LETTERS
PUBLISHED ONLINE: 4 MARCH 2012 | DOI: 10.1038/NCLIMATE1434

nature climate change

Trade-offs and synergies in urban climate policies

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Cities are at the forefront of climate policies[1–6]. However, urban climate policies are not implemented in a vacuum; they interact with other policy goals, such as economic competitiveness or social issues. These interactions can lead to trade-offs and implementation obstacles, or to synergies[7,8]. Little analysis investigating these interactions exists, in part because it requires a broad interdisciplinary approach. Using a new integrated city model, we provide a first quantification of these trade-offs and synergies, going beyond the qualitative statements that have been published so far. We undertake a multicriteria analysis of three urban policies: a greenbelt policy, a zoning policy to reduce flood risk and a transportation subsidy. Separately, each of these policies seems to be undesirable because each one negatively affects at least one of the different policy goals; however, in a policy mix, the consequences of each policy are not simply additive. This nonlinearity permits building policy combinations that are win-win strategies. In particular, flood zoning and greenbelt policies can only be accepted if combined with transportation policies. Our results show that stand-alone adaptation and mitigation policies are unlikely to be politically acceptable and emphasize the need to mainstream climate policy within urban planning.

Urban policies have many goals, such as enhancing the quality of life and the city's economic competitiveness by means of affordable housing and office space, amenities and efficient public services. They also have social objectives aimed at poverty and social segregation issues, safety and security, and public health. Urban policies have environmental goals as well, such as reducing air and water pollution and preserving natural areas. Further to this long list of goals, urban policies now face new challenges from climate change, including adaptation and mitigation needs[1–6].

Adaptation and emission-reduction policies rely on the same tools, giving rise to both synergies and conflicts[7,8]. Synergies and conflicts with other policy goals also exist and environmental policies can result in positive feedback with respect to economic and social issues. A decrease in car congestion increases residents' quality of life, enhances economic competitiveness, reduces accessibility inequalities among neighbourhoods and decreases air pollution and greenhouse-gas (GHG) emissions. Conversely, although enlarging parks and introducing more vegetation in cities can be a useful way to adapt them to higher temperatures and can improve the quality of life, such actions may also reduce population density and lead to increased GHG emissions from transportation. These effects can vary by community or location, for example, impact in the suburbs versus that in the city centre, leading to unintended redistributions of wealth or amenities that may or may not be consistent with policy goals.

In this context, a pertinent tool is integrated city models (ICMs)[9]. ICMs are highly simplified representations of reality that describe the most important drivers of city change over time and can assess the consequences of various policy choices. These models are not supposed to forecast the future of a city, but they can provide decision makers and stakeholders with useful information and help them understand the main mechanisms and linkages at work. We use a multicriteria analysis to capture the synergies and trade-offs with respect to urban climate policies aimed at mitigation and adaptation using a simple ICM, non-equilibrium urban model, two-dimensional version (NEDUM-2D; see Methods). Our analysis focuses on Paris, but its qualitative conclusions are generic and likely to be valid for many cities.

In this analysis, we assess urban policies with respect to five policy goals: climate change mitigation, climate change adaptation and disaster risk reduction, natural area and biodiversity protection, housing affordability, and policy neutrality. These goals can be translated into quantitative indicators in many ways. As an illustration, we suggest five possible and relevant ones that our ICM can measure and model. Indicator choice is a crucial issue that depends on the objectives for a given policy and on decision makers' priorities. Moreover, for all practical purposes, indicators (and their weights in the decision process) should be chosen in collaboration with stakeholders and policymakers[10].

The indicators we use do not encompass all possible policy impacts on the five policy goals, but are informative for the policies we will be considering (see Supplementary Information Section S1) and each can be directly measured. First, climate change mitigation: urban policies can influence GHG emissions resulting from transport, heating and air conditioning. Here, we focus on transportation emissions. Our proposed indicator, the average distance travelled by car for commuting, is a simple proxy for GHG emissions in the absence of comprehensive modelling of urban GHG emissions. Second, climate change adaptation and disaster risk reduction: in Paris, one of the main disaster risks is flooding, and climate change may increase this risk, even though models still disagree. We therefore use the population living in flood-prone areas as an indicator. Third, natural area and biodiversity protection: the transformation of natural areas into an urbanized area has many environmental impacts, for example, on biodiversity and on water and flood management. For this policy goal we use the total urbanized area as an indicator. Fourth, housing affordability: access to housing plays an important role in the quality of life and the competitiveness of a city. Improving housing affordability can therefore be both a social and an economic objective. This is particularly crucial in most major cities and can be measured using either rents or average dwelling size. Here, we use average dwelling size in the centre of the urban area as an indicator. An increase in average dwelling size can lead to an increase in residential GHG emissions. This effect is not taken into account in our indicator for climate change mitigation and, therefore, not included in this analysis, because it is mainly influenced by building norms and heating-system regulations, much more than by the urban planning

