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Trade-offs and synergies in urban climate policies

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1 Indicators for policy effects

This section describes the indicators used for each dimension of policy assessment (Sup. Tab. 1). We are aware of the fact that our indicators are simple compared with the complexity of the problems we are dealing with. However, this problem is classical with indicators, which need to be simple enough to be measurable and consensual.[29]

Average distance traveled by car for commuting In the model, we only consider commuting trips assimilated to trips towards the center of Paris. Partly because of the high job density near the center of Paris and of Paris urban area star-shaped public transport network, this assumption is not unrealistic (cf. Sup. Sec. 3.2). These trips can be made either by walk, or using public transport or private vehicles, with different possible itineraries (see model description in Section 3.1). The indicator is the average distance traveled by car by households in the city.

We do not account for residential emissions because they are mainly influenced by housing policies, which are not studied here.

Population living in flood-prone areas Flood-prone areas are defined by the extent of extreme historical floods.

In model simulations, the total population living in these areas is in good agreement with empirical measurements : in 2006, approximately 520 000 households were living in such areas in Ile de France (Paris administrative region),[27] whereas in model simulations this figure is 530 000. The indicator is the number of households living in flood-prone areas.

We did not aim here at a comprehensive analysis of cities vulnerability to climate change, and chose flood risk as an illustrative example. Heat wave vulnerability is another important topic, but it can only be investigated by coupling the urban model with a urban microclimate model.[30]

This indicator could also be made more refined by coupling the urban model with a hydrological model to take into account the impacts of climate change on the frequency and intensity of floods.[31] In the current version of the model, the flood-prone area in Paris is assumed constant, assuming that climate change may change the frequency of floods, without modifying in a significant manner the flood-prone areas. More sophisticated hydrological modeling would be needed to go beyond this assumption.

Total urbanized area We measure the total area where more than half of the ground surface has been built-up.

Urbanization impact on biodiversity can be mitigated through the creation of properly designed conservation areas and corridors. However urban sprawl is one of the factors contributing to an increased pressure on biodiversity, all other things being equal.[32,33] An interesting development of our article would be to consider a fourth policy consisting in land-use regulations to protect biodiversity, and to assess its side-effects on the other policy goals.

Average dwelling size in the center of the urban area The indicator is the simulated dwelling size in the center of Paris. In our modeling, and in urban economic models in general, housing cost and housing size are jointly determined, and households spend (at equilibrium) a constant share of their income for housing. Everything else being equal, households live in larger dwellings when rents are lower, and either of these two indicators can be used equivalently.

Of course, increased housing affordability is not always positive, and is not positive for everybody. In particular, building owners may see a decrease in the value of the buildings (and thus of their assets) as a result of a higher housing affordability. But increased housing affordability (and reduced rent) is today a consensual policy objective in Paris, this is why we introduced it in our analysis.

Spatial gini index of the profitability of real estate investments We measure real estate investments profitabilities as the relative increase in rents between 2010 and 2030. The indicator for policy neutrality is the Gini index of all relative rents increase in the urban area, weighted by available ground surface. If the Gini index is high, it means that rents follow different trajectories in different locations, creating wealth redistribution.

Redistribution may be an intended consequence of policies, even if it is not necessarily written into the policy goals.[34] Here, intended distributional impacts are mainly captured through our "housing affordability" criterion. Beyond this point, the differential impact on housing prices and rents (non-neutrality) is thus considered as making the policy implementation more difficult. We consider therefore as positive a policy that compensates these unintended transfers, and as negative a policy that enhances them.

Policy goals	Indicators
Climate change mitigation	Average distance traveled by car for commuting
Adaptation and disaster risk reduction	Population living in flood-prone areas
Natural area and biodiversity protection	Total urbanized area
Housing affordability	Average dwelling size in the center of the urban area
Policy neutrality	Gini index of the profitability of real estate investments

Supplementary Table 1: List of policy goals and proposed indicators.

2 Urban policies

This section describes the do-nothing scenario and the three policies that are assessed in this analysis.

Do-nothing policy It corresponds to a case in which city development is considered to be only driven by market forces and evolution in boundary conditions (e.g., oil prices, technologies). These boundary conditions are described in Section 4).

Green-belt policy We supposed in this policy that building is possible only in locations where more than half of ground surface is already built-up in 2010. In other locations, new buildings are forbidden and existing buildings cannot be enlarged.

Public transport subsidy Differentiated public transport tariff, increasing with the distance from city center, is replaced by a single tariff for all destinations in Paris urban area. This new tariff is equal to 20% of the lowest tarif for all destinations in do-nothing scenario. The money needed to finance this policy is obtained through a lump-sum tax.

Zoning policy to reduce the risk of flooding This policy prohibits new buildings and enlargement of existing ones in flood-prone areas, after 2010. As in the measurement of population living in flood-prone areas, these areas are defined by the extent of extreme historical floods.

3 The NEDUM-2D model

The classical urban economics framework is an economic modeling approach developed in the end of the 1960s.[20−22] It aims at explaining the spatial distribution - across the city - of the costs of land and of real estate, housing surface, population density and buildings heights and density. It is based on two main assumptions, and two main mechanisms.

First assumption, the city structure and characteristics are assumed to be determined by the presence of jobs, which are assumed located at the center of the city. Second assumption, the original model assumes that city characteristics depend only on the distance to the center (in other terms, the city is axi-symmetric). In our NEDUM-2D model, instead, the actual transport network structure (roads and public transport networks) is used to calculate trip durations and costs. Thus, the city is not axi-symmetric anymore, and geographical information can be included in the analysis.

The driving mechanisms are as follows. First, households choose their accommodation location and size by making a trade-off between the proximity to the city center (i.e. to the jobs) and rents level (or, equivalently, between the proximity to the city center and the housing surface they can afford). Our analysis shows that this assumption is acceptable in Paris (see below). Theoretical extensions to account for decentralized production have been proposed, but are not included in this analysis.[23–26] Second, land owners choose to build more or less housing (i.e. larger or smaller building) at a specific location, depending on the local level of rents and construction costs.

