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Urban densification to support climate adaptation: Balancing costs and agglomeration benefits in the Netherlands

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Abstract

Where should we build new housing under growing climate hazards? This paper develops a framework that balances the economic benefits of density against the geographically varying costs of climate adaptation. We apply it to the Netherlands, where demand for new housing is high, but much of the land lies in floodplains or subsidence-prone areas. Agglomeration benefits are proxied by land values, while adaptation costs are derived from engineering estimates of flood protection and soil subsidence. Combining these data allows us to map spatial trade-offs and identify where development remains welfare-enhancing. Our findings show that dense cities continue to generate strong net welfare gains, even in places with high costs, while low-density settlements generate a welfare loss for new housing. We identify density thresholds above which housing development becomes feasible. Many medium-sized Dutch cities already exceed these thresholds, making densification more beneficial than peripheral expansion. Climate adaptation thus strengthens—rather than weakens—the case for urban densification.

Keywords: Housing development, Climate adaptation, Agglomeration effects, Land values, Urban density
JEL-classification: Q54, R11, R14, R31, R58

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1 Introduction

Climate change is driving up adaptation costs worldwide, creating new challenges for the functioning and planning of the built environment. Many urban areas are concentrated in coastal deltas and river valleys that are vulnerable to sea level rise and land subsidence. This is no coincidence: historically, waterways offered access to trade routes, which triggered powerful agglomeration forces that continue to shape the geography of cities today (Bleakley & Lin, 2012; Mustafa, 1998). While physical geographers increasingly consider retreat to safer ground as a rational and perhaps inevitable adaptation strategy (Hino et al., 2017; Siders, 2019), economic geographers stress that such strategies underestimate the increasing returns to density that characterize cities and act as engines of the welfare of nations (Van Ginkel et al., 2025; Van Haaren et al., 2023). In general, economic geographers and urban economists therefore tend to continue to advocate development in the most productive places (Glaeser et al., 2006; Hsieh & Moretti, 2019), despite the fact that these locations tend to be more exposed (Kocornik-Mina et al., 2020). Indeed, some evidence even suggests that deteriorating geographical conditions can coincide with increased urbanization (Castells-Quintana et al., 2021). These discussions call for a strong theoretical integration in economic geography (see, for example, Fields, 2018).

In this paper, we develop a framework that guides housing development by weighing the economic benefits of density against the geographically determined costs of climate adaptation. While climate adaptation encompasses a broad range of measures across multiple spatial scales, we focus specifically on adapting new housing development to the water and soil system. These costs vary strongly across locations due to differences in local geographical conditions, whereas other adaptation measures are typically less spatially dependent or not systematically quantified. At the core of our analysis lies a simple model of a city within an urban system, in which climate adaptation costs are integrated into a welfare function that weighs agglomeration benefits against costs as a function of density. We calibrate the model for the Netherlands—a particularly relevant case, given the country's rising demand for housing and the fact that much of its available land lies in floodplains or subsidence-prone areas. Empirically, we link agglomeration benefits—proxied by land values—to adaptation costs derived from engineering estimates of flood protection and land subsidence. This approach enables us to identify the spatial trade-offs between economic and physical geography and to assess where new housing development remains welfare-enhancing once adaptation costs are taken into account.

The existence of increasing returns to scale in urban development arises from the fact that dense clusters benefit from shared infrastructure and markets, matching between firms and workers, and localized knowledge spillovers from daily encounters (Duranton & Puga, 2004). They attract talent and amenities, cultivate openness to new ideas, and provide the buzz of city life, all of which make them magnets for human capital (Glaeser et al., 2001). These forces combine to turn cities into engines of growth and innovation (Glaeser, 2011; Jacobs, 1969). Crucially, history shows that such benefits often persist even in the face of extreme shocks. Cities destroyed by war or flooded by storms have been rebuilt in the same places, suggesting that the enduring benefits of density often outweigh severe disasters (Davis & Weinstein, 2002; Husby et al., 2014; Kocornik-Mina et al., 2020; Koster et al., 2012). The aftermath of Hurricane

Sandy in New York provides a vivid example. Subway tunnels flooded, power was cut to millions, and damage along the East Coast exceeded sixty billion dollars (Strauss et al., 2021). Yet New York's role as a global hub of finance and culture was never seriously questioned, and neither was its relocation; instead, attention turned to investments in sea walls, elevated parks, and flood-proofed buildings (Aerts et al., 2014).

Classical models of city size emphasize the balance of agglomeration benefits and urban externalities (Casetti, 1971; Duranton & Puga, 2004; Henderson, 1974). However, these frameworks rarely incorporate the additional costs of climate adaptation for new housing development. Moreover, while the benefits of agglomeration are inherently linked to density, the relationship is more complex for climate adaptation. Denser places may require higher levels of protection to keep economic activity safe, but they also benefit from economies of scale by spreading the protection costs among more people. Density and adaptation costs may also coincide because dense cities often situate close to rivers and seas, but this reflects historical location choices rather than an intrinsic economic mechanism. The question of how climate adaptation costs affect the existing balance between agglomeration benefits and costs is therefore highly context-specific. The framework developed in this paper offers guidance for mapping the density-cost relationship at the country or regional level, allowing a more precise evaluation of where urban development remains economically feasible.

Our results for the Netherlands show that, while the benefits of agglomeration increase with density, adaptation costs correlate primarily with geography and only modestly with density. As a result, even in exposed locations, dense cities can generate net welfare gains large enough to justify substantial investments in climate adaptation. At the same time, our analysis also identifies areas where new development is no longer economically viable. In these cases, the costs of adaptation outweigh the benefits of density, allowing us to derive a minimum density threshold required for long-term feasible construction under current climate scenarios (see Section 5). Limiting development in high-density but exposed areas may therefore lead to spatial misallocation. Adaptation policies should therefore account for both the persistent economic rationale of urban concentration and the density levels below which adaptive development is no longer feasible.

The remainder of the paper proceeds as follows. Section 2 develops the theoretical model that integrates agglomeration benefits and adaptation costs. Section 3 presents the empirical strategy and data. Section 4 shows the estimations of agglomeration benefits across the Netherlands, and where housing development remains feasible. Section 5 estimates the parameters of our theoretical model and derives the density thresholds. Section 6 situates these findings in broader debates on adaptation strategies and spatial planning, and concludes.

2 Theoretical model

The spatial distribution of population and organization of economic activity has always involved a trade-off between the benefits of agglomeration and the costs of concentration. Many cities emerged in coastal deltas and along major rivers, where water provided access to trade routes and enabled dense settlements (Bleakley & Lin, 2012). These same areas are now increasingly being exposed to climate hazards (Kocornik-Mina et al., 2020). To make this tension explicit, we develop a simple model that combines economic and geographical forces in the spirit of the classic urban systems model by Henderson (1974), further developed by many authors in the field of economic geography and urban economics, including Duranton and Puga (2004), Duranton (2008), and Brinkman (2016). Unlike these contributions, which focus on explaining differences in (optimal) city size in terms of population, we focus on population density as the key variable because our interest lies in how the spatial distribution of water and soil adaptation costs affects the economically viable distribution of population density.

Agglomeration benefits are widely understood to increase with city size or density (Duranton & Puga, 2004). Three main mechanisms are generally considered to drive these increasing returns. First, larger cities enable sharing of indivisible facilities, risks, and gains from variety and specialization—making it easier to recover fixed costs of infrastructure or specialized services. Second, they allow for better matching between employers and employees, buyers and suppliers, or entrepreneurs and financiers, raising both the probability and the quality of productive matches. Third, dense settings accelerate learning and knowledge spillovers by fostering frequent face-to-face interactions. This typology focuses on how agglomeration economies arise (sharing, matching, learning) and complements the classic Marshallian "trinity" of labor pooling, input-output linkages, and knowledge spillovers (Marshall, 1890).

