Low Carbon Commons: changing property rights for urban retrofits

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Abstract

This paper develops a analysis of challenges to urban low carbon urban retrofits, caused by the scarcity of urban space and the presence of pre-existing property boundaries. There is growing evidence that the spatial characteristics of a city influence the environmental footprint of its citizens and that this creates a range of context specific challenges for the governance of low carbon transitions in cities. On the one hand, more compact cities are associated with lower carbon lifestyles. But on the other hand, more urban space allows for more retrofit options, e.g. for external insulation, installation of more renewables and accommodation of more active travel infrastructure (e.g. bike lanes) or green space to provide nature based solutions. But it is not only the existing urban morphology, street design and housing types that shapes the options for low carbon interventions. The city is a dense network of rigid property boundaries and old rules about access to and use of space, and existing literature pays limited attention to the ways and extent to which this can hamper the adoption of more efficient and equitable low carbon investments and behaviours, especially when many homes are privately owned by their residents. Through real world examples, this paper seeks to characterise these property barriers and spatial constraints, and organise low carbon interventions into a generic set of options to change property archetypes – typically away from exclusionary private control towards a better low carbon utilisation of scarce urban space. Focusing on substantive urban issues in the UK (i.e. concerning millions of households), this paper highlights how the existing landscape of allocated private rights (from user right to exclusionary ownership) creates significant inefficiencies in deploying low carbon interventions in particular parts of the city, and discusses what (in terms of property rights) would need to change in order to overcome these inefficiencies and achiever faster and deeper decarbonisation of existing houses, streets and neighbourhoods.

Introduction

The aspired transition to a low carbon society cannot be achieved through supply-side measures only; this huge and very urgent challenge requires maximum effort across the available measures. Hence it poses huge challenges to our cities, which are places of high and concentrated energy consumption. Most of our existing urban areas were built during an era of cheap oil and gas and insufficient awareness of and policy attention to the risks of global warming and other (more local) health and environmental concerns. In order to lower our carbon footprint, we need to significantly retrofit our existing urban environment[i]. This is not 'simply' a matter of making buildings more energy efficient or switching to electric vehicles. These are important individual measures but the retrofit needs to also address more cross-cutting and systemic issues, e.g. integrated transport strategies that combine reduction of car dependency with increased support for active travel and public transport, and spatial planning strategies that seek to make some cities more compact. Indeed, in different parts of the world, research has shown that (currently) more compact cities tend to have lower per-capita carbon footprints (e.g. Clark 2013; Jones & Kammen 2014; Timmons et al., 2016; Yi et al., 2021) and that moves towards 'mobility as a service' holds significant promises in carbon emissions reductions (Hietanen, 2014; Smith and Henscher, 2020). Implicit within these systemic changes, lies a question of who currently has (what kind of) rights in the city, and how will they embrace or resist the changes needed to reduce carbon emissions? I posit that this issue is important enough to merit (much) more research attention.

Academic interest in the management of commons has grown since 'the tragedy of the commons' (Hardin, 1968), which drew attention to environmental degradation in the absence of individual property rights; Hardin didn't write about cities but he did mention the atmosphere[ii].

In recent decades, social science interest in the notion of 'urban commons' has grown, yielding critiques on how these are encroached and enclosed through neo-liberal capitalist policies and how such privatisation can exacerbate existing inequalities (Lee and Webster, 2006; Foster, 2011; Gidwani and Baviskar, 2011; Huron, 2015; Williams, 2018). Few of these papers have combined this with detailed attention to climate concerns, although some explicit links have been made with the transitions literature emerging from science and technology studies (Radywyl and Biggs, 2013; Chatterton, 2016). Between the often more a-political and sectoral attention to decarbonisation from the energy research community and the justice and power focus on the urban commons from the critical social sciences, there is a gap, focused on property but largely detached from politics, which this paper seeks to address; what kind of systemic 'private property rights and privileges' issues are posing a specific challenge to the low carbon retrofit of (particular) existing cities?

I will seek to address this aim by:

a. Working across the two dominant forms of private property in the city, namely the home and the car (not often examined together). Car and home ownership is widespread in high and middle income countries, and very few people will ever own 'things' that are more expensive and more energy consuming.
b. Presenting relevant and concrete examples of such challenges. These will hopefully resonate in many countries, but I will draw specifically on UK statistics to illustrate the relevance of such challenges in a country with a lot of old buildings (oldest in Europe if not the world, i.e. a huge retrofit challenge), high levels of private home ownership (>60%) and a relative predominance of houses over flats (BRE, 2021).
c. Characterising the kind of changes to property rights that are needed to facilitate urban transition through low carbon retrofit. This characterisation will be grounded in theory; in the penultimate part of the paper I will be linking the practical examples of low carbon interventions in the urban environment, to an established economic typology of private, common, club and public goods.