Using these two mechanisms, it is possible to determine the structure of the city from information on the population size, the households' income, transport network locations, building construction costs and developer behavior parameters. An immediate consequence of this model is for example the fact that, if the price of transportation increases, households will have less incentive to live in the suburbs and the city density will increase close to the center.

3.1 Equations

We model the household trade-off using the following utility function:

$$U = Z^{\alpha} h^{\beta}$$

where α and β are coefficients ($\alpha + \beta = 1$), h the surface of the households' dwelling and Z the money remaining after the household has paid its rent and a commuting round-trip per day to the center of Paris. Such a functional form is consistent with the fact that the share of household income devoted to housing expenditures is relatively constant over time and space.[35]Household income constraint reads:

$$Y = Z + hR + t_r$$

where Y is the average household income, R is the rent per square meter, and t_r the transportation costs (monetary cost added with time cost).

The cost of transportation includes the monetary cost of transportation and the cost associated with the trip duration, which we consider as an actual loss of income. Transport mode choice is computed through a comparison of generalized transport costs, taking into account trip duration and trip price for public and private transport. A logit weighting is then used to take into account heterogeneous preferences of agents. Our modeling of the modal choice remains simple but appears robust. Simulated public transport modal share is in good agreement with empirical measurements: in 2002, public transport modal share was 47 % (Source: DREIF), whereas in model simulations this figure is 46 %.

We assume that absentee landowners own the land, and that they combine land with capital to produce housing. The housing production function reads, in a classical way:[21,36]

$$H = AL^a K^b$$

where A, a and b are coefficients ($a + b = 1$), H the housing surface built, L the land surface occupied by the buildings and K the financial capital used for construction. The benefit of land owners reads therefore:

$$\Pi = (R - R_0)H - (\delta + \rho)K$$

Π is the profit, ρ represents the joined effect of real estate capital depreciation and annual taxes payed by land owners on the real estate capital, and δ the interest rate. The metropolitan area boundary is defined by a rent R_0, below which it is not profitable to build housing building (this value corresponds both to other uses of the land like agriculture and to transaction costs in the building and renting process). Developers build to maximize their profit: at each point of the metropolitan area they construct, i.e. choose K, to maximize Π under the constraint that $\frac{H}{L}$ ratio is limited by an urbanism constraint (see details below).

3.2 Hypotheses of the model

We suppose that there exist a unique city center. Several theoretical and operational models exist to capture polycentric nature of cities,[23−26] however, the monocentric simplification is still acceptable in Paris, as can be seen in Sup. Fig. 5 and 6: rents and population density reach a peak at a point that corresponds to the center of Paris and decrease in all directions on a regular basis when one moves away.

High job density near the center of Paris and Paris urban area star-shaped public transport network explain the relevance of the monocentric approach. Results presented below confirm that the monocentric assumption is still able to explain the major characteristics of the Paris urban area. We have therefore put aside the issue of polycentrism, to develop only scenarios in which the urban area keeps evolving in a monocentric way.

Second, this model only describes market mechanisms related to urbanism. A city model based on urban economics ideas is for instance probably unable to tell much on cities with no functioning land markets, as it is the case in many developing countries.

In practice, because of urbanism constraints (e.g. limits to building heights) and of direct public investment (e.g. in public housing or infrastructure) the structure of the Paris urban area does not directly correspond to the resulting balance of the free play of market. We introduce explicitly constraints of this type in the model. For instance, we limit the height of buildings in Paris. Indeed the model tells us that, otherwise, real estate developers would build much higher buildings than what is observed, in response to the high rent level in Paris.

We also forbid to build in some areas (natural parks, public gardens...), and introduce a constraint on the maximum ground surface devoted to housing construction at each location, to take into account transportation infrastructures (roads, sidewalks, railways, etc.). We based our constraint on data gathered by the Paris urbanism institute (APUR) for the EPICEA research project. According to pictures taken by airplane, roofs cover 62% of ground surface in most dense areas in Paris, public parks excluded; we therefore suppose that 62% of ground surface is available for building, in places where construction is not forbidden.

We do not describe direct public investment aiming at changing the urban shape. For instance, "Villes nouvelles" ("new towns") are an historic example of a planned urban development that the model is not able to anticipate, and which could renew itself in this century. Thus, it can be considered that the model provides spontaneous urbanization trends, that urban policy may alter.

Finally, we assume that households and landowners do not take into account flooding risk in their location and construction choices, as reflected by the current building rate in flood-prone areas in France,[27] and as supported by behavioral economics research.[28]

3.3 Calibration

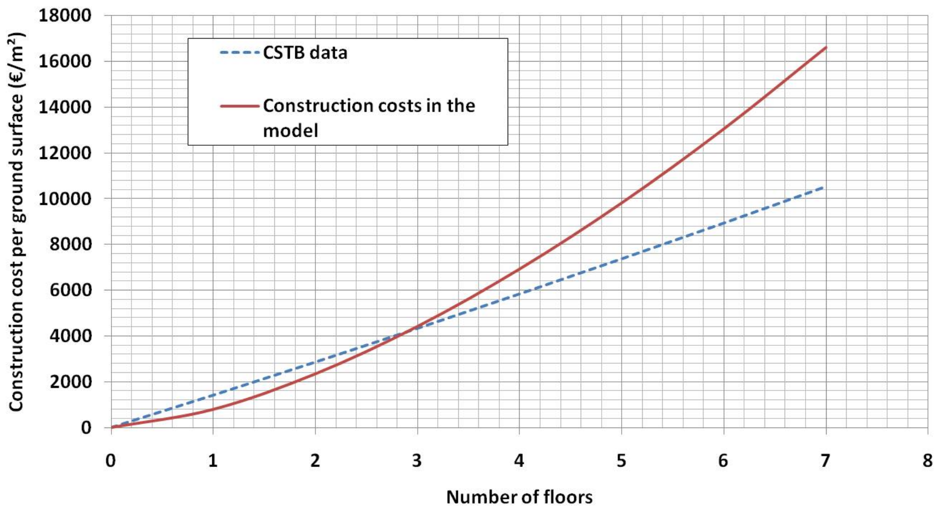
Sup. Tab. 2 presents the numerical data we used in our simulations. In absence of adequate data for some parameters, for instance the cost of time and construction costs, these parameters have been calibrated on the Paris structure in 2006. A detailed comparison of model results with available data is provided below, and shows a good agreement on the model with observed urban evolutions.