Agglomeration also generates costs. As cities grow, congestion, commuting times, housing prices, retail prices, and other non-tradable consumption costs rise, while negative externalities such as noise and pollution intensify (Brinkman, 2016; Broersma & Van Dijk, 2008; De Groot et al., 2010). These urban costs tend to increase convexly with density (Ahlfeldt et al., 2015; Combes et al., 2019; Duranton & Puga, 2023). Climate adaptation adds a third category of costs that are primarily geographical rather than density-driven. Places located near rivers or coasts, or on weak soils, require protective measures to remain habitable (Erkens et al., 2016; Giovannettone et al., 2018). While some adaptation costs may exhibit scale economies, many are largely fixed by local geography. We formalize this intuition as follows. Agglomeration benefits are increasing and convex in density, reflecting the presence of agglomeration externalities even at low density levels:

$$B(d) = \alpha d + \beta d^2, \quad \text{with } \alpha > 0 \text{ and } \beta > 0 \tag{1}$$

Agglomeration costs start with fixed costs f, as some basic infrastructure (roads, utility cables, and sewage) is always required. There is also a component that captures the negative externalities, which rises convexly with density, which is low at low densities:

$$C_u(d) = f + \gamma d^2, \quad \text{with } \gamma > \beta > 0 \tag{2}$$

The costs of climate adaptation are location-specific and driven by exogenous geographic conditions κ that may scale with density d:

$$C_a(d) = \kappa \pm qd, \quad \text{with } \kappa \geq 0 \text{ and } q > 0 \tag{3}$$

With + and − representing increasing and decreasing adaptation costs in relation to density, respectively. Net welfare W (net benefits) is then given by:

$$W(d) = B(d) - C_u(d) - C_a(d) = (\alpha \pm q)d + (\beta - \gamma)d^2 - f - \kappa \tag{4}$$

The first-order condition (FOC) for an interior optimum is:

$$\frac{\partial W}{\partial d} = \alpha \pm q + 2(\beta - \gamma)d \tag{5}$$

Setting $\frac{\partial W}{\partial d} = 0$ yields the optimal density:

$$d^* = \frac{\alpha \pm q}{2(\gamma - \beta)}, \quad \text{with } \gamma > \beta,\ q < \alpha \tag{6}$$

with $\gamma > \beta$ ensuring $d^* > 0$. The second-order condition (SOC) is:

$$\frac{\partial^2 W}{\partial d^2} = 2(\beta - \gamma) < 0 \quad \text{since } \gamma > \beta \tag{7}$$

This result confirms that d^* is a unique maximum and that $W(d)$ has an inverted-U (bell-shaped) profile. Agglomeration benefits dominate the agglomeration costs at low density, but the reverse occurs beyond d^*. The maximum welfare associated with optimal density d^* is:

$$W(d^*) = \frac{(\alpha \pm q)^2}{4(\gamma - \beta)} - f - \kappa \tag{8}$$

Equation 8 shows that local variation in economic fundamentals (α, β, γ), fixed cost f, geography (κ), and scale economies in density for the costs of climate adaptation q jointly determine both the optimal density and whether development is viable (W(d*) > 0). Development is economically viable when $W(d^*) > 0$, which requires:

$$\kappa < \frac{(\alpha \pm q)^2}{4(\gamma - \beta)} - f \tag{9}$$

If κ exceeds this viability threshold at a certain location, even the optimum d^* does not deliver positive net benefits, implying no welfare-enhancing development at that location. By shifting the entire welfare curve downward, adaptation costs C_a limit the feasible density range. Comparative statics (cross-location shifts) then yield that locations with high agglomeration potential (high α, β) and low crowding costs (low γ) or adaptation costs (low κ) can sustain higher densities, whereas places with low productivity fundamentals or high adaptation costs will fall below the viability threshold. More precisely, the term $4(\gamma - \beta)$ in Equation 9 represents the adaptation capacity of a location: the greater the benefit-cost margin of agglomeration ($\frac{\beta}{\gamma}$), the higher the level of climate adaptation costs that can be absorbed without undermining the location's economic viability. Put differently, adaptation costs pose a more serious threat to the economic sustainability of a location when the agglomeration benefits are relatively small compared to its agglomeration costs.

This simple framework thus links the economic geography of urban concentration with the geography of climate adaptation. In summary, its structure yields three key insights. First, development becomes viable only above a minimum density, where agglomeration benefits outweigh crowding and adaptation costs. Second, net benefits peak at an interior optimum d^*. Third, beyond a maximum density, negative externalities outweigh further gains. Figure 1 illustrates these equilibria with and without adaptation costs. Panel (a) shows the baseline case where net benefits form an inverted U, without any adaptation costs. The first equilibrium (I) is unstable. A lower density yields a loss as the fixed costs of infrastructure outweigh the agglomeration benefits. Beyond the minimum density, the net benefits increase with density. The city will attract more people and firms and require higher densities as the benefits increase until the new equilibrium (II). This is the maximum welfare where the difference between agglomeration benefits and costs is maximized. This is also an unstable equilibrium as more people and firms are moving into the city, because the net benefits remain positive. Although agglomeration costs rise faster than the benefits at this point, the city will continue to expand until the stable equilibrium (III), where the agglomeration benefits equal the costs. This is the maximum density the city will reach, and at which it remains.

Panel (b) introduces adaptation costs that do not vary with density (assuming $q = 0$). This raises the minimum density needed for viable development but does not change the optimal density. The maximum density is lower, meaning a less dense city compared to the baseline. Panels (c) and (d) extend the baseline model by allowing the adaptation costs to vary with density—either increasing or decreasing—rather than assuming they are constant. In panel (b), adaptation costs were treated as fixed across density levels because they stem from exogenous geographic conditions. In practice, however, these costs may co-vary with density, not through direct causation but through historical correlation: cities that concentrated early in deltas or floodplains often exhibit both high density and elevated exposure, and thus face higher adaptation costs today—implying a positive correlation between density and adaptation costs. In contrast, adaptation costs may also decrease linearly with density, for example, due to scale economies in shared defenses against floods. Thus, decreasing costs result in a larger feasible density at which development becomes feasible, and a larger stable maximum density. The opposite is true for increasing costs.

In sum, if adaptation costs increase in density, the area for viable development shrinks. In the opposite case, development remains feasible even for high geographically determined costs κ. We empirically test this model using data for the Dutch context. We use land values as a proxy for agglomeration benefits, combine these with spatially explicit estimates of adaptation costs, examine how these costs correlate with density, and derive net benefits as a function of density to identify where new urban development generates positive welfare effects.