Urban low carbon retrofit – the boundaries of what a private owner can do

It is well understood that factors such as insulation, housing density, roof-mounted solar (PV or hot water) and low carbon mobility (switching to cleaner vehicles, cycling or walking), are key to making some buildings, neighbourhoods and cities more low-carbon than others. But how do these generic factors inform local retrofitting options, and what consequences can this have for existing patterns of ownership and privileges of cars and homes? This section is divided into three parts, focusing on retrofitting residential buildings, retrofitting low carbon heating systems and retrofitting streets.

PRIVATE HOMES, LIMITED

This sub-section sets out to explore how individual control of energy retrofit options may be constrained, dependent on the type of home you own. I will focus on physical types of homes and streets, rather than legal types of home ownership. For the sake of the argument, it is assumed here that the resident enjoys full individual ownership of the home[iii]. At the city level, there is a precursor for this interest in the established literature on Compact Cities and the energy use associated with urban density (for international examples and diversity of methods and findings, see Breheny, 1995; Holden & Norland, 2005; Rerat, 2012; Lee and Lim, 2018; Shi et al., 2016). In addition to the different scale of focus, this paper is also different in its attention to the adoption of new retrofit measures and the changes in dynamic interactions as adoption is scaled up.

Table 1 lists standard property types and their generic restrictions in terms of the exclusive rights of a resident owner to undertake energy retrofits. Flats (20.9 % of UK homes; BRE, 2020) are most restricted, because flat owners usually have rights but no individual ownership or control of the external walls, the roof, the external stairs and hallways, and sometimes the under-ground sections of the building and land adjacent to the building used as gardens or for parking. In most countries, these are communal spaces which have to be managed collectively by the resident homeowners (Cirman et al., 2013; Ho & Gao., 2013). Sometimes this mixed ownership model also includes a role for housing associations or the council. Technically, blocks of flats offer significant opportunities for improvements in insulation, heating systems and the installation of renewables. Co-ownership of blocks of flats can be a barrier for the adoption of retrofit policies designed for individual homes (as mentioned above), but it also offers unique opportunities for approaches that benefit from the expert input of public or third sector organisations with significant organisational capital, and which can help overcome the need to depend on the active participation of each individual household (for an interesting EU project, see Lowitzsch, 2019). Indeed, the idea that households have to accept (an energy retrofit that requires) physical changes to their home, organised by the state, but then get to co-own them, is not all that new; it has been the basis for Denmarks' successful long-term policy to develop district heating systems (Johansen & Werner, 2022).

This stands in stark contrast with UK government policies that had all but eradicated district heating in the country and disempowered local authorities to develop local heating (Russell, 1993). Even within the UK there appears to be a long running cultural divide in the support or resistance to more collective approaches of home building, heating and management. Whilst in Scotland there has been a significant growth of community housing (McKee, 2010), in England & Wales homeowners associations are rather rare and a unique 'leasehold' model dominates the market. Leaseholders can only purchase their flats for a time limited period (often 99 years) and the

Table 1. Exclusive ownership and freedom to retrofit (Yes/No), according to building type.

Type of home	Floors/ ceilings	Inner walls	Outside walls	Roof	Windows	Staircase
Flat	N (shared)	N (shared)	N*	N*		N*
Terraced house	Y	N (1-2 shared)	Depends	Y	Y	n.a.
Semi-detached house	Y	N (1 shared)	Y	Y	Y	n.a.
Detached house	Y	Y	Y	Y	Y	n.a.
Listed building (UK)	*?*	*Y?*	*N*	*N?*	*N*	*n.a./?*

**in a flat, the outside walls, roof, staircase, cellar are often in communal ownership.*

communal spaces the block of flats are managed by a separate entity (the 'freeholder' or their agents), who can recoup management and repair costs through compulsory service charges imposed on the residents (Cole & Robinson, 2000). Given this scope for exploitation, it seems to be fair to assume that the leasehold model is not conductive for the adoption of low carbon retrofits.

