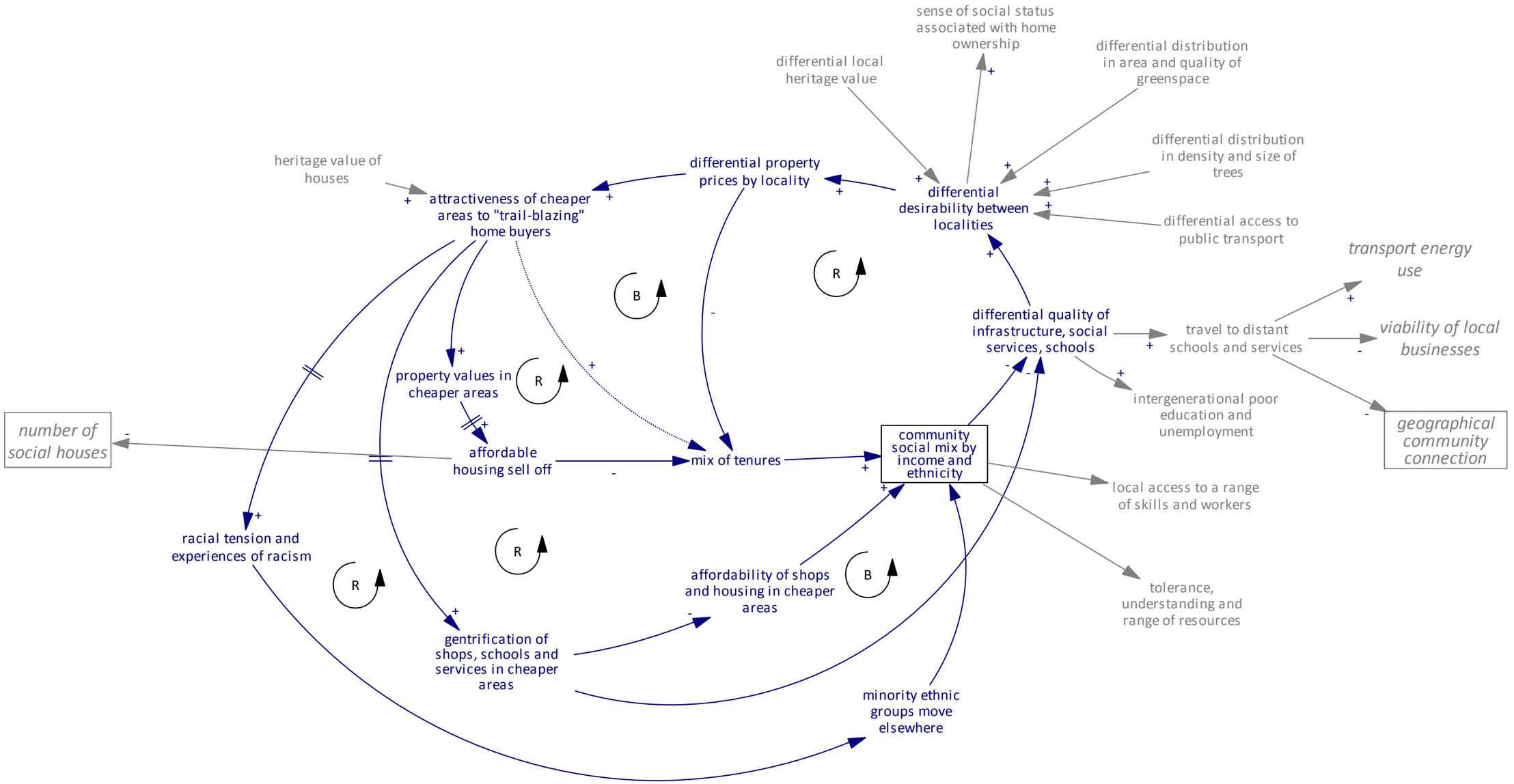
Household crowding



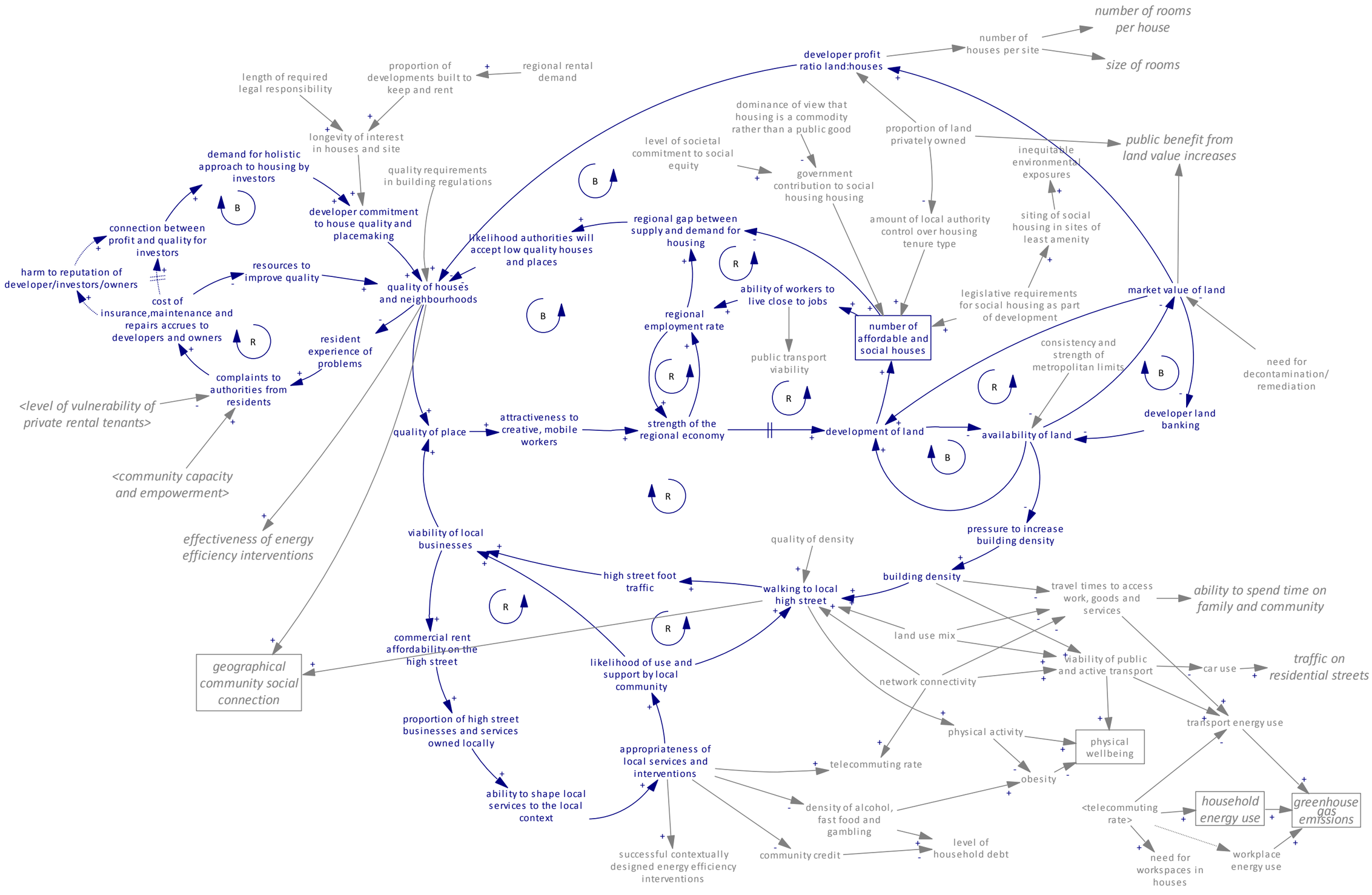
Housing affordability



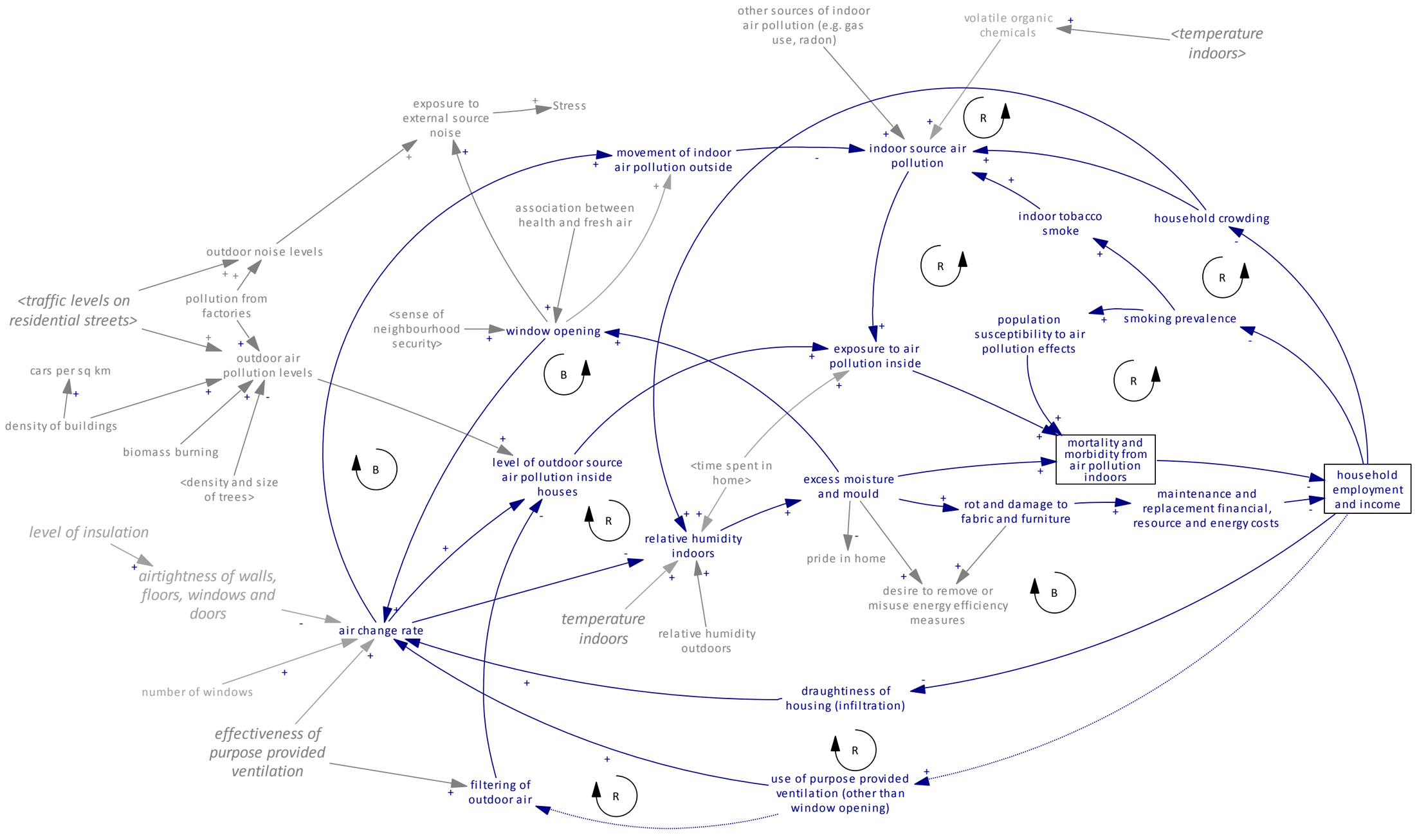

rural population
<number of social houses>
stigmatisation of social housing
number of people homeless or living in informal accommodation
<number of households in the property market>
stringency of criteria for social housing
<national average house price>
size of group socially excluded from any housing
median regional property prices
ability of social housing to meet need
level of vulnerability of private tenants
<regional private rent affordability>
landlord spending on housing improvements
social housing demand
R
population
regional property demand
regional rental demand
proportion of households in poverty
community-level social mix by income and ethnicity
B
<national average wages>
regional private rent level
R
regional job availability
regional wages
other lifestyle attractions
housing social support
level of choice about where to live
regional attractiveness to businesses and employees
movement of low income households
regional private rent affordability
sense of control over life
gap between supply and demand of social housing
community cohesion
R
B
quality of education and services
ability of key workers to live near work
disposable income
consumption in other sectors
<household running costs>
demand for social housing
regional housing affordability
healthy eating and nutrition
other sector energy use and greenhouse gas emissions
presence of local police, nurses, emergency staff
sense of security in neighbourhoods and houses