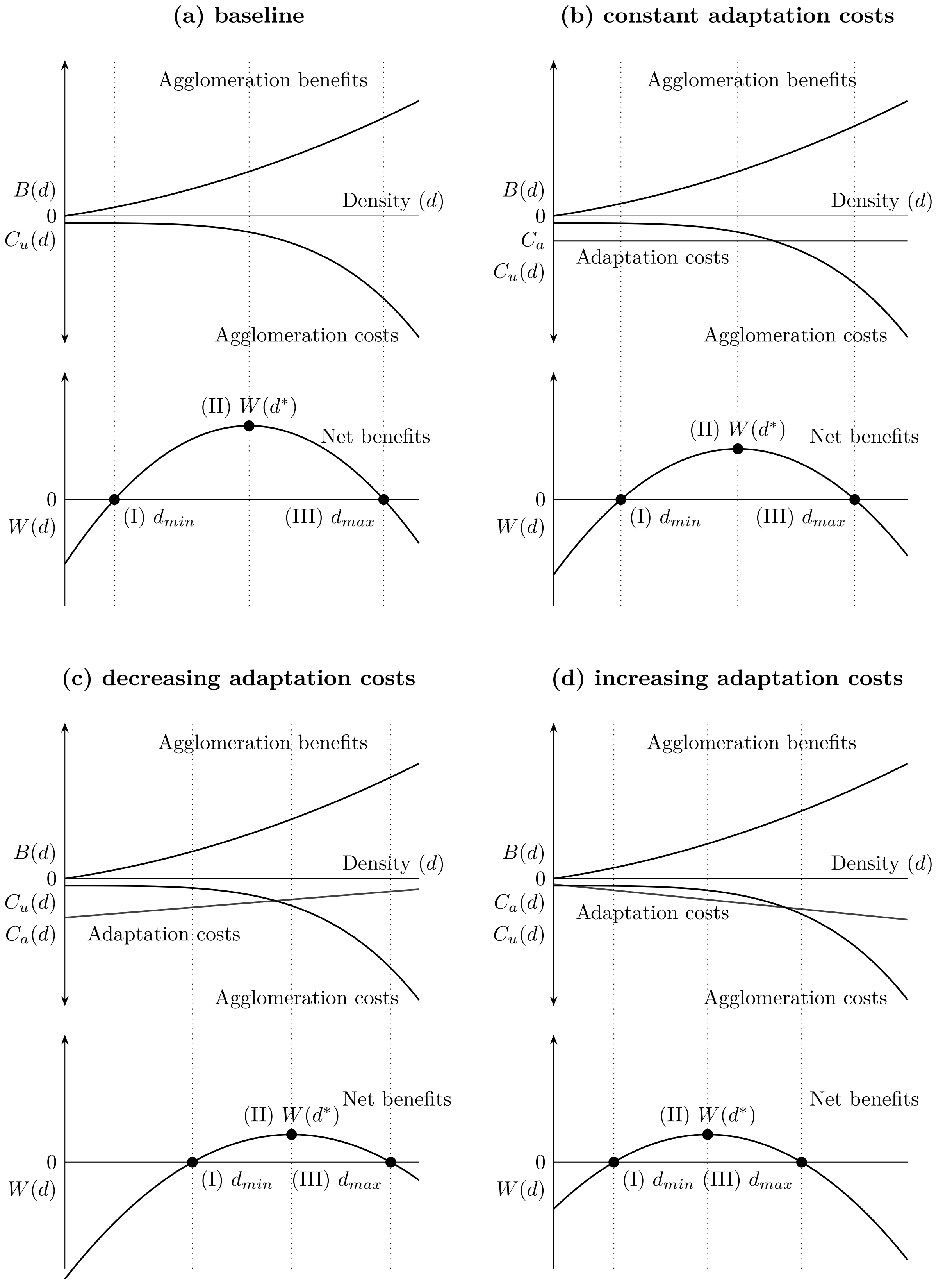

Figure 1: Theoretical model: agglomeration benefits, agglomeration costs, and adaptation costs as functions of urban density (the vertical scale in the lower panels is not the same as in the upper panels).

3 Methodology & data

3.1 Empirical strategy

In this section, we translate the theoretical model into an empirical framework, which we apply to the Netherlands. We first show how land values can be used to capture both agglomeration benefits and urban externalities, and outline the hedonic pricing approach we use to estimate neighborhood-level land values from housing transactions. We then estimate adaptation costs by linking engineering-based measures for flood and subsidence protection to geographical characteristics such as distance to water, elevation, and soil type, and allow these costs to vary with density. Finally, we combine the estimated parameters of the land values and adaptation costs in the welfare function (Equation 4) to identify where development remains viable and how density and geography jointly affect the minimum density threshold for economically feasible housing development. In doing so, our empirical strategy adopts a cross-city perspective on the stylized theoretical model of a city within an urban system, as our focus is on the spatial relationship between net agglomeration benefits and adaptation costs across locations rather than within a single city.

Agglomeration benefits are commonly measured through urban wage premia, labor productivity, or land values (Combes et al., 2011, 2019; Duranton & Puga, 2004). Following the approach of De Groot (2011) and De Groot et al. (2010), we use land values as a proxy for net agglomeration benefits. This approach is rooted in classical urban theory: David Ricardo argued that land becomes more valuable where productivity is higher, while William Alonso (1964) formalized how urban wage premiums are capitalized into higher land prices, as households trade off commuting costs and housing costs across space. In spatial equilibrium, differences in land values across locations thus reflect productivity differences across locations.

Land values are particularly suitable for our framework for two reasons. First, they provide a spatially detailed measure of the net effect of agglomeration forces at the neighborhood level. Negative urban externalities such as congestion, crime, or pollution are already implicitly capitalized into prices—meaning land values reflect the balance between agglomeration benefits and costs (De Groot et al., 2010; Vermeulen et al., 2016). We thus assume that land values LV capture the sum $B(d) - C_u(d)$ in the welfare function (Equation 4). Second, land values are directly expressed in monetary terms, which makes them comparable to our square-meter-based estimates of adaptation costs. One caveat is that markets may internalize expected climate damage into house prices and thus land values. Evidence from the Netherlands, however, suggests that buyers discount some—but not all—expected flood or subsidence damage when sufficiently aware (Daniel et al., 2009; Premchand et al., 2024). Apart from this partial effect, it is noted that the costs of damage are different from the costs of protective measures in our analysis. Hence, in our empirical strategy, we treat land values as a proxy for net agglomeration benefits, which is different from the adaptation costs $C_a(d)$ (the final term in Equation 4).

Importantly, land values are not directly observed because non-agricultural land is almost never sold separately from the buildings on top of it. We therefore retrieve implicit land values from over one million house transaction records using a hedonic pricing approach, in which we isolate the price of land from the total house price (De Groot, 2011):

$$\ln P_{ijt} = \alpha + \sum_{j=1}^{J} \beta_j \ln L_{ijt} + \sum_{k=1}^{K} \psi_k X_{ijt}^k + \sum_{t=2015}^{T} \delta_t D_t + \varepsilon_{ijt} \tag{10}$$

where P is the transaction price of house i in neighborhood j at time t, and L is the lot size. The coefficient β_j is the marginal effect of land on the transaction price, after controlling for k number of structural attributes X (type, year of construction, floor space) and time-fixed effects D. Following De Groot (2011), β_j simultaneously represents the share of land in the transaction price: $\frac{\partial \ln P_{ijt}}{\partial \ln L_{ijt}} = \beta_j = \frac{L_{ijt}}{P_{ijt}} \times \frac{\partial P_{ijt}}{\partial L_{ijt}}$. From this, we can calculate the land value LV_j per m^2 at the neighborhood level by multiplying β_j with the transaction price divided by the total lot size of a house:

$$LV_j = \beta_j \times \frac{P_{ijt}}{L_{ijt}} \tag{11}$$

Once we have obtained the land value, we can estimate the parameters of Equation 4 of the theoretical model in two steps. First, using a reduced form of the welfare function (Equation 4) in which net agglomeration benefits are captured by $\rho \equiv (\beta - \gamma)$, we regress land values on density:

$$LV_j = \lambda + \alpha d_j + \rho d_j^2 + \epsilon_j \tag{12}$$

The term λ represents the intercept that captures everything else not related to density, including the fixed costs f of our theoretical model. We impose $\alpha > 0$ and $\rho < 0$, implying an inverted-U shape of net benefits with respect to density. Second, we estimate the adaptation costs κ, while not knowing a priori how adaptation costs $C_a(d)$ scale with density, such that $C_a(d)$ can be $\kappa \pm qd$ in:

$$\kappa_j = qd_j + \epsilon_j \tag{13}$$

Next, we elaborate upon this specification by identifying adaptation costs as a function of geographical characteristics, including distance to primary water, elevation, and soil types s (consisting of peat, clay/peat, clay, and a category for all other soil types), as follows:

$$\kappa_j = qd_j + \phi_1 \textit{distance to water}_j - \phi_2 \textit{elevation}_j + \sum_s \phi_s \textit{soil}_{js} + \epsilon_j \tag{16'}$$

We expect costs to decline with distance to water and elevation, and to be higher on weak peat soils (Erkens et al., 2016; Giovannettone et al., 2018). In case q is statistically significant ($q \neq 0$), adaptation costs systematically vary with density.