The second most restricted building category are terraced houses (27.4 % of UK homes; BRE, 2020). Conceptually, they could be seen as 'horizontal blocks of flats' but from a property rights perspective, they are very different. They usually have a private garden (or yard) at the back, and/or at the front. Resident owners share two internal walls with neighbours and if they do not have a garden at the front, then their front wall borders onto the street, which is usually owned by the council (except if it is a private road). End of terrace houses share only one internal wall with a neighbour, but if there is no garden on the side, then their external side wall will border onto the land of someone else (usually a neighbour or the council); this limits any external (retrofitting) alterations they can make. Terraced houses in working class neighbourhoods were often quite small and over the years, many homeowners have added extensions at the back, sometimes all the way to the end of the garden. These individual extensions and the often limited physical access to the back of these homes (e.g. a footpath, or none at all), provide significant barriers to scaling up retrofit approaches – to street, neighbourhood or district level.

A third housing category is where at least one of the walls of the house stands at the property boundary, which means that the owner-resident has exclusive ownership of that wall but nothing beyond it. Semi-detached houses are the main category here (25.0 % of UK homes; BRE, 2020), along with the end-of-terrace houses mentioned above. Retrofit work at the property boundary thus requires neighbours' consent and access over their land.

Finally, listed buildings are useful to note as a special category, as they represent a set of unique state-imposed restrictions on what the owner-resident can do with their home. There is a huge variety of listed buildings, but they are always old, and often very old, and can have the lowest levels of energy efficiency, hence they pose some of the biggest maintenance challenges going forward. Most technical options for low carbon retrofits are blocked by restrictive regulations or by confusion about their interpretation, often leaving decisions in the hands of individual planning inspectors (Ginks & Painter, 2017). There are some 400.000 listed buildings in England (Historic England, undated), whilst Edinburgh has the greatest concentration of listed buildings for any UK city (9651 according to Gouk, 2016). Conservation legislation is evidence of value; it shows that successive governments (and presumably the people who voted them in) want to see old buildings protected against change. If we assume that these buildings will continue to leak heat for centuries to come, then it would be logical to implement heating systems that are low carbon and not too disruptive within these old buildings. In cities like Edinburgh, an area-wide, collective approach like district heating would seem to be the logical way forward. It is also worth noting that old buildings often sit in conservation areas, which may further affect and limit the kind of (low carbon) changes that are permitted in the wider area.

Table 1 lists the theoretical restrictions, but this still needs to be translated in terms of the consequences for energy retrofit. Table 2 lists the major retrofit technologies available to individual homes and maps the range of potential conflicts that may arise when residents have restricted rights to (low carbon) retrofit their property. The third column seeks to provide the building and neighbourhood characteristics of where these conflicts may arise. The final and right-most column draws attention to some of the key solutions to overcome these conflicts or barriers, and serves to illustrate that these solutions require a higher level of governance and coordination that goes beyond the individual action of a private homeowner. The potential benefits of more coordinated and collective action on energy retrofits include:

1. Economies of scale (whole street retrofit is cheaper per individual household)
2. Improved energy efficiency (less heat-loss at property boundaries; more efficient use of public space; increased technological efficiency of a larger unit)
3. More funding, ownership and management options to help overcome the high upfront costs.
4. Stronger position to negotiate quality guarantees, maintenance and after-care (or to take legal action if the retrofit work was poorly delivered)

Where pre-existing institutional structures are absent, it can be very challenging for individual homeowners to self-organise and pursue these benefits through a grass-roots approach (collective action problems; high transaction costs; e.g. Cirman *et al.,* 2013; Ho & Gao, 2013). What this section seeks to dem-

Table 2. Potential conflicts arising from the deployment of low carbon retrofit options for individual homes in dense urban neighbourhoods (assuming individual home ownership).

Low carbon retrofit options for individual homes	Potential conflicts or barriers	Which tend to arise under the following (material) conditions:	Possible solutions at a scale that exceeds individual homes
Double glazing, external wall insulation, PV	Existing regulations about the property's look / character.	Historic listed buildings and neighbourhoods	Set new retrofit standards at city and neighbourhood level (combining 'character' with low carbon); coordinated retrofit programme
External wall insulation	If you don't own the land beyond your wall - how to get permission	Solid wall homes + small plots/dense neighbourhoods	Compulsory purchase or shared (dual) ownership models.
Rooftop PV	Risk of shade from (growing) neighbouring trees.	Tree-lined streets; trees in neighbours' gardens	Pay for PV elsewhere, (cheaper, more sun, less shade). E.g. Rent-a-roof PV, solar coops
EV charging socket	Cable needs to cross the pavement; lack of private/reserved parking	Properties with (only) on-street parking	Club-based privilege for EV parking
Air source heat pump	Neighbour's concerns; noise, eyesore, resource competition	Gardens/outdoor spaces are too small	Collective/scaled up tech e.g. vertical ground source; water source (with district heating)
Biomass stoves/boilers	Local air pollution (especially particulate matter)	(gets much worse in windless conditions)	Install sensors in the chimney; certify feedstock; Limit permissions to windy days; switch to district heating (single chimney, better filtering)