Construction costs The calibration process provides construction costs between 1173€ $/m^2$ for a housing-surface/land-surface ratio of 2 and 794€ $/m^2$ for a ratio of 1. We compare in

Main Data	
Urban area population	5,101,300 households
Fraction of ground surface devoted to housing	0.62
Households average income	€ 56,098
Transport times and costs in Paris urban area	cf. Supplementary Notes[37]
Interest rate	$\delta = 5\%$
Built capital depreciation time	$\rho = 0.5\%$
Calibrated parameters	
Households utility function parameter (cf. Section 3.1)	$\alpha = 0.7$
Coefficients of construction cost function (cf. Section 3.1)	$A = 2.0140$ and $a = 0.36$
Cost associated with travel time	cf. below
Rent determining city border	$R_0 = 11€/m^2$

Supplementary Table 2: Summary of main data and calibration parameters

Sup. Fig. 1 the calibrated costs to construction cost estimates from the Centre Scientifique et Technique du Bâtiment (CSTB), a French public institution providing analysis and research on construction and housing issues. These data are partial, since they are prices announced by developers in several public procurement documents and in various estimates of building construction costs, as well as technical documents. What emerges from CSTB data is an average cost of construction of 1200 €$/m^2$ before tax, or approximately 1400 €$/m^2$ including all taxes, which increases slightly as the building becomes higher. However, these estimates are quite uncertain: because of the diversity of types of buildings that it is possible to build, it is difficult to obtain a cost that can be used as a reference cost. The order of magnitude of the calibrated cost seems to agree with the order of magnitude of the data. These data present however a less convex profile than calibrated data. An explanation of the discrepancy may be that the so-called "actual" costs in CSTB data are direct construction costs, while in reality developers consider also additional costs when the height of buildings increases.[38] These additional costs include administrative costs (building permits etc.), financial costs (the risk associated with a larger investment cost), and technical costs (duration and technical difficulty of the works), which may introduce more convexity in the real cost curve.



Supplementary Figure 1: Construction costs

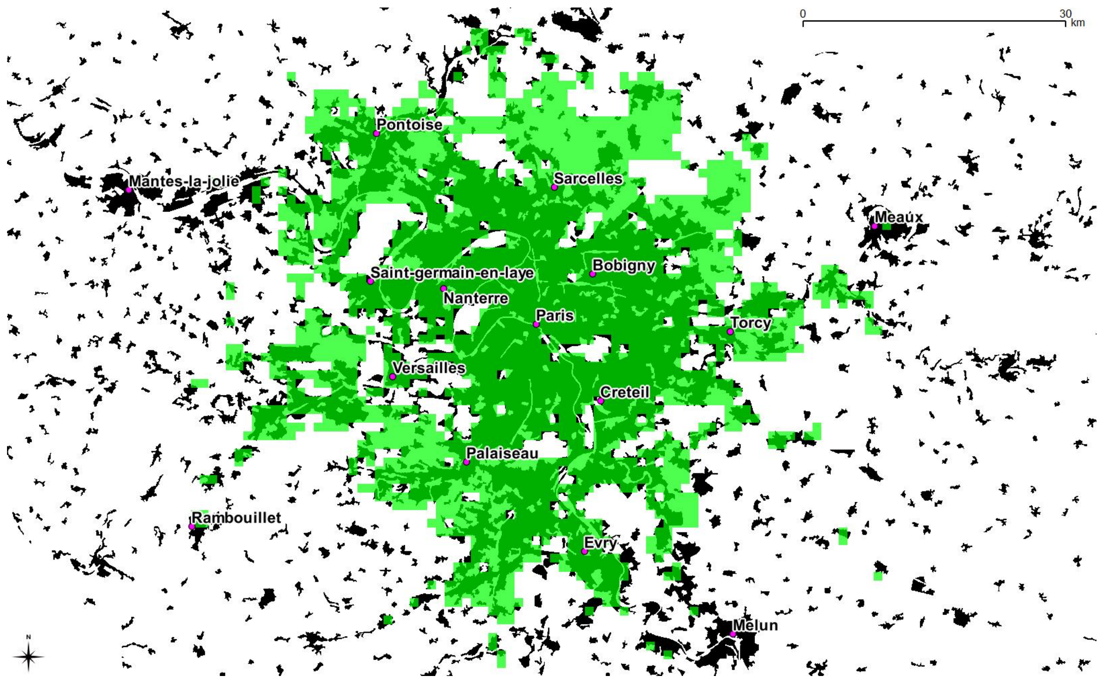
Cost of time In the model, rents (per surface unit) decrease when moving away from the center of Paris because households have to pay a generalized transportation cost, which is the sum of a perceived monetary cost (interpreted here as the cost of fuel) and of the cost associated with transport time, assuming that households do a round-trip per day towards the center of Paris. In the simulation, cost associated with transport time represents generally the bigger part of generalized cost, and the way we assess this cost has an important role in our results.