Finally, we use the estimated parameters to derive the minimum and maximum density $d_{min/max}$ where housing development remains economically feasible under climate adaptation costs, by setting Equation 4 to 0 and solving for d (using the discriminant rule). We leave out the fixed costs f, as this has already been absorbed in the constant λ of Equation 12:

$$d_{min/max}(\kappa) = \frac{(q - \alpha) \pm \sqrt{(\alpha - q)^2 + 4\rho\kappa}}{2\rho} \tag{14}$$

This shows that if $\rho > 0$ only a minimum density exists, and if $\rho < 0$ both a minimum and maximum density exist. Stronger agglomeration benefits α lower the minimum (and raise the maximum). If the costs decrease with density due to scaling effects q, this lowers the minimum density (and increases the maximum density). Both the minimum and maximum density depend fully on the adaptation costs. When $\kappa = 0$, the minimum density for viable development is also 0.

3.2 Data

We use two main sources of data: housing transactions to estimate land values and engineering studies to estimate climate adaptation costs. Land values are derived from microdata on housing transactions provided by the Dutch Association of House Brokers (NVM), covering about 70% of all transactions between 2000 and 2023. The dataset includes house characteristics such as size, type, and rooms. For apartments, we allocate the lot size proportionally, since they share the building lot. All prices are deflated using the consumer price index from Statistics Netherlands (CBS), ensuring year-fixed effects capture only business-cycle and market-specific trends. Land values are estimated with a hedonic pricing model, following De Groot (2011).

Adaptation costs focus on the two hazards used in the assessment framework of EIB (2025) that guides new housing development as set by the Dutch government: floods and land subsidence. Flood hazards are taken from the Klimaateffectatlas, defined as the probability of flooding with a depth of at least 20 cm, based on the current climate scenario. Land subsidence is modeled by TNO Geological Survey and defined as settlement after preloading soil with one meter of sand—a measure that minimizes future subsidence and maintenance costs for the year 2050 (Booister et al., 2021). Both datasets are available at a 100 × 100 meter resolution.

We distinguish between dwelling-level and regional-level costs. Dwelling-level measures include check valves, breakwater bulkheads, watertight facades, and preloading soil. Costs are derived from EIB (2025) for a representative single-family house of 89 m^2 and converted to a per-m^2 basis (Appendix A). Other housing types were not included in the EIB (2025) report, but they state that the costs of apartments are lower. Therefore, the costs are an overestimation for dense cities, where apartments usually dominate the housing stock. Table 1 shows costs increasing with hazard class; each hazard class requires protection against different water depths, ranging from 0.5 to 1.5 meters. Regional-level costs concern reinforcements of dikes, dunes, and storm surge barriers, based on official engineering estimates of additional investments required by 2050 (Appendix B). The costs mostly relate to current climate scenarios. Depending on how climate change evolves, these costs may increase when climate change becomes more severe. To give some insights into this, we perform several robustness checks with various cost increase factors.

Table 1: Costs per m² by climate hazard class (EIB, 2025).

Flood (>20 cm water)		Land Subsidence (1 m preloading)	
Chance (1/year)	€/m²	Range (cm)	€/m²
Never	0.00	<5	0.00
>1/30,000	0.00	5–30	44.94
1/30,000–1/3,000	30.34	30–60	78.65
1/3,000–1/300	86.52	60–90	112.36
1/300–1/30	132.58	>90	224.72
<1/30	132.58		

Table 2 summarizes the main variables. Density varies widely across the Netherlands: some Randstad neighborhoods exceed 10,000 people/km², while rural areas approach zero. Land values show similar variation. Adaptation costs are bimodally distributed: many regions face either substantial costs or none at all. Appendix C documents the spatial variation.

Table 2: Summary statistics of main variables at the neighborhood level ($N = 3352$).

Variable	Mean	SD	Median	Min	Max
Density (people/km²)	2144.114	3369.739	427.000	1.000	27 607.000
Land value (€/m²)	338.737	536.432	191.756	2.932	7623.510
Net benefits (€/m²)	223.000	545.342	87.483	−354.120	7573.357
Costs (€/m²)	104.823	85.059	88.609	0.000	393.197
Distance to water (km)	11.488	12.264	6.968	0.000	63.980
Elevation (m)	10.433	20.664	3.509	−5.833	213.255
Clay (=1)	0.062	0.241	0.000	0.000	1.000
Clay/peat (=1)	0.118	0.323	0.000	0.000	1.000
Peat (=1)	0.017	0.129	0.000	0.000	1.000

Figure 2 maps flood and subsidence hazards. High flood hazards are concentrated along rivers, with some areas facing events within 30 years. Much of the western Netherlands also faces substantial flood hazard, with return periods of 30–300 years. Subsidence clusters in the same region. The highest adaptation costs per m² occur in the west, along rivers, in the province of Zeeland, and in the northern part of the country, often in low-density open areas surrounding major cities such as Amsterdam, Haarlem, Leiden, and The Hague.