onstrate, is that in particular pre-existing urban environments, private ownership of homes represents an explicit barrier to energy retrofits, even if every homeowner wanted to participate and could afford to pay for the retrofit. The nature of the technological interventions required, mapped against the existing landscape of individual homeowners' rights, means that strong support and coordination is needed to assist even the most willing of property owners to participate in low carbon retrofits. Ironically, the big ownership restrictions on flats, combined with the pre-existence of a separate institutional arrangement to manage the spaces of the building that are not privately owned, makes retrofit-at-scale a lot more feasible and therefore the retrofit in itself much quicker and more efficient. It raises the obvious question of whether there is a need or scope for similar institutional arrangements for a street or neighbourhood of terraced houses. Academic papers that think through or model low carbon retrofits at the street or neighbourhood level are growing in number (e.g. Dixon & Eames, 2013; Marique & Reiter, 2014; Alavirad et al., 2022), but there is scope for more work on successful institutional arrangements.

HOME COMFORT WITH THERMAL COMMONS

With the exception of those who live off-grid, all individual homeowners already rely on a wider energy system to deliver energy services to the home. Electricity and gas flow directly into the home through a fixed and permanent infrastructure. Bottled gas, heating oil, wood pellets etc. are typically home delivered through an existing supply chain, and the same can be said of petrol and diesel, even though we drive our car to pick it up ourselves at the fuel station. But when it comes to retrofitting heating or cooling systems in the home (e.g. a new boiler, stove or air conditioning system), this is largely still a private decision for each individual household. In more crowded urban environments, this logic can be problematic; it might be too slow (for low carbon technologies), or conversely, unanticipated problems may occur in the case of rapid mass adoption. One example is the retrofitting of individual air conditioning (AC) units on the outside walls in flats and terraced streets; this increases the temperature in the street (i.e. increasing the heat island effect) to the detriment of pedestrians and forces every AC unit to work harder, i.e. reducing efficiency (Tremeac et al., 2012; Jin et al., 2020). Another example is the widespread adoption of (modern) wood stoves in urban environments in the last 20 years, in the UK and elsewhere in Europe. Perhaps early adopters saw it as a green fuel, sourced regionally from sustainably managed woodlands, providing both heat and domestic amenity. But the scale of adoption has impacted on local air quality, causing concerns about negative health impacts (Cincinelli et al., 2019) and the most recent research has even shown that indoor air quality can be affected negatively (Chakraborty et al., 2020). These two examples could be labelled as tragedy of a local atmospheric common, for thermal comfort and for breathing, respectively.

Locally sourced wood can be expected to remain a popular fuel for low carbon residential heating in rural areas. Hydrogen is not a serious contender yet for decarbonised heating[iv] and it is difficult to see how biogas could ever provide a substantive contribution to decarbonising heat at city or national scale. District heating is still quite rare in the UK, but can be operated with any low carbon fuel, or indeed with large heat pumps (e.g. Popovski et al., 2019). This currently leaves heat pumps as seemingly the go-to solution to decarbonising residential heating in most settings (e.g. Kaufman et al., 2019; Barnes and Bhagavathy, 2020). But wider deployment of air source heat pumps for individual homes in denser urban environments (if there is space for them to start with) is likely to cause exactly same local atmospheric thermal commons tragedy as AC has already caused. Ground source heating is more efficient than air source heating, and in dense urban environments the scope for horizontal ground source heat pumps (GSHP) may be far more limited than the scope for vertical GSHP, both because horizontal space (i.e. land) is scarce to begin with, and it is also more valuable which means that digging it up is relatively more disruptive. A logical solution would be to install more vertical GSHP units. As these are more expensive to install, but also often have more thermal capacity (Wu, 2009), it would make sense to implement these at a larger scale, i.e. for multiple adjacent households. This would be the equivalent of a mini district heating grid and it is likely that the well itself would have to be drilled on council land (e.g. under the road?) as most private gardens are small, may be hard to access for a drilling rig, and many residents are likely to be quite reluctant to accommodate the well. Research into the use of the subsurface for thermal storage appears to be most advanced in areas with a sub-surface mining legacy, where (water in old) mine shafts could be used for heating and cooling (Malolepszy et al., 2005; Verhoeven et al., 2014). This means that aquifers under cities could become a new resource frontier for the thermal regulation of the buildings above them (heating in the winter and/or cooling in the summer). And as the scale of deployment would increase, the need would grow for this subterranean thermal common to be managed sustainably, at the city level (demand-side) as well as the aquifer level (supply-side).