sense of social status associated with home ownership
differential local heritage value
differential distribution in area and quality of greenspace
differential distribution in density and size of trees
differential access to public transport
heritage value of houses
differential property prices by locality
attractiveness of cheaper areas to "trail-blazing" home buyers
differential desirability between localities
B
R
R
differential quality of infrastructure, social services, schools
transport energy use
travel to distant schools and services
viability of local businesses
intergenerational poor education and unemployment
geographical community connection
property values in cheaper areas
R
number of social houses
affordable housing sell off
mix of tenures
community social mix by income and ethnicity
local access to a range of skills and workers
tolerance, understanding and range of resources
racial tension and experiences of racism
R
R
affordability of shops and housing in cheaper areas
B
gentrification of shops, schools and services in cheaper areas
minority ethnic groups move elsewhere

Land ownership, value and development patterns

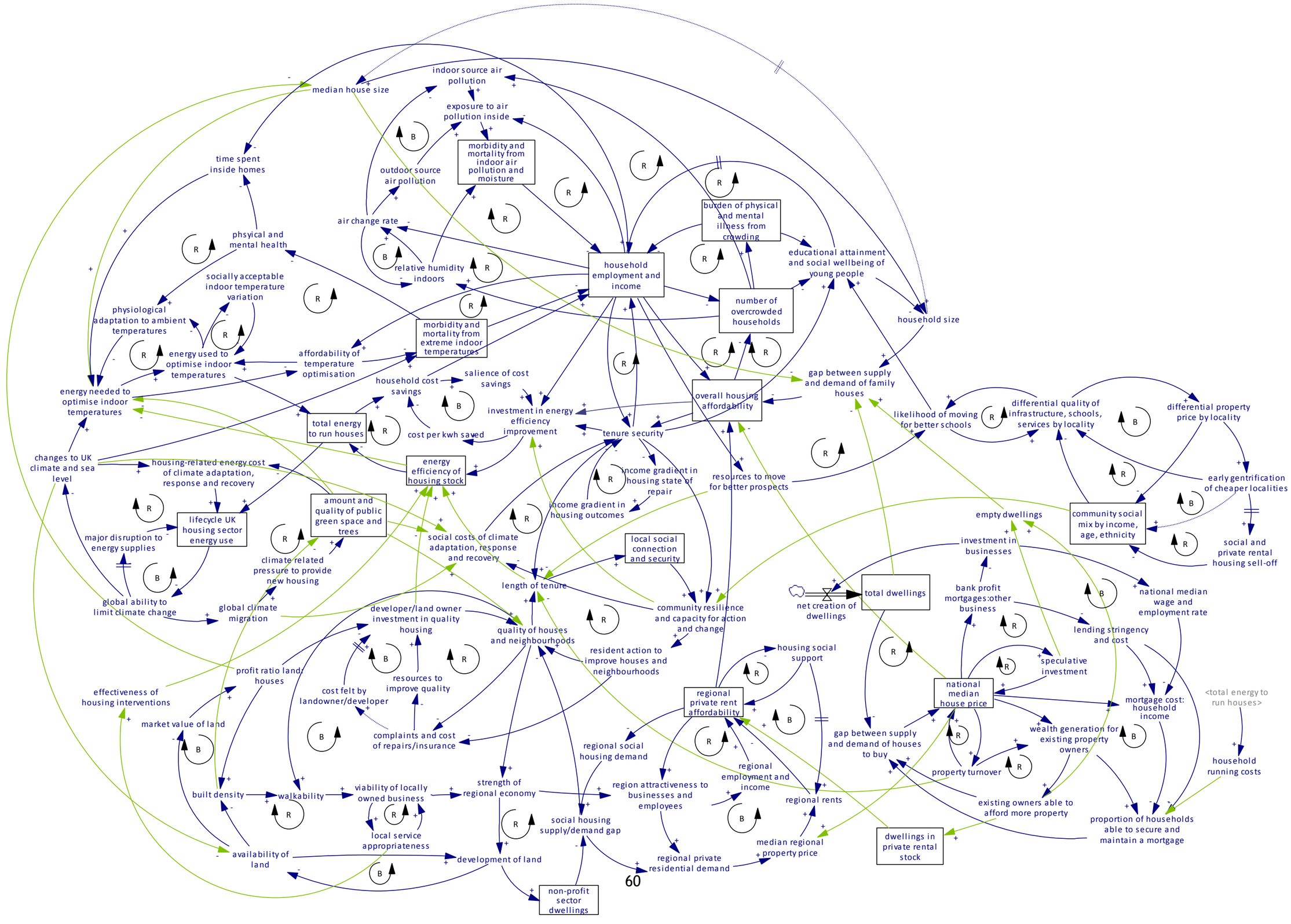


Ventilation and indoor air quality



Appendix B: Summary map of housing, energy and wellbeing

Using all the information collected so far from the interviews, workshops and existing data, we have developed the following map (next page) that summarises all the feedback loops and demonstrates how they are interconnected. The blue feedbacks shown in the map are simplified versions of the feedback loops already described. The green arrows are links between sectors.


median house size
indoor source air pollution
exposure to air pollution inside
morbidity and mortality from indoor air pollution and moisture
outdoor source air pollution
time spent inside homes
air change rate
relative humidity indoors
phsyical and mental health
socially acceptable indoor temperature variation
physiological adaptation to ambient temperatures
energy used to optimise indoor temperatures
energy needed to optimise indoor temperatures
morbidity and mortality from extreme indoor temperatures
affordability of temperature optimisation
household employment and income
burden of physical and mental illness from crowding
educational attainment and social wellbeing of young people
number of overcrowded households
household size
gap between supply and demand of family houses
overall housing affordability