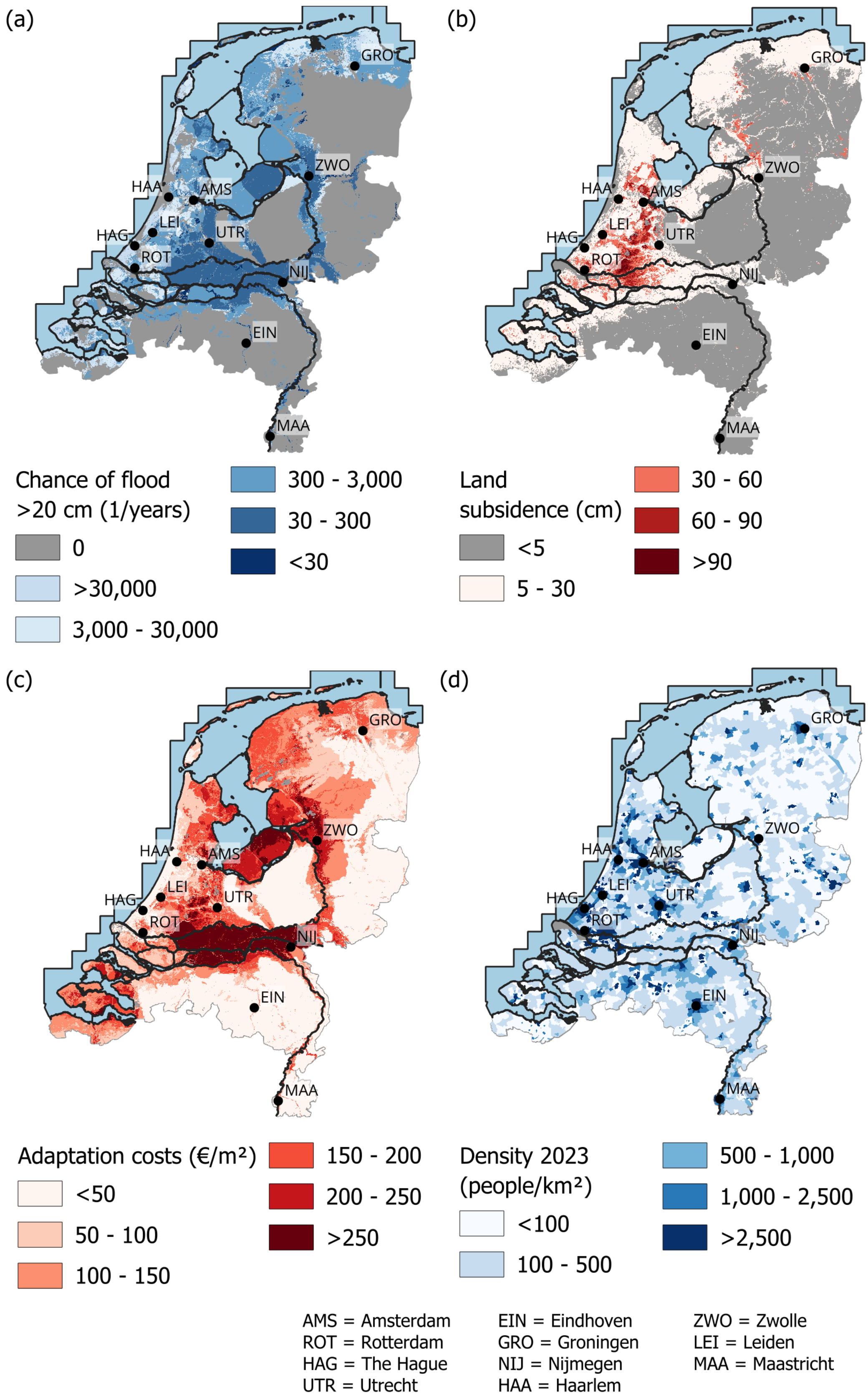

Figure 2: Climate hazards, adaptation costs, and density in the Netherlands.

4 Agglomeration benefits and land values

This section presents the results of estimating agglomeration benefits and shows how these weigh against the geographically determined costs of climate adaptation. Figure 3 conceptualizes this trade-off space by classifying locations into four quadrants based on their density and adaptation costs: high-density/high-cost (I), low-density/high-cost (II), low-density/low-cost (III), and high-density/low-cost (IV).

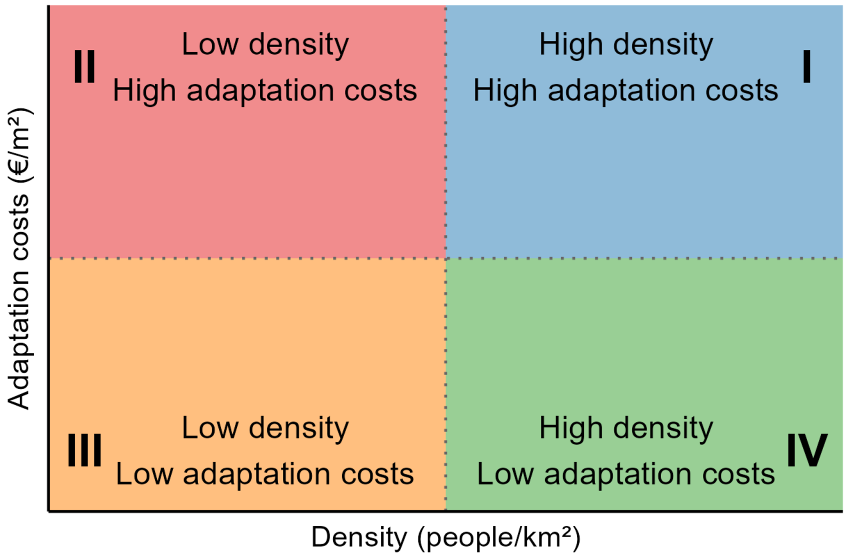

Figure 3: Quadrants for urban density and adaptation costs.

In Quadrant I, dense cities face high adaptation costs but can still yield positive net benefits if density-driven agglomeration gains outweigh those costs—think of large cities along rivers. Quadrant II combines low density with high costs, where the absence of strong agglomeration effects usually makes development unviable. Quadrant III represents low-density, low-cost areas that may support development, though with limited economic potential. Quadrant IV is the sweet spot of high density and low costs, where strong agglomeration benefits combine with modest adaptation expenses.

Figure 4 translates this trade-off to the map of the Netherlands, classifying locations by high/low density and high/low adaptation costs—high/low values are split at the median. It shows that red areas with low density and high costs typically cluster around the major rivers and the coast. In contrast, green locations featuring high-density and low-costs typically include the economically most powerful urban centers such as Amsterdam and Eindhoven. The trade-off between agglomeration benefits and adaptation costs is most evident in the orange and blue areas. In low-cost regions, development remains viable even at relatively modest densities, since limited agglomeration benefits are offset by the low expense of adaptation. More interestingly, several high-density yet high-cost cities—such as Utrecht, The Hague, and Groningen—continue to appear attractive for new housing development, as density-driven gains can outweigh substantial adaptation costs. High adaptation costs, therefore, do not in themselves preclude viable development. What matters is the joint configuration of density and geography: a dense but exposed city can still generate higher welfare than a sparse but geographically safer settlement.

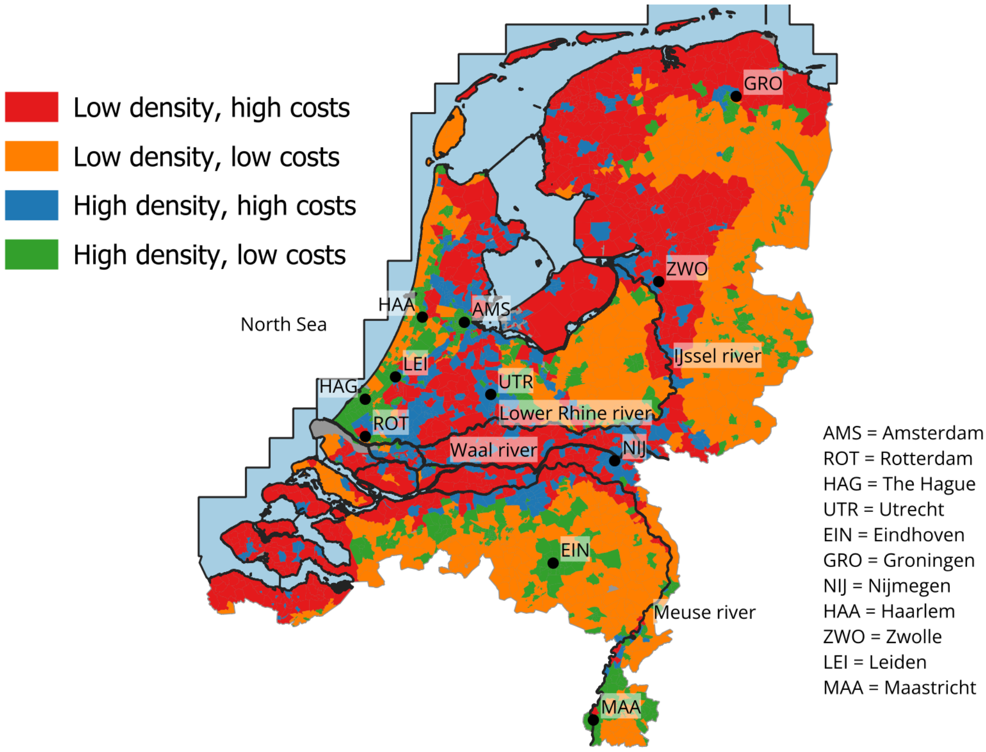

Figure 4: Quadrants split by median urban density and adaptation costs.