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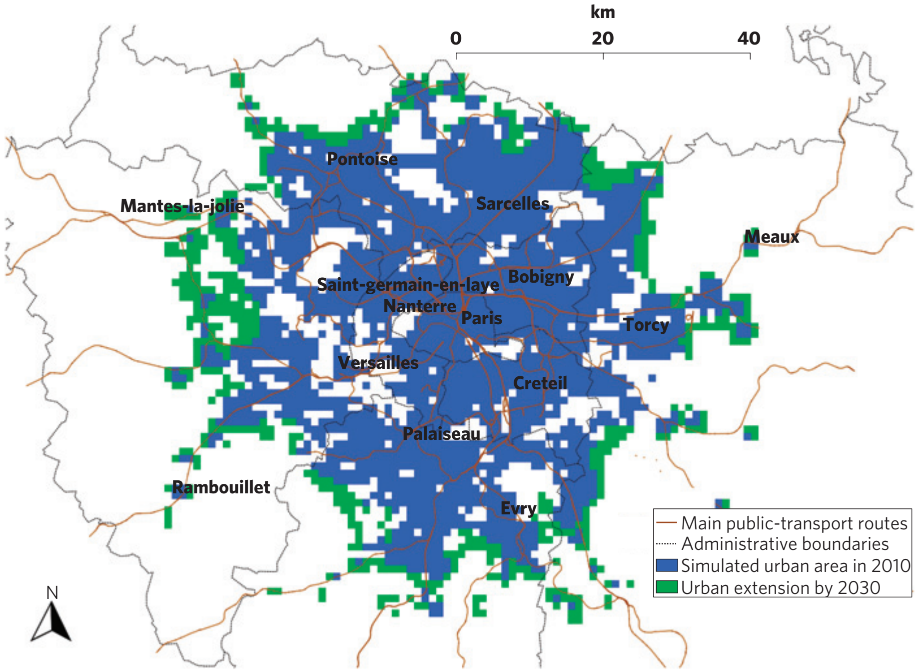

Figure 1 | Map of the total urbanized area of Paris under the do-nothing scenario, 2010 and 2030.

policies that are considered here[11]. Fifth, policy neutrality: even if a policy has a positive impact as measured using aggregated indicators, it may have large unintended redistributive effects or particularly large negative effects on one category of residents or on one area of the city. Such redistributive effects often make implementation difficult or require corrective measures. To build a quantitative indicator for policy neutrality, we use the spatial distribution of returns on real-estate investments in the city and calculate the spatial Gini index of the profitability of real-estate investments. A high value of this indicator means that the evolution of a city leads to large changes in relative land prices.

We consider three budgetary-neutral policies that aim at different targets, but have consequences on the aforementioned five goals: a greenbelt policy, a public-transport subsidy and a zoning policy to reduce the risk of flooding (see Supplementary Information Section S3). Using our NEDUM-2D model, we compare these policies with a do-nothing scenario, whereby urbanization is driven only by market forces and the external drivers: transport and energy costs, population, income and so on (see Supplementary Information Section S4). Figure 1 illustrates the do-nothing scenario. The model projects a significant extension of the urbanized area between 2010 and 2030 as a result of increased population and decreasing transportation costs relative to income.

The first policy is a greenbelt policy whereby land-use regulations prohibit building in areas that are not already densely inhabited. This policy aims at limiting urban sprawl and protecting natural areas. With this policy, the urbanized area in 2030 is the same as in 2010, even though building and population densities are different. As Table 1 shows, this policy also limits the increase in private vehicle usage, increases real-estate prices and reduces dwelling sizes by making land more scarce. This increased land scarcity leads more people to live in flood-prone areas, which has been empirically observed[12,13].

The second policy is a public-transport subsidy financed by a lump-sum tax. We take the example of the recently proposed replacement of the differentiated public-transport tariff—which increases with distance from the city centre—by a single tariff for all destinations in the Paris urban area. Such a policy aims at promoting public transport, as well as decreasing the burden of transport costs on suburban households, which in Paris are, on average, poorer than those living in central Paris. The side effects of such a policy are to increase the incentive to live farther out in the suburbs, leading to an increase in the total urbanized area and a decrease in real-estate pressure in the city centre.

The third policy is a zoning policy to reduce the risk of flooding. This policy prohibits new buildings in flood-prone areas. Such a policy reduces the available urban ground surface, thereby increasing land scarcity, and causes an increase in housing prices, leading to smaller dwelling sizes in the city centre (as can be seen in Table 1).

Table 1 | Multicriteria analysis of urban policies on Paris in 2030 with respect to the five policy goals.