In summary, low carbon urban heating or cooling is likely to depend increasingly on thermal commons, requiring heating and cooling systems that limit the personal decision space for individual homeowners in more densely populated urban areas; collective or scaled up approaches are needed there. This contradicts the policy narrative that UK homeowners should invest in individual air source heat pumps as the main 'go to' option.

PRIVATE CARS IN TRANSPORT COMMONS

There is much critical literature about the car and the city and a growing awareness that urban sustainability means a reduction of car use. In cities that were not designed and built to accommodate the ubiquitous use of the car, road space is particularly scarce and on-street parking can be quite problematic as it limits the use of the road by others, including busses, lorries and vans delivering goods and services, other private cars, bikes and pedestrians. The use of cars with internal combustion engines (ICE) in the urban environment is spectacularly wasteful in terms of space, energy and other negative externalities (Table 3). Most urban car trips are short-distance, which is far less fuel efficient and more harmful per km travelled for ICE cars (e.g. compared to driving on the motorway) and which could be most easily be avoided through mode-shift, i.e. walking, cycling or taking the bus instead.

A switch from ICE to electric vehicles (EVs) will reduce most of the externalities, and is thus most valuable in urban areas where more people are exposed to these externalities. But the competition for scarce road space would remain. In the same way that pedestrian road use is sensitive to the presence of safe (e.g. raised) pavements, an effective mode switch to cycling would require the retrofitting of segregated cycling lanes (Hull & O'Holleran, 2014). Where urban roads are too narrow to accommodate this, the most logical solution is to give cyclists priority rights over car drivers. This is justified on the ground of uneven risk exposure (Hierarchy of Risk'[v]; Dollimore, 2020) as well as the uneven occupation of road space (Table 3). Changing the privileges of road use away from motorists has the potential benefit of encouraging more people to cycle instead (*ibid.*). The emergence of electrical bicycles presents a smart alternative to short distance car use, with the spatial footprint and affordability of a bicycle and the capability to overcome steeper streets, strong head winds and sweaty arrival. In the UK, current on-street bicycle infrastructure and storage space homes and gardens is hugely insufficient to accommodate wider bike ownership across the city. A single car parking space can be converted for the parking of up to 10 bikes[vi], which could be reserved for residents. An Australian study even found that an inner city parking space can generate more revenue from charging for bikes than for cars (Lee & March, 2010). However this could also be interpreted as evidence that car use in cities has long been privileged and under-charged. Even in residential areas where on-street parking is not free, the cost of resident parking permits is always far lower per m^2 than the commercial cost of land. Given that homes are much more essential for humans than cars, is there any justification for why a homeowner pays a much higher rate for the land on which their house sit, than for the public land which their private car occupies?

Even if all ICE cars were switched to electric and would run on 100 % renewable electricity, private car ownership and use will still be constrained in local street commons where demand for space exceeds availability. In the UK, one out of four car owners has no access to private parking and must therefore rely on on-street parking (Field Dynamics, 2020). When these owners live along wide streets that can accommodate their parked cars as well as cycling lanes (and other space demands, like green space), concerns about locally scarce space would not seem to apply so the main priority is to facilitate rapid switching to electric vehicles. With constrained local authority budgets, one logical solution would be to help car owners set

Table 3. Comparison of energy use, space use and other externalities between cars, bikes and pedestrians.

	Cars	Bicycles	Pedestrians (benchmark)
Energy use (assuming car = IC & single occupant)	2% - IF: combustion engine efficiency=0.2 multiplied by weight ratio of human/car=0.1	200-300%	100%
Space use (stationary)	8-12 m^2	<1.5 m^2	Nil; see below
Other negative externalities (in **bold**; also applies to electric vehicles)	Noise, stench, air pollution (tailpipe, **brakepads, tyre wear**), **wear on roads, congestion, risk to more vulnerable road users (bikes, pedestrians)**	Risk to vulnerable road users (pedestrians); nuisance IF parked on pavement	Nil because every human has the right to 'be' in the city

up and fund their own residential charging clubs with chargers installed at public parking spots near their home, using digital means to efficiency share access to the charging stations. But in the parts of town where streets are narrow and car parking space is already scarce and should be reclaimed for more useful purposes, it would make sense to help residents to break their dependence on quick access to their private car altogether. Overnight parking spaces may be reserved for the local car club, but in time maybe even these can go, as autonomous vehicles could be called to pick up residents who want or need to go on a car trip from their home.