The scatterplot in Figure 5 further illustrates the central role of density. At the neighborhood level, they show how net agglomeration benefits—measured as land values corrected for climate adaptation costs (cf. Equation 4)—relate to density. As expected, many low-density, high-cost neighborhoods generate negative net benefits, as do some low-density, low-cost areas. These negative benefits imply that a project developer would make a loss or would require subsidies to break even. More revealing, however, is that certain high-density, high-cost neighborhoods also exhibit negative net benefits. Despite relatively high densities (between 500 and 1000 people per km^2), these places fail to produce sufficiently strong agglomeration effects to compensate for adaptation costs, presumably due to peripheral locations or reliance on declining industries. By contrast, the highest net benefits are found in high-density, low-cost neighborhoods and in larger cities where robust agglomeration effects more than compensate for substantial adaptation costs.

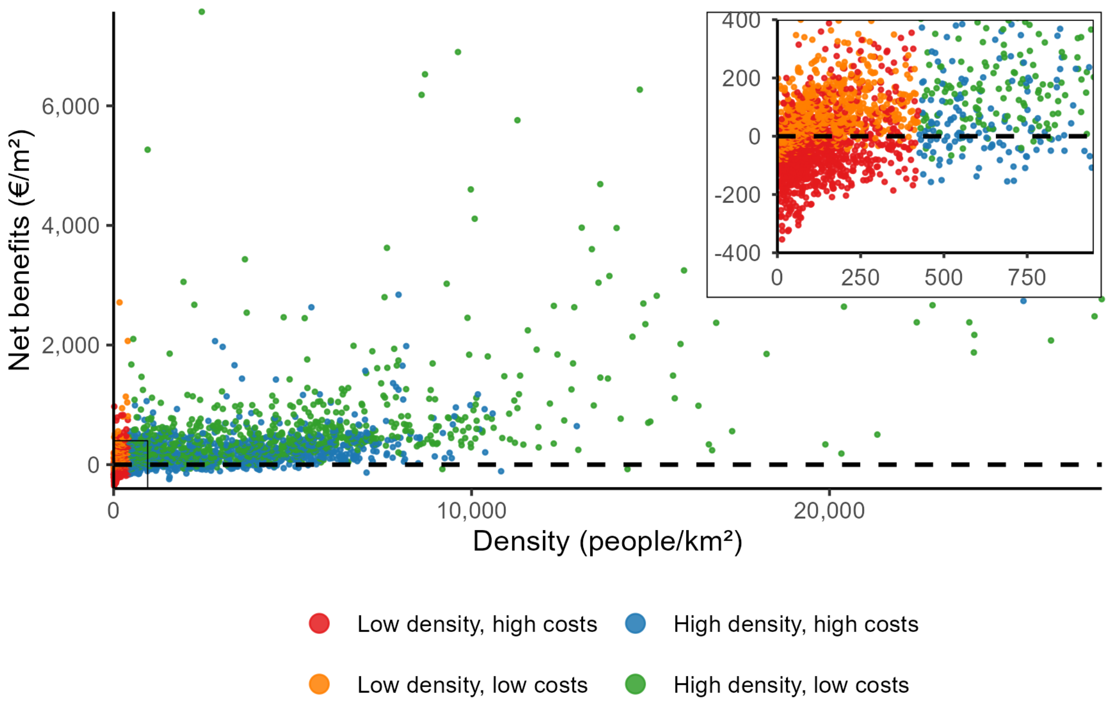

Figure 5: Urban density and net benefits by quadrants.

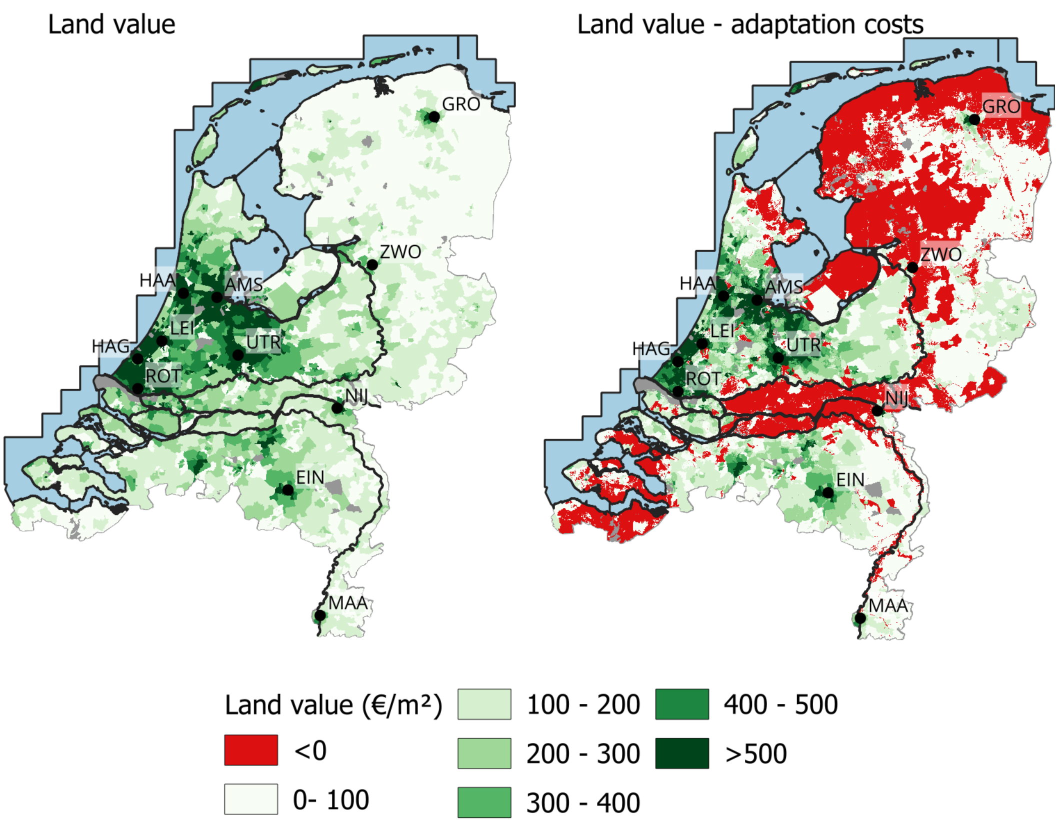

Figure 6: Left: land value ($B(d) - C_u(d)$). Right: welfare effect after subtracting adaptation costs from land value ($B(d) - C_u(d) - C_a(d)$).

Figure 6 illustrates how the trade-off plays out geographically by mapping the spatial distribution of gross and net agglomeration benefits, measured as land values over the period 2015—2023, before and after correcting for climate adaptation costs. As expected, the highest land values—exceeding €500/m^2—are concentrated in the urbanized western Randstad area (Amsterdam, Utrecht, The Hague, Haarlem). Outside the Randstad, cities such as Eindhoven, Groningen, and Nijmegen also stand out, while rural and peripheral regions display substantially lower land values. Appendix D documents how this contrast has widened over time, with land values rising sharply in dense cities while peripheral areas lag behind.

Net benefits follow a similar pattern. After subtracting adaptation costs, corrected land values remain highest in the dense urban cores of the Randstad, whereas highly exposed peripheral regions—such as Zeeland in the southwest and the northern provinces—yield the most negative outcomes. Notably, the maps also confirm negative net benefits in certain high-density, high-cost towns, including Terneuzen, Lelystad, and Gorinchem. As noted earlier, despite their density, these places fail to generate agglomeration effects strong enough to offset adaptation costs.