Numerous studies have dealt with this issue, but no conclusive result exists on this complex subject. In Ile-de-France, French Government's Strategic Analysis Center proposed to use net hourly wage as an estimate for commuting time cost, but explained that the value of actual commuting time cost depends greatly on several factors such as households characteristics or modal choice.[39]

Due to the importance of time cost choice in the simulation, we calibrated time cost instead of using an a priori fixed value. We computed this cost using our data on rent spatial distribution: out of these data, assuming our model perfectly exact, it is indeed possible to estimate a theoretical generalized transportation cost. Assuming that this generalized cost reflects the sum of the direct cost of transport and of the cost associated with transport time, and assuming that households do a round-trip per day towards the center of Paris, the transport time cost was estimated as a function of journey time.

Marginal time cost seems to decrease with travel time, and we chose to model simply this decrease using a piecewise affine function. This representation leads us to use a cost of time worth 105% of the net hourly wage when the travel time is less than 25 min (or, equivalently, when the distance to the center of Paris is less than 15 km), then a lower cost (6.6% of the net hourly wage) for portions of journey in excess of this limit. The value of time for journeys during less than 25 min is therefore very close to commuting time cost in Ile de France according to French Government's Strategic Analysis Center.

This observed decrease in marginal time cost can be attributed to the limits of our approach, in particular to the monocentric framework and to the hypothesis that households do a round-trip per day towards the center of Paris. In the real world, in places where travel time exceeds 25 minutes, a large fraction of households do not commute to the center of Paris. This leads to a shorter average trip length than in the mono-centric case, and using actual average trip length would enable to use more realistic time cost values and smaller total fuel costs for locations far from Paris city center. In absence of needed data, we did not take into account explicitly this variation in trip length, and modeled it with a non-linear time cost.

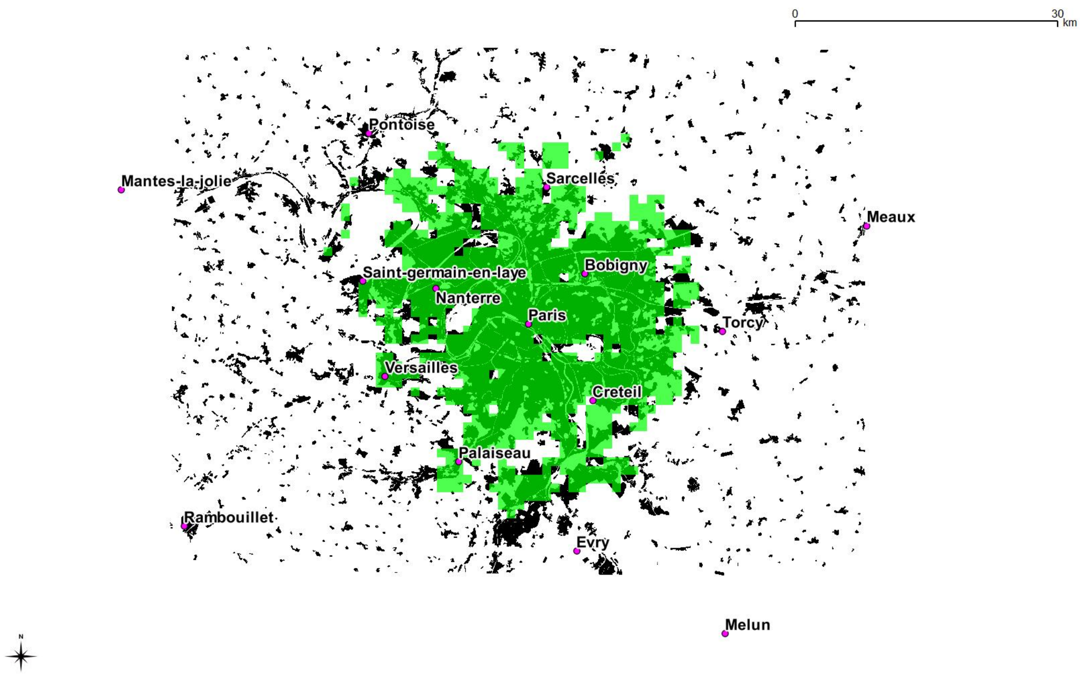


Supplementary Figure 2: Simulated urbanized area in 2006. Actual urban area appears in black (Source : Corinne Land Cover), whereas model simulation appears in transparent green.

3.4 Validation: urbanized surface evolution

As can be seen on Sup. Fig. 2, the model reproduces well Paris urban area general shape. The main mismatch is in the north of Paris, near Charles-De-Gaulle airport: in model simulations, this area is urbanized, whereas in reality it is not. This can be partly explained by the airport noise zone, which limits city expansion, and which is not taken into account by the model. The same phenomenon can be observed near Orly airport, in the south of the urban area. Conversely, in the west (Mantes la Jolie) and in the south of the urban area (Melun), the model does not capture observed urbanized areas. These two zones correspond to cities which were built long before being included in Paris urban area, whereas the model only represents built areas due to Paris urban area sprawl.

It is possible to use this model to simulate city evolution from 1960 to 2010. For instance, Sup. Fig. 3 and Sup. Fig. 4 compare simulated urban area with actual urbanized area, in