Indicators	Greenbelt	Public-transport subsidy	Flood-risk zoning	Policy mix	Do-nothing scenario
Change in average daily distance driven in car per household (m)	+1,570	−440	+2,550	−880	+2,560
Change in population in flood-prone areas (thousands of households)	+39,000	−4,000	−6,000	−8,000	+6,000
Change in total urbanized area (km^2)	0	+690	+470	0	+480
Redistributive impacts (Gini index)	+0.093	+0.271	+0.201	+0.146	+0.203
Change in dwelling size in the centre of Paris (m^2)	+0.17	+1.73	+0.79	+0.95	+0.82

NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE1434

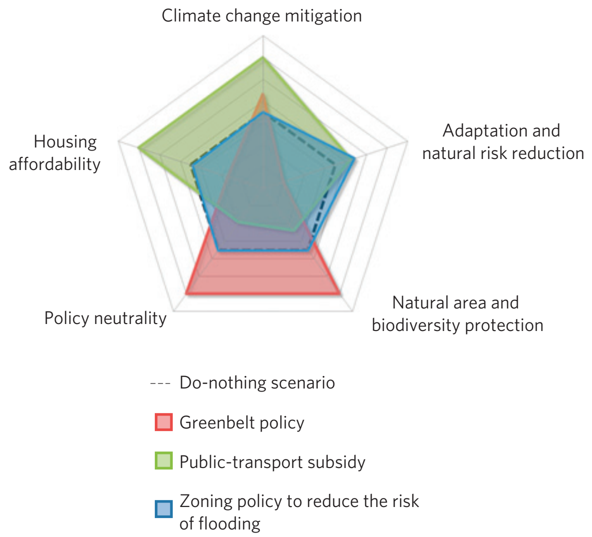

Figure 2 | Consequences of a greenbelt policy, a public-transport subsidy and a zoning policy to reduce the risk of flooding compared with the do-nothing scenario. Axes orientation is such that directions towards the exterior of the radar plot represent positive outcomes. Preferred outcomes are a decrease in average distance travelled by car, in the population living in flood-prone areas, in total urbanized area, in spatial Gini index, and an increase in average dwelling size.

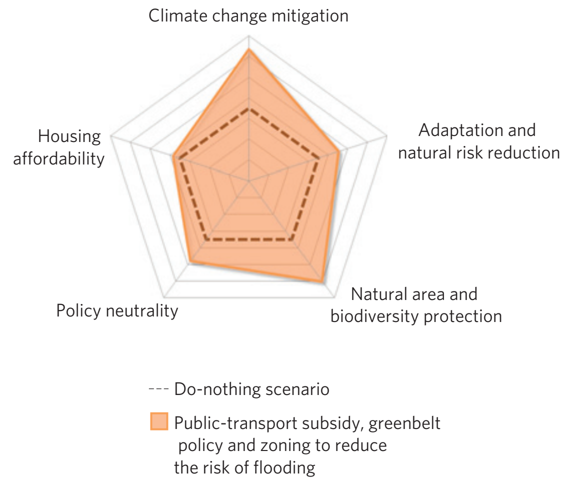

Figure 3 | Consequences of a policy mix including all three policies. Axes orientation is such that directions towards the exterior of the radar plot represent positive outcomes.

Figure 2 presents graphically the positive and negative impacts of the three policies. The impact of each policy on each indicator has been assigned a score and is located along one of the five axes of the figure. The −100% score is in the middle of the figure; the +100% score is at the extremity of each axis. All scores are measured relative to the do-nothing scenario, which is assigned a 0% score. The +100% score goes to the preferred outcome among all considered policies. Each policy is thus ranked best when the corresponding coloured area is biggest. For instance, Fig. 2 shows that a public-transport subsidy improves the situation compared with the do-nothing scenario for three policy goals (climate change mitigation, housing affordability, and adaptation and disaster risk reduction), and makes it worse with respect to two policy goals (natural area and biodiversity protection and policy neutrality).

As Fig. 2 shows, each policy causes both positive and negative outcomes with respect to different policy goals when compared with the do-nothing scenario. Each policy thus seems to be undesirable because it has negative consequences with respect to at least one policy goal. This result can explain, for instance, why it is so difficult to implement efficient flood-zoning or greenbelt policies on a local scale, even when it is required by national law[14]. Indeed, negative side effects on housing availability and on development opportunities understandably create political resistance.

However, as Fig. 3 shows, a mix that includes the three policies can mitigate the adverse consequences of each individual policy. For instance, public-transport subsidies decrease the real-estate pressures caused by a greenbelt or a flood-zoning policy. Flood zoning also prevents the greenbelt from increasing the population at risk of floods. When all three policies are applied together, the situation is improved as measured along all policy goals compared with the do-nothing scenario. In particular, these results indicate that flood-zoning and greenbelt policies need to be combined with transportation policies to gain real political momentum and effectiveness.