A key assumption underlying these results is that adaptation costs are not fully capitalized into land values. Evidence for the Netherlands, however, suggests that homebuyers do account for part of the expected damage when sufficiently aware (Daniel et al., 2009; Premchand et al., 2024). The outcomes also critically depend on the assumed level of adaptation costs. Figure 7 therefore maps recalculated net agglomeration benefits under two capitalization rates and under different multipliers of adaptation costs. The upper panel shows that higher capitalization rates reduce the share of land area with negative land values, although the northern provinces and scattered peripheral neighborhoods continue to yield negative outcomes. The lower panel demonstrates that when adaptation costs are doubled, most regions along rivers and in the north turn negative, while at fivefold costs, only the largest and densest cities in the western Randstad (Amsterdam, The Hague, Haarlem) remain economically viable regions to construct new dwellings.

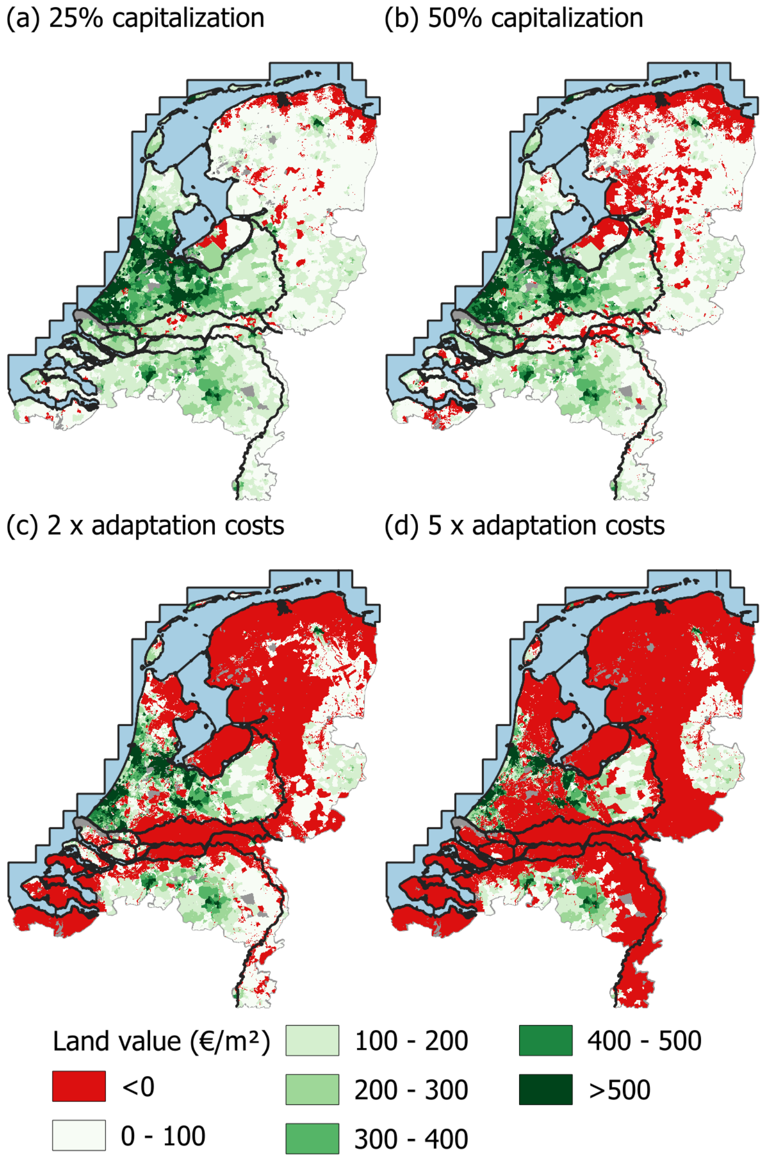

Figure 7: Net benefits under different scenarios: part of the adaptation costs already capitalized, and cost increases.

5 Economic viability of housing development

In this section, we calibrate the parameters of the theoretical model developed in Section 2 using our empirical estimates. This allows us to identify density thresholds for economically viable urban development under different adaptation cost scenarios. From these thresholds, we derive simple rules of thumb to guide housing development, linking economic feasibility not only to density but also to geographical conditions such as distance to water, elevation, and soil type.

We first estimate how density shapes land values (Table 3; Appendix E shows correlations between variables). Column (1) presents the linear specification, where each additional person per km² in a neighborhood raises the land value (agglomeration benefits) by €0.098/m² (for instance, via higher local productivity and knowledge spillovers). Column (2) introduces a quadratic term to test for an inverted U-shape. The linear effect decreases slightly ($\alpha = 0.078$), while the quadratic term turns out positive ($\rho = 0.000001$). This implies that, unlike the prediction of the theoretical model, land values in the Netherlands do not decline at higher densities. Instead, they follow a weakly convex pattern that is in practice close to linear, given the small magnitude of ρ. Columns (3) and (4) repeat the analysis at the municipality level, where agglomeration effects are likely to be most pronounced. Results are consistent: the preferred specification in column (4) shows a lower α but a higher ρ, suggesting that the convexity is somewhat stronger at this scale. Overall, the estimates reinforce earlier findings by De Groot et al. (2010), and point to a near-linear, rather than hump-shaped, relationship between density and land values in the Dutch context.

Table 3: Estimating land value as a function of density.

	Neighborhood level		Municipality level	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS
Dependent variable	Land value	Land value	Land value	Land value
Density (α)	0.098***	0.078***	0.103***	0.028*
	(0.002)	(0.004)	(0.006)	(0.013)
Density^2 (ρ)		0.000 001***		0.000 013***
		(0.000000)		(0.000001)
Intercept	125.195***	145.746***	131.915***	180.225***
	(8.793)	(9.537)	(13.120)	(14.630)
R^2	0.384	0.390	0.469	0.525
Observations	3241	3241	342	342

Note: Standard errors in parentheses. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Next, we estimate how geographical characteristics influence climate adaptation costs, as reported in Table 4. Overall, adaptation costs rise with unfavorable geographical conditions. Column (1) shows that adaptation costs are modestly correlated with density, with each additional person per km^2 associated with €0.003/m^2 lower adaptation costs. Columns (2)–(6) disentangle the effects of individual geographical variables. Our preferred specification, column (6), regresses adaptation costs on all geographical characteristics together, including the scaling parameter q to capture potential scale economies of density.

The estimates highlight several consistent patterns. First, proximity to primary water bodies substantially increases costs: every additional kilometer of distance from water lowers adaptation costs by €2.87/m^2. Second, elevation matters: each extra meter above sea level reduces costs by €0.93/m^2. Third, soil quality strongly affects outcomes. Neighborhoods dominated by peat soils—the weakest soil type—incur an additional €111.23/m^2 in adaptation costs, while mixed clay-peat soils add €40.78/m^2. By contrast, the effect of clay soils is statistically insignificant, suggesting no systematic additional costs relative to the reference category (which are all other soil types). Finally, the density parameter reinforces these results. In column (6), we find $q = -0.006$, indicating that higher population densities slightly reduce adaptation costs. This effect is even stronger than in column (1), underscoring the modest but consistent scale economies of density in climate adaptation.

Table 4: Geographic determinants of costs (neighborhood level).