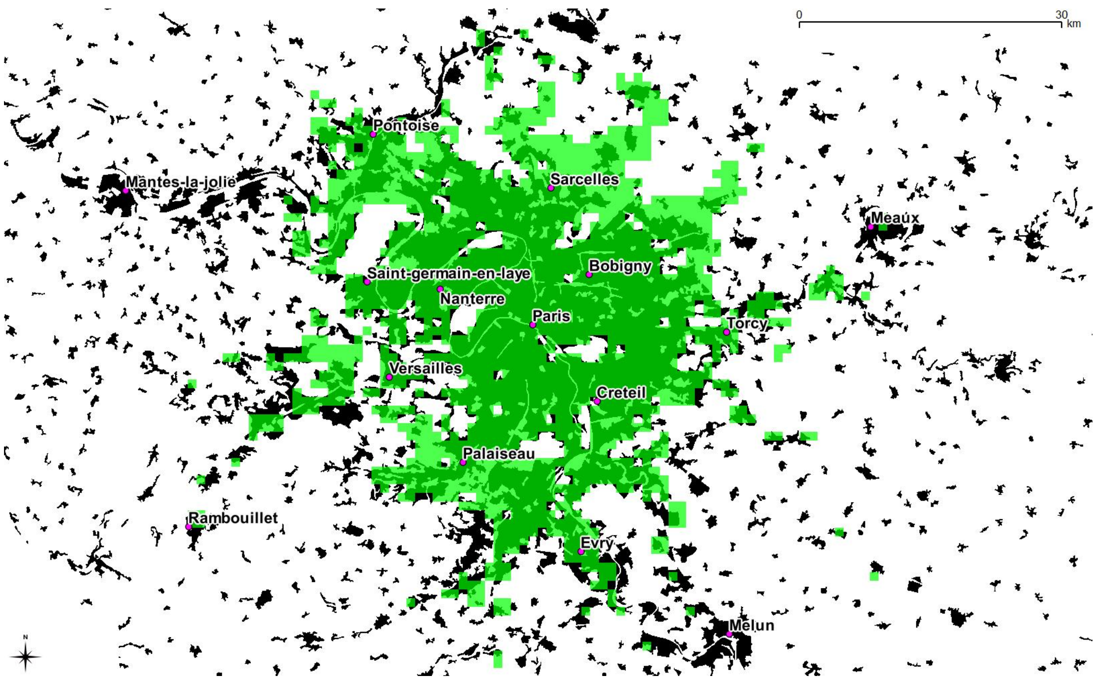
Supplementary Figure 3: Simulated urbanized area in 1960. Actual urban area appears in black (Source : MOS, IAURIF), whereas model simulation appears in transparent green.

1960 and 1990, respectively. Large-scale trends between 1960 and 2010 are well described, suggesting that the model captures the main determinants of city shape evolution.

The comparison of simulated urbanized area and the actual urban area should be handled with caution because it is strongly dependent on the definition of city limits (for instance, in terms of population density). Comparisons of continuous variables, as will be done in the next section, are more significant.

3.5 Validation: city structure

As shown in Sup. Fig. 5, the model describes the distribution of rents across the city in 2008 quite satisfactorily. It explains 51.8% of the two-dimensional variance of the data. When all locations at the same distance from city center are averaged (blue dotted curve), the fit is even better: the model explains then 89.5% of the variance. That is because doing so cancels out



Supplementary Figure 4: Simulated urbanized area in 1990. Actual urban area appears in black (Source : Corinne Land cover), whereas model simulation appears in transparent green. Corinne Land cover data are available at `www.eea.europa.eu/publications/COR0-landcover`.

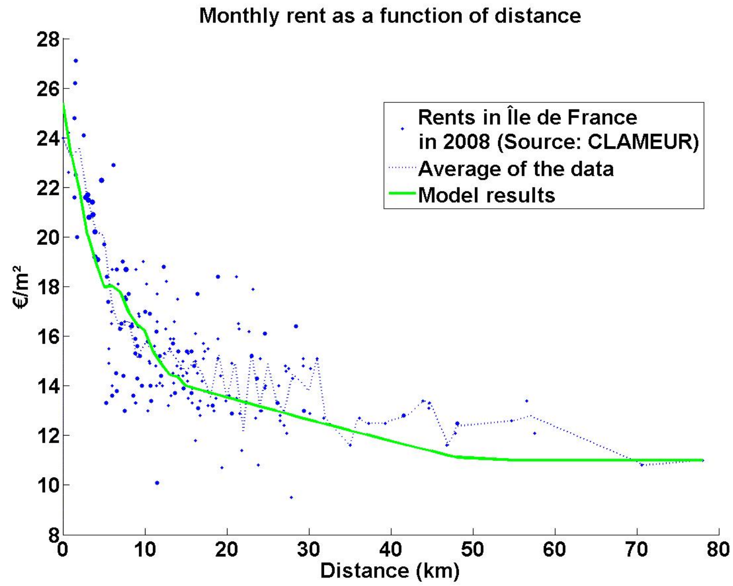
other characteristics of the area (e.g., amenities, quality of public services), and the proximity from city center is the major driver of housing prices.

Supplementary Figure 6 shows that there is also a good agreement between the model and data in terms of population density (the model explains 77.2% of the two-dimensional variance, and when all locations at the same distance from city center are averaged, the model explains 95.9% of the variance).

Similarly, Sup. Fig. 7 shows a reasonable agreement in terms of dwelling size, even though we have little data on this aspect and the curve representing "interpolation of INSEE data" should be considered carefully.

Supplementary Figure 8 compares the ratio between inhabited surface and ground surface dedicated to housing as calculated by our model and as computed from our data on population density and on accommodation sizes. The curve representing model results grows when moving towards the center of Paris, and saturates at a ratio of 2, driven by land-use constraints in Paris downtown. This value may seem low as most buildings in Paris have approximately 6 floors, which would induce a ratio of about 6 at the center of Paris. However, our ratio is only taking into account housing surface, and not the total built surface, and the discrepancy is simply caused by built surface intended for purposes other than housing (it includes, on the one hand, corridors and lobbies in buildings dedicated to housing and, on the other hand, all buildings not dedicated to housing : offices, shops, museums, train stations, office buildings, schools, universities, etc.). As we had little data on accommodation sizes, the data points should be considered more as orders of magnitude than as a specific value.

Model and data seem to match well on the urban area scale, even if local differences can be large, due to the lack of several locally important mechanisms (e.g., public services supply and local amenities).