Property archetypes and low carbon interventions

The previous sections spoke about private property and commons in general terms, but there is a need to embed this in a more systematic framework. The property archetypes found in economics textbooks are based on a two-by-two matrix, identifying goods that are rivalrous or non-rivalrous on the one hand, and excludable or non-excludable on the other. A good is rivalrous if the use by one person prevents the (simultaneous) use by another. This can be use without diminishment (e.g. a seat in a cinema), or 'use up' so that the good is substantially transformed (e.g. the consumption of food, fuel, building materials). Excludability is often a technical, legal and practical question, how feasible is it to exclude others? Private goods (rivalrous and excludable) stand in strong contrast with public goods (non-rivalrous and non-excludable), whilst common goods (rivalrous but non-excludable) and club goods (non-rivalrous but excludable) constitute the final two categories. Club goods have the peculiar characteristic that they can gain more value (within certain parameters) when more people join in. The classic example is a telephone; it has little to no use if you are the only one who has one. Common goods are typically allocated to a defined group of users and are susceptible to scarcity. Public goods can be used by all without diminishment. Very often, real world examples do not map perfectly onto these four archetypes and dependent on the context, the same material good can belong in different categories; Oxygen in a spaceship is a common good, with the astronauts being the defined set of 'commoners' who need to closely monitor the use of this key resource. The very same oxygen in the atmosphere is a public good, used freely by all humans (and all other animals).

There are various ways in which some types of goods or services could be seen to 'shift' from one of the four archetypes to another. For example, if a piece of land has no fence, security guards, motion sensors or cameras to (respectively) block, deter, detect or identify trespassers, then the title deeds may belong to a particular individual, i.e. it is legally private, but it might actually be used by many others. Similarly, in rural areas, some footpaths across private land may be legally protected (public ways are public goods) but if the farmer puts bulls in the field, or doesn't cut the hedges or nettles, then users are deterred from using the footpaths i.e. the land reverts to exclusive private use. Technologies, like the above-mentioned fences, sensors, cameras and spaceships, can be used to enclose a resource and exclude others from using it. But there are also technologies that can be utilised to un-enclose a resource, like internet streaming services opening up the enjoyment of films (previously only seen in cinemas) in space, time, affordability and (subsequently) user numbers. The digitally enabled switch from the purchase of goods (like cars or bikes) to the purchase of the services these can provide, could be interpreted as a form of un-enclosing, making such services more affordable and accessible to larger sections of the population[vii].

Table 4 displays these four categories, illustrated with examples mentioned earlier in this paper. Some types of low carbon interventions are more difficult to pigeon-hole. For example, car-clubs could be seen as providing services that fall under the 'common goods' label; assuming that new members are welcome (i.e. being non-excludable) and that they may not have enough cars to serve everyone at a moment of peak demand (not just the number of currently unused cars, but also the location where they are currently parked), i.e. they provide a rivalrous service. But if they have lots of cars locally available and membership fees are quite high or limited to some parts of town, we could say that their services are excludable and non-rival (i.e. club goods). Crowdedness is indeed a key factor in the labelling of the property characteristics of a particular good or service. Trees (in public space or in private gardens) can help to reduce the heat island effect in cities, and can provide visual amenity for anyone walking past; both of these are public goods. But when it comes to providing shade, which can only be enjoyed in the scarce space right underneath the tree, a single tree in public space in the centre of town on a hot day will be a coveted common good.

In summary, it is possible to identify a number of ways in which the use of goods and services can be changed for the purpose of urban low carbon retrofit, and this change can be characterised from a property archetype perspective. Within the technical menu of urban decarbonisation options, I would argue that it is possible to identify (at least) eight types of changes to existing property rights:

1. Combining the use of **private goods** with **club services** (partial substitution). E.g. park & ride schemes
2. Using **private *goods*** to facilitate **club *services***. E.g. buy a EV charger and join an EV charging club

Table 4. The private, common, club and public good archetypes, each provided with examples relevant to decarbonisation of the residential sector.

	Excludable	*Non-excludable*
Rivalrous	Private goods Houses, gardens, cars,	Common goods On-street parking spaces (with or without permits)
Non-rivalrous	Club goods (assuming sufficient capacity) District heating Electric vehicle charging clubs	Public goods Local air quality Climate change mitigation Trees (amenity; cooling)

3. Curtailing **private goods** to facilitate **club services.** E.g. removal of individual gas boilers and replace these with a district heating system
4. Curtailing the rights to the enjoyment of **private goods** where this infringes on **common services**. E.g. pedestrianised streets (i.e. restrict use of/access with private cars).
5. Transferring the rights to **utilise the common good** characteristics of **private goods** (where these are currently underutilised). E.g. if a home owner has a south-facing roof but refuses or can't afford to place solar panels, they could be made to pay for solar panels elsewhere, or they could be forced to allow a regulated or trusted third party (the council?) to install solar panels and own and manage these.
6. Curtailing the rights to the enjoyment of **private goods** where this infringes on **public services**. E.g. restrictions on air polluting activities (lighting a fire in your yard, driving older diesel cars in the city)
7. Using **common *goods*** to facilitate **public *services***. E.g. converting a parking space into urban green space (e.g. plant a tree, or install a raised bed with flowers)
8. Opening up **common goods** for more (groups of) beneficiaries. E.g. convert an on-street parking space of one car, into a bike rack for 10 bikes.

Conclusions

This paper has explored the role of property rights and privileges in reducing carbon emissions in existing urban environments. Because space is scarce in densely inhabited areas, long existing urban neighbourhoods represent a particularly complex patchwork of existing and contested property rights. Whilst acknowledging the (long-established) critical literature about rights to the city and to social, economic and environmental justice in urban development and governance across the world, this paper does not set out to make a normative contribution to debates about private property and inequalities, other than to explore what is needed for decarbonisation. I acknowledge that there are important contributions that property owners could make to decarbonisation. Probably the most iconic examples that spring to mind are (largely) grid independent homes, where property owners have secured sufficient renewable energy generation to match all their energy needs. But even if these individualistic models became mainstream (i.e. adoption at scale), they do not translate well to more urban settings, where a 'service' approach to energy provision can be expected to result in a more efficient use of energy technologies, i.e. fewer and better units, used more frequently. There are other cases where private ownership can encourage more low carbon behaviour. For example households with their own PV panels (a.k.a. energy prosumers) have sometimes been observed to change their consumption patterns in order to better align with the amount of electricity their PV panels produced (Goulden et al. 2014; Christens et al., 2017). Private ownership of bicycles and other active travel technology, will encourage utilisation, which often entails a mode switch away from more polluting modes of transport (private or public). It could be argued that climate friendly private ownership in cities hinges first of all on the relatively small environmental and spatial footprint of the property and if that is low enough, then it needs to be sufficiently affordable too, to ensure wider participation. Poorer sections of the urban population tend to have lower carbon footprints already and if you cannot afford a car, then being able to afford a bicycle will not further lower your carbon emissions. But developing a cycling culture in the city, is akin to a club good; the more people are cycling (including those who cannot afford a car), the more others will be inclined to join them (including those who currently do have cars), thus creating a 'low carbon lock-in' (to reverse the term popularised by Unruh, 2000) and a greater overall impact in terms of emissions reductions[viii].

This paper sought to identify spatial and infrastructural conditions which, when combined with existing privileges of private property ownership, can constitute a systemic hinderance for a faster, wider and deeper deployment of technically mature low carbon interventions in existing streets and urban neighbourhoods. Having identified eight different ways in which property rights need to shift in the city in order to accommodate low carbon retrofits, the paper has highlighted important cases where exclusionary private property may indeed have to be changed. This list of changes also illustrates that we are rarely faced with a (potentially painful or politically difficult) binary choice between private and public ownership, but that effective urban decarbonisation also needs to be more equitable as it requires a wider and more diverse portfolio of opening up, reorganising and redistributing property rights which benefit the many. Whilst we can see that some of this change is already happening in some places, the analysis provided here can serve as a template for a systematic spatial assessment of what needs to change where, and for spatially benchmarking the systemic change that is required for deep decarbonisation of the urban environment. For example, we could identify narrow streets where most of the car parking will have to go eventually, or areas of the city where district heating will the only feasible approach to decarbonising heat. We could identify privately owned urban space that is under-utilised for decarbonisation and offer owners options, ranging from active full ownership to passive co-ownership of newly installed decarbonisation measures, to charging a waiver fee for continued exclusive non-use of a locally scarce resource with public good characteristics (i.e. to mitigate climate change). More positively, we could identify and value the contributions that private gardens with trees make to mitigate the urban heat island effect.