Dependent variable	(1) OLS Costs	(2) OLS Costs	(3) OLS Costs	(4) OLS Costs	(5) OLS Costs	(6) OLS Costs	(7) OLS Costs
Density (q)	-0.003^{***}						-0.006^{***}
	(0.000)						(0.000)
Dist. water (km) (W)		-3.219^{***}					-2.870^{***}
		(0.106)					(0.101)
Elevation (m) (E)			-1.431^{***}				-0.933^{***}
			(0.067)				(0.059)
Peat (= 1) (P)				109.447^{***}			111.231^{***}
				(11.207)			(9.281)
Clay/peat (= 1) (CP)					61.422^{***}		40.783^{***}
					(4.422)		(3.802)
Clay (= 1) (C)						23.600^{***}	7.749
						(6.091)	(4.987)
Intercept	111.402^{***}	141.803^{***}	119.752^{***}	102.961^{***}	97.548^{***}	103.365^{***}	153.394^{***}
	(1.739)	(1.783)	(1.543)	(1.461)	(1.522)	(1.514)	(2.097)
R^2	0.016	0.215	0.121	0.028	0.054	0.004	0.368
Observations	3311	3352	3352	3352	3352	3352	3311

Note: Standard errors in parentheses. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Our parameter estimates for the Netherlands yield several insights. First, the small but positive estimate for ρ suggests that land values rise convexly with density. This implies that no interior optimum exists: in the Dutch context, higher density is consistently associated with greater agglomeration benefits. Panel (a) of Figure 8 illustrates this analytically. Adaptation costs also show a slight correlation with density, as displayed in panels (a) and (b) for different levels of κ. The lower panes combine both elements to show net welfare effects. Panel (a) illustrates that under low adaptation costs, the land value curve shifts downward and introduces a minimum density threshold for viable housing development. Under high adaptation costs, shown in panel (b), the curve shifts further downward, raising the minimum density required.

Finally, we use the results above to parameterize Equation 14 in order to derive the minimum density required for viable housing development across neighborhoods. Figure 9 reports current density levels and the results for three scenarios: the baseline, a doubling of adaptation costs, and a fivefold increase. In the baseline scenario, the Green Heart region in the west requires the highest densities, exceeding 2,000 people per km^2 (the median density in the Netherlands is 427 people/km^2). This reflects its unfavorable geography: weak peat soils, low elevation far below sea level, and proximity to primary water bodies, all of which correlate with high adaptation costs. By contrast, in much of the east and south, where fewer adaptation measures are needed, required densities remain relatively low. When costs are doubled, most areas in the west, along the coast, and near the major rivers require densities above 3,000 people per km^2, reaching nearly 6,000 in the most exposed locations. Under a fivefold increase, virtually the entire country—except for parts of the eastern and southern province of Limburg—requires minimum densities above 3,000, with some areas exceeding 13,000 (a tenfold increase even results in densities reaching beyond 24,000).

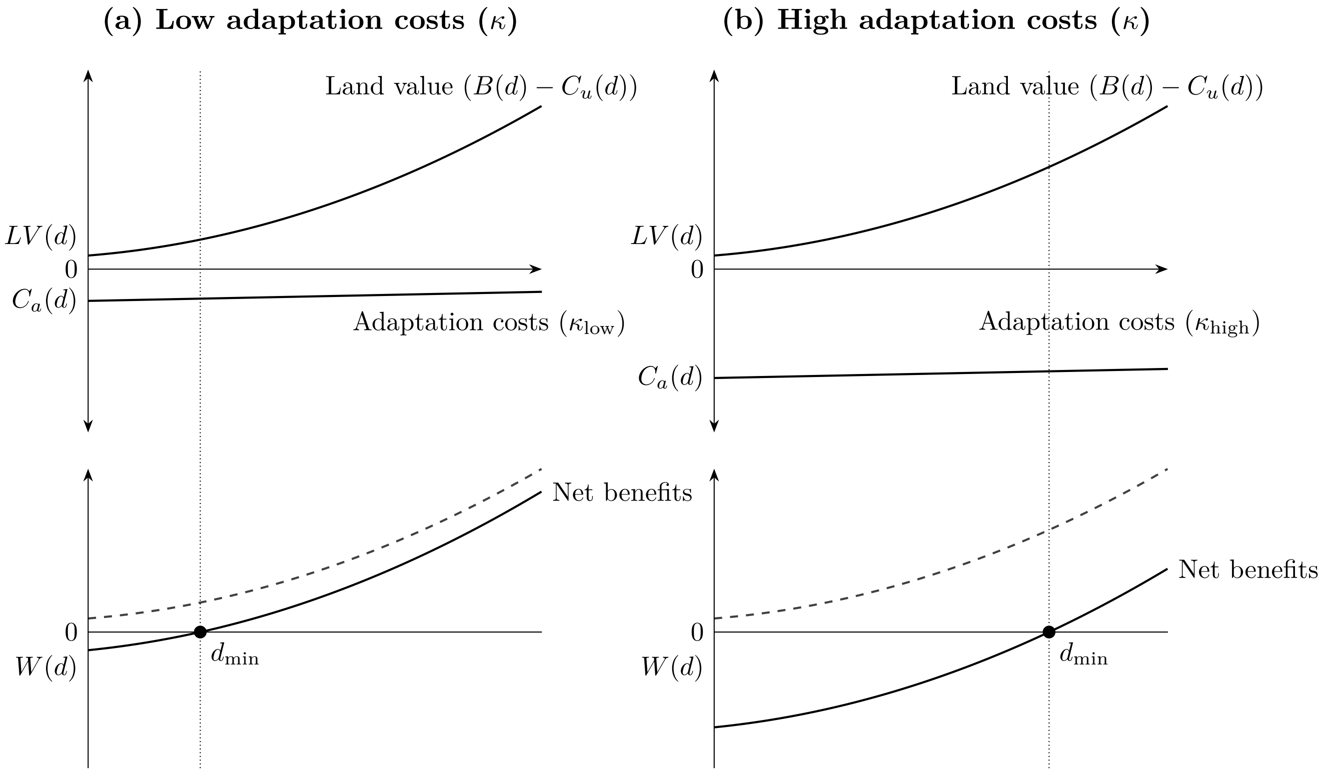

Figure 8: Empirical application of the theoretical framework to the Netherlands.

While these thresholds may seem prohibitively high, panel (a) in Figure 9 also shows that such density levels already exist in the Netherlands. This means that development from scratch in rural places may generate a welfare loss, but utilizing the densities of existing cities could be welfare-enhancing. Figure 10 shows that some places can withstand cost increases of more than a factor of 20. Amsterdam would only lose viability if adaptation costs rose by a factor greater than 100—underscoring the strength of agglomeration effects in dense urban centers. Moreover, the estimates refer to minimum densities. Higher densities generate additional benefits, implying that even in high-cost regions of the West, very dense development may still outperform low-density settlements elsewhere.

To provide stylized facts and rules of thumb regarding the minimum density (d_{min}), Table 5 reports the effects of key geographical characteristics. Based on the means in Table 2, we take as benchmark an "average" Dutch location situated at 10.43 meters above sea level, 11.48 kilometers from the coast or a major river, and with a soil composition of 1.7% peat and 11.8% clay/peat. Such a location incurs average adaptation costs of €117/m^2, implying a d_{min} of 1,375 people per km^2. If the same location were characterized entirely by peat soil, d_{min} would rise by 1,189. Conversely, each additional kilometer from primary water reduces d_{min} by about 32, while each additional meter of elevation lowers it by 11. The most exposed location in the Netherlands—directly adjacent to water, 5.8 meters below sea level, and on peat soil—requires a minimum density of 3,101 for feasible development. This corresponds roughly to the density of an average neighborhood in the provincial town of Alphen aan den Rijn (population $\sim 75,000$).

These thresholds and results highlight how geography strongly shapes the viability of urban expansion, with peat soils and proximity to water dramatically increasing the minimum density requirements, where peat soil has by far the strongest effect of all geographical characteristics.