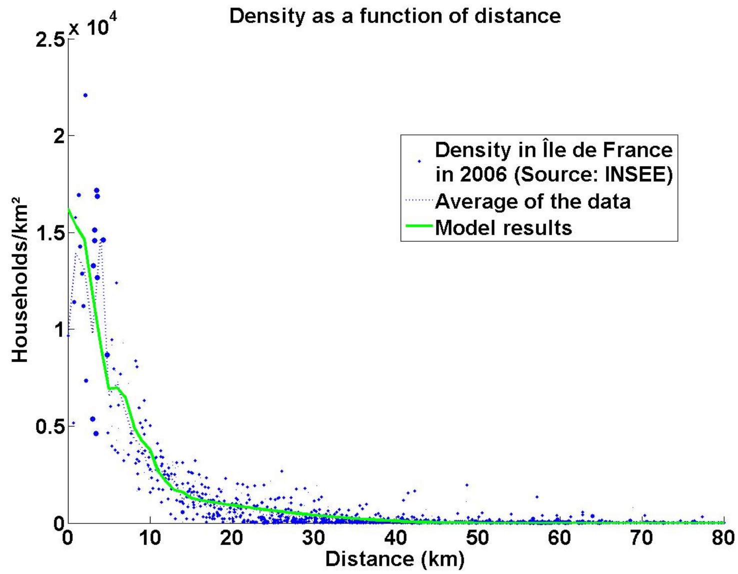


Supplementary Figure 5: Rents computed by the model (plain line) and from data. Dots represent data for individual localities, from the CLAMEUR data base. The dotted line represents the average value at a given distance from Paris center. CLAMEUR data are available at `http://www.clameur.fr/`.

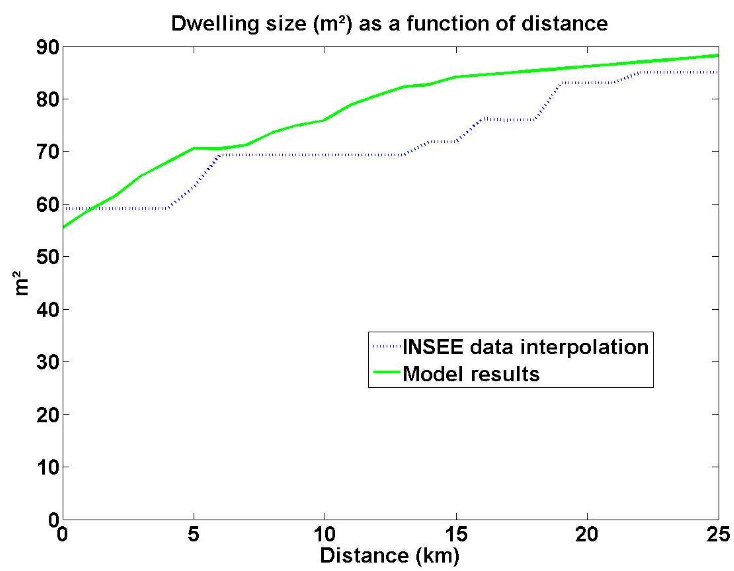
3.6 Model sensitivity analysis

We are well aware of the limits of our model, a very simplified vision of reality, and of the limits of our calibration. To estimate the robustness of our model, a systematic analysis of the sensitivity of different outputs to different inputs has been carried out. Supplementary Table 3 summarizes the elasticities of model output with respect to model inputs.

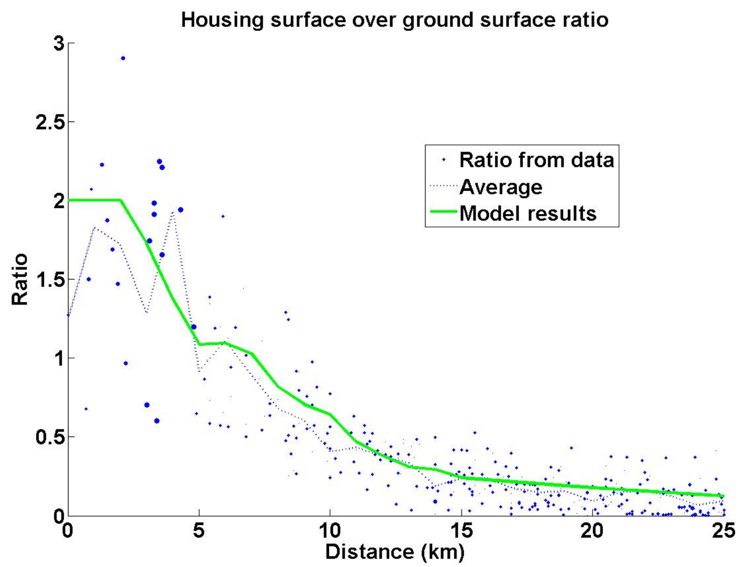
Apart from those relating to construction costs, all these percentages are close to 0.5% or 1%, which means that numerical uncertainty on urban shape caused by a change in our parameters is equivalent to the uncertainty on the variation of our parameters. It means that there is no parameter for which a small uncertainty can translate into a large uncertainty in model result, which is comforting and suggest that our model results are rather robust.



Supplementary Figure 6: Population density computed by the model (plain line) and from INSEE data (dots). The dotted line represents the average value at a given distance from Paris center. INSEE data are available at `http://www.recensement-2006.insee.fr/basesChiffresCles.action`.



Supplementary Figure 7: Dwelling sizes computed by the model (plain line) and from INSEE data (dotted line). INSEE data are available at `http://insee.fr/fr/themes/document.asp?reg_id=20&ref_id=13321`



Supplementary Figure 8: Housing surface over ground surface ratio, computed by the model (plain line) and from data (dots). The dotted line represents the average value at a given distance from Paris center.