household cost savings
salience of cost savings
investment in energy efficiency improvement
cost per kwh saved
total energy to run houses
energy efficiency of housing stock
tenure security
income gradient in housing state of repair
income gradient in housing outcomes
resources to move for better prospects
likelihood of moving for better schools
differential quality of infrastructure, schools, services by locality
differential property price by locality
early gentrification of cheaper localities
changes to UK climate and sea level
housing-related energy cost of climate adaptation, response and recovery
lifecycle UK housing sector energy use
amount and quality of public green space and trees
major disruption to energy supplies
climate related pressure to provide new housing
social costs of climate adaptation, response and recovery
local social connection and security
length of tenure
community social mix by income, age, ethnicity
social and private rental housing sell-off
empty dwellings
investment in businesses
bank profit mortgages:other business
national median wage and employment rate
lending stringency and cost
speculative investment
global ability to limit climate change
global climate migration
developer/land owner investment in quality housing
quality of houses and neighbourhoods
community resilience and capacity for action and change
resident action to improve houses and neighbourhoods
net creation of dwellings
total dwellings
housing social support
regional private rent affordability
national median house price
mortgage cost: household income
<total energy to run houses>
household running costs
profit ratio land: houses
effectiveness of housing interventions
market value of land
cost felt by landowner/developer
resources to improve quality
complaints and cost of repairs/insurance
gap between supply and demand of houses to buy
wealth generation for existing property owners
property turnover
existing owners able to afford more property
proportion of households able to secure and maintain a mortgage
built density
walkability
viability of locally owned business
local service appropriateness
strength of regional economy
region attractiveness to businesses and employees
regional employment and income
regional rents
regional social housing demand
social housing supply/demand gap
regional private residential demand
median regional property price
availability of land
development of land
non-profit sector dwellings
dwellings in private rental stock