Note that in a policy mix, the consequences of each policy are not simply additive. For instance, when all three policies are implemented, the decrease in population in flood-prone areas is smaller than the sum of the variation caused by each policy taken separately. This nonlinearity and the complexity of policy interactions explain why it is useful to analyse various urban policies together, in a consistent framework.

Our analysis shows that building win–win solutions by combining policies is possible and leads to more efficient outcomes than a set of policies developed independently. Climate goals can thus be reached more efficiently and with higher social acceptability, if they are implemented through taking into account existing strategic urban planning, rather than by creating new independent climate-specific plans. Such mainstreaming of climate objectives with other policy goals is found to help design better policies in our model, confirming previous findings in other domains[15–17].

Obviously, it does not mean that win–win strategies are always available. In some cases, trade-offs will remain unavoidable and urban decision makers will need to make tough choices. This can be done by associating different weights to our indicators—through a process of stakeholder engagement—and by maximizing the resulting weighted sum of indicators. But our analysis shows that a mainstreamed approach can allow for the design of policies that are robust to differences in the weights of different indicators, as they improve all indicators. Such policies are particularly easy to implement, because they are more likely to seem desirable to all stakeholders, in spite of their different priorities, objectives and world views.

Methods

We use the NEDUM-2D model to simulate the evolution of the Paris urban area between 2010 and 2030. This model is an extension of that described in previous papers[18,19], which is based on classical economic theory[20–22]. This theory explains the spatial distribution of land and real-estate values, dwelling sizes, population density, and building height and density.

Our approach aims to bridge the gap between high-complexity land-use–transport interaction models[23] and theoretical urban-economics models. To do so, we propose a model that is fully based on microeconomic foundations describing economic agent behaviours (like theoretical models), but that can be calibrated on realistic transportation networks and include precise land-use regulations and natural land characteristics (for example, rivers and other natural areas).

Two main mechanisms drive the model. First, households choose where they live and the size of their accommodation by assessing the trade-off between proximity to the city centre and housing costs. Living close to the city centre reduces transportation costs, but housing costs (per unit of area) are higher there. Theoretical extensions to account for decentralized production have been proposed, but are not included in this analysis[24–26]. Second, we assume that landowners combine land with capital to produce housing: they choose to build more or less housing (that is, larger or smaller buildings) at a specific location depending on local real-estate prices and construction costs. We assume that households and landowners do not take into account flooding risk in their location and construction choices, as reflected by the present building rate in flood-prone areas in France[27] and as supported by behavioural economics research[28]. Transportation costs include monetary costs such as the cost of gasoline and the cost of time. We assess them using the spatial structure of the Paris transportation networks (roads and public transport). See Supplementary Information Section S3 for a full description of the model and its equations.

As described in Supplementary Information Sections S3.3–S3.5, a validation of the model over the 1960–2010 period shows that it reproduces the available data on the city's evolution fairly faithfully and captures its main determinants. It also reproduces the spatial distribution of dwelling size, population density and rents in the urban area fairly well. These results suggest that this tool can be used to inform policy decisions.

The evolution of the Paris urban area depends on several external factors, including demographic, socioeconomic, cultural and political changes (see Supplementary Information Section S4 for a more precise description of the scenarios). Our conclusions are robust to changes in these values, as demonstrated by a sensitivity analysis (Supplementary Information Section S5).

The model can be used to test many different assumptions about the future development of transport infrastructure. For simplicity, we assume that it remains unchanged between 2010 and 2030 and that congestion on the roads and public transport remains constant, that is, we assume that future investments in the transportation network maintain the same level of service despite population growth (Supplementary Information Section S4).

Received 4 July 2011; accepted 1 February 2012; published online 4 March 2012

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Acknowledgements

This study received financial support from the Agence Nationale de la Rercherche through the projects Vulnérabilité Urbaine aux épisodes Caniculaires et stratégies d'Adaptation (ANR-08-VULN-013) and Modélisation Urbaine et Stratégies d'adaptation au Changement climatique pour Anticiper la Demande et la production Energétique (ANR-09-VILL-0003-01). The authors are grateful to D. Rouchaud, A. Sauvant, J-L. Salagnac and N. Coulombel for providing data. T. Bigio, J. Corfee-Morlot, M. Fay, E. Genovese, L-G. Giraudet and P. Avner provided comments. The findings, interpretations and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations or those of the executive directors of the World Bank or the governments they represent.

Author contributions

V.V. carried out the computational analysis. S.H. initiated the study. S.H. and V.V. continued and finalized its design. They both wrote the paper.

Additional information

The authors declare no competing financial interests. Supplementary information accompanies this paper on www.nature.com/natureclimatechange. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to V.V.