	Population	Income	ratio ground surface decicated to housing/total ground surface	Rent determining city border	Fuel price	Time cost near Paris	Duration of the journey when time cost changes	Time cost far from Paris	Coefficient A in construction costs function	Coefficient b in construction costs function	Coefficient β in utility function	Built capital depreciation time	Interest rate
Rent in the center	0.10	0.90	-0.10	0.74	0.10	0.11	0.38	0.05	-0.26	-1.24	-0.50	0.04	0.13
Average rent	0.01	0.90	-0.01	0.94	0.11	-0.27	0.46	0.06	-0.09	-0.26	-0.31	0.01	0.04
Dwelling size in the center	-0.10	0.10	0.10	-0.74	-0.10	-0.11	-0.38	-0.05	0.26	1.24	1.50	-0.04	-0.13
Average accommodation size	-0.04	0.11	0.04	-0.88	-0.10	0.14	-0.40	-0.06	0.13	0.51	1.18	-0.02	-0.06
Density in the center	0.10	-0.10	-0.10	0.74	0.10	0.11	0.38	0.05	-0.26	-1.24	-1.50	0.04	0.13
Average distance to city center	0.43	0.46	-0.43	-1.06	-0.46	1.02	-1.59	-0.26	-0.99	-5.60	1.49	0.14	0.49
Average construction cost per sqm	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.56	-21.79	0.00	0.00	0.00

Supplementary Table 3: Sensitivity analysis. Elasticities of model outputs with respect to model inputs : in each cell is written the percentage of change of the quantity of y-axis when the quantity of x-axis varies by 1%.

4 Scenario and boundary conditions

This section describes the scenarios and boundary conditions used in this analysis.

The scenario we simulate is not in any way a forecast of future evolution of the Paris urban area. Instead, it represents a consistent and possible scenario, which can help understand main drivers of urban evolution and the impact of various policies.

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.

	Value in 2010	Low hypothesis for 2030	Central hypothesis for 2030	High hypothesis for 2030
Private vehicle usage cost (€/km)	7.1	5.8	7.6	9.8
Minimum monthly public transport pass price (€)	47.4	61.7	71.5	93.0
Households income (€/year)	51 000	78 000	89 000	91 000
Urban area population (number of households)	5 255 000	5 566 000	5 859 500	6 163 000

Supplementary Table 4: Techno-economic and demographic scenarios data

The evolution of the Paris urban area depends on several external factors, including demographic, socioeconomic, cultural, and political changes. The model thus requires input assumptions on these factors. To provide these inputs, we extrapolate the future costs of public transport and private vehicles (taking into account changes in technologies, oil prices, taxes, and so on) and of household incomes over the 2010-30 period based on the average growth rate in the Paris urban area between 1988 and 2008. We took future population and household sizes from the central demographic scenario for the Paris urban area developed by the Institut national de la statistique et des études économiques, the French statistical organization, and from the Institut d'aménagement et d'urbanisme, the urbanism agency for the Ile-de-France area. The data we used are listed in the "Central hypothesis for 2030" column of Sup. Tab.4.

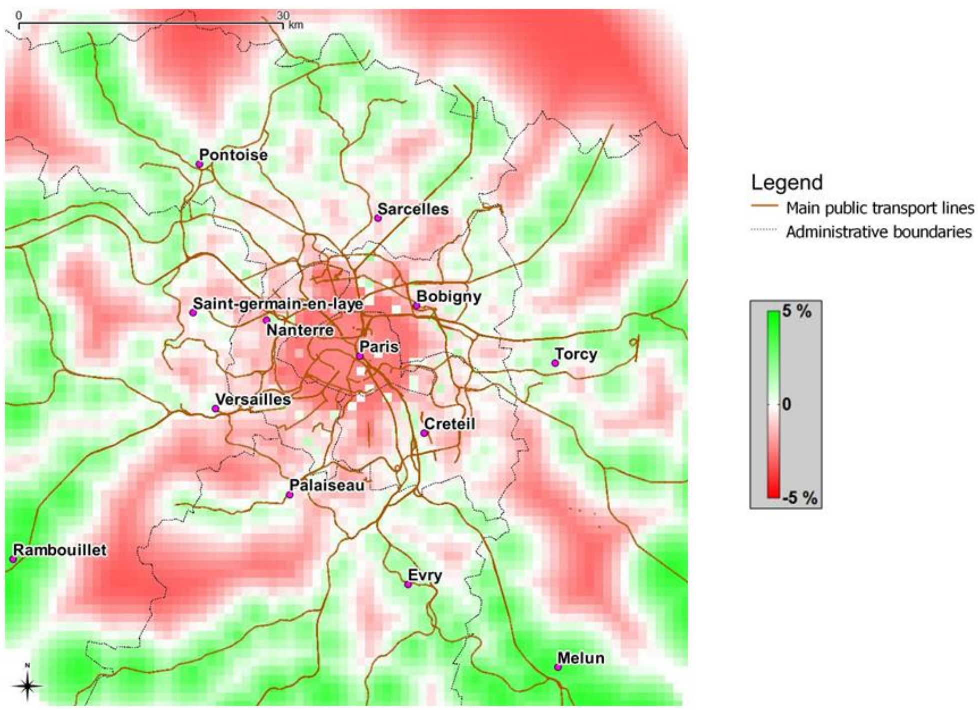
Indicators	Greenbelt	Public transport subsidy	Flood risk zoning	Policy mix	Do-nothing scenario
Variation in average daily distance driven in car (m)	+ 1570 *(90/ 3070)*	-440 *(-2140/ 900)*	+ 2550 *(290/ 4860)*	-880 *(-2180/ -70)*	+ 2560 *(290/ 4870)*
Variation in population in flood-prone areas (thousands of households)	+ 39 *(4/ 84)*	-4 *(-36/ 29)*	-6 *(-44/ 18)*	-8 *(-25/ 8)*	+ 6 *(-37/ 65)*
Variation in total urbanized area (km^2)	0 *(-30/ 0)*	+ 690 *(510/ 880)*	+ 470 *(90/ 750)*	0 *(-20/ 0)*	+ 480 *(80/ 760)*
Redistributive impacts (Gini index)	+ 0.093 *(0.043/ 0.131)*	+ 0.271 *(0.237/ 0.326)*	+ 0.201 *(0.049/ 0.273)*	+ 0.146 *(0.136/ 0.174)*	+ 0.203 *(0.042/ 0.275)*
Variation in dwelling size in the center of Paris (m^2)	+ 0.17 *(-1.47/ 1.17)*	+ 1.73 *(0.6/ 2.55)*	+ 0.79 *(-1.21/ 1.94)*	+ 0.95 *(-0.15/ 1.73)*	+ 0.82 *(-1.1/ 1.96)*