In summary, a more systematic attention to property rights within existing and crowded urban environments may help to (a) illustrate current barriers and inefficiencies to the deployment of the best available low carbon technologies and policies, (b) provide a common framework for place-based analysis of those changes to property rights that can yield the greatest local progress in decarbonisation. This includes the explicit identification of the stakeholders involved, the assessment of potential losses or opportunities for these stakeholders, and an analysis of the tools most suitable to help these stakeholders accept, embrace and progress these situated changes. An evaluation of existing property rights through the lens of climate policy, is perhaps still novel exactly because it can have significant political consequences; in the pervading political climate any (perceived or real) curbs or restrictions to private property will not be an easy sell to some voter groups. There is potential role for academics to play to make place- and carbon-based arguments to what needs to change where, feeding into public debates, challenging expectations and thus preparing the ground for targeted future policies on these issues.

Cities are very complex ecosystems and whilst low carbon retrofits at scale (street, neighbourhood, district level) are clearly and urgently needed, the implementation is fraught with challenges, as is acknowledge by the few papers that explore this issue with practitioners (Häkkinen et al., 2019). Given the dearth of substantive progress that can be studied retrospectively, it can be argued that some of the most valuable types of research should be action-oriented, i.e. helping to make change happen, more quickly and deeply. The physical and social heterogeneity of streets, communities and neighbourhoods means that there is scope and need for co-producing assessments with residents and other key stakeholders; taking account of the size of such property barriers and of their geographical extent, feeding into the development of business cases for place-based low carbon interventions that manage to be both technically effective and socially legitimised.

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Endnotes

i Just to clarify: with 'retrofit' I mean change the existing physical infrastructure to make it more 'fit' for a new purpose; in this case especially to help reduce greenhouse gas emissions (but often to also deliver other/co-benefits). Retrofit stands in opposition to 'new-built' and may relate to any aspects of the existing bio-physical environment, including buildings, streets, sewage networks, green infrastructure, dykes, canals etc. There is of course also the option to simply knock-down whole streets and neighbourhoods, but I am assuming here that for most cities in the global north, this option is relatively limited at the 'whole city' level, due to high direct costs, the huge level of disruption it causes and the carbon footprint of destroying and building up again.

ii Hardin's paper was heavily criticised by social scientists for its naïve and implicitly political assumptions on how local and community institutions (can) function; a research topic for which Ostrom won the nobel prize.

iii Very important for retrofit options, but unfortunately outside the scope of this paper, there is a wide range of (hybrid and co-)ownership models (for international comparisons on community land trust models, see Crabtree et al., 2012; and for housing cooperatives, see Ahedo et al., 2021) and varying levels of protection for long-term residents. Examples of conflicts around energy retrofits and the rights and benefits to long-term residents (not full owners) can be found in the large and relatively well protected rental sector in Germany (März et al., 2022) and the lease hold sector in the UK where faulty external cladding has become a national scandal after the Grenfell tower fire disaster (Bright & Maxwell, 2019).

iv First of all, current production levels of low carbon hydrogen (i.e. 'green' or 'blue') are tiny. Secondly, whilst it can already be deployed in a mix with natural gas, through the natural gas network and utilised in existing residential boilers, that is only possible at low levels of concentration (i.e. relatively small scale and fully dependent on continued use of a fossil fuel). Third, it is argued that the priority purpose of low carbon hydrogen should be to decarbonise energy intensive industrial processes, like steel making.

v Decades after neighbouring countries, this concept (i.e. assigning responsibility to road users based on their relative vulnerability) was finally adopted into the UK highway code, along with other measures to give pedestrians and cyclists more protection. This positive shift still illustrates the long privileged position of the car on UK roads. Other 'illustrations' include; in icy conditions, roads are gritted days before the footpaths; there are many road crossings with traffic lights for cars but not for pedestrians; zebra crossings are few and far between).

vi Commercially available bike shelters for 10 bikes have a spatial footprint of about 4mx2m (x2m in height).

vii This is the basis for the 'Sharing Economy', although some would argue that that term only applies to peer-to-peer trade (as opposed to the council, commercial or third sector owning the assets and selling these services)

viii There is no space here to try to unpack the driving forces to create a cycling culture (or even 'bike-dependence'), but Geel's multi-level perspective (MLP) would obviously provide a useful lens and we can identify plausible factors that range from shifting social norms and practices, to an evolution of the biking economy (skills development, growth in customising, maintaining and storing bikes; sale of protective clothing and paraphernalia, drop in unit price due to higher sales and competition), development of the supporting infrastructure (bike lanes, bike parking, showers at work..) and growth in regulations to support an 'urban regime change' from cars to bikes, and better manage conflicts with other (weaker and stronger) road users.