Supplementary Table 5: Multicriteria analysis of urban policies on Paris in 2030 with respect to the five policy goals. The numbers are the median value over all exogenous socio-economic scenarios (income, transport prices and technologies). The number in parenthesis are the extreme values when changing scenarios.

5 Results and sensitivity analysis

Supplementary Table 5 reproduces quantified results from the model, in the five scenarios (greenbelt policy, public transport policy, flood risk zoning, policy mix, and do-nothing scenario), for the five indicators.

Of course, the model provides more detailed information, and especially geographic information on the spatial impact of a given policy. For instance, the impact of the public transport subsidy on rents is shown in Sup. Fig. 9.

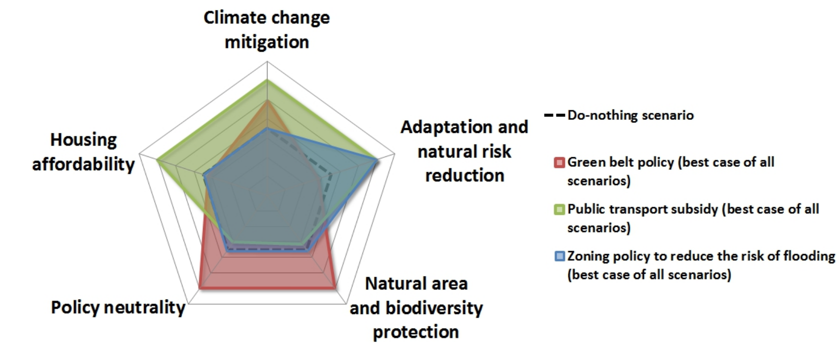


Supplementary Figure 9: Rents in the public transport subsidy scenario compared to rents in the "do-nothing" scenario.

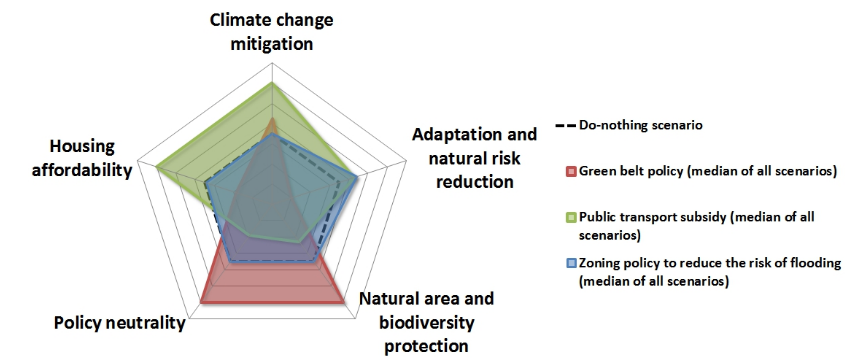
To test the sensitivity of our conclusions to the scenario choice, we computed 81 scenarios by letting our scenario parameters vary. Alternatives for public transport prices, private vehicle travel prices, and households income growth rate correspond to maximum and minimum observed growth rates (averaged over 5 years) in Paris urban area between 1988 and 2008.

Alternatives for population and household size growth are based on high and low demographic scenarios for Paris urban area developed by INSEE, the French statistical organization and IAU, Ile-de-France urbanism agency. Alternative scenario parameters are summarized in Sup. Tab.4.

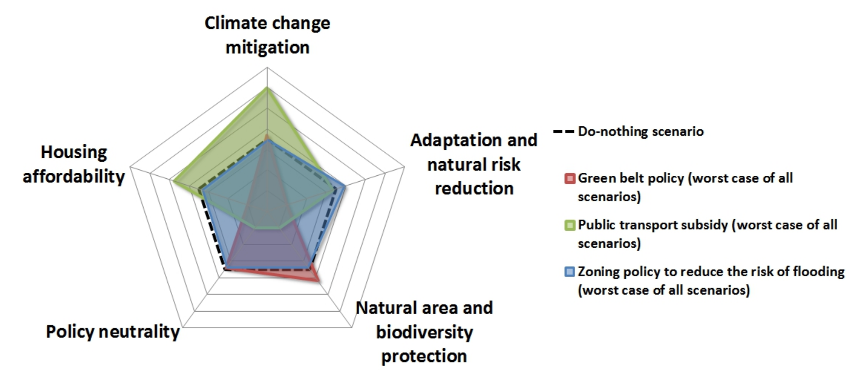
As can be seen on Sup. Tab. 5 and Sup. Fig. 10a, 10b and 10c, policies outcomes depend strongly on the selected world scenario. However, the relative impact of each policy for the different policy goals is not sensitive to this scenario choice, making the decision-making almost independent of this choice. The policy-mix improves the situation for all policy goals compared to the do-nothing policy in 65% of all scenarios. A policy-mix with a stronger transport subsidy or a private vehicle tax enables to increase this percentage.



(a) Best cases of all scenarios.



(b) Median of all scenarios



(c) Worst cases of all scenarios

Supplementary Figure 10: 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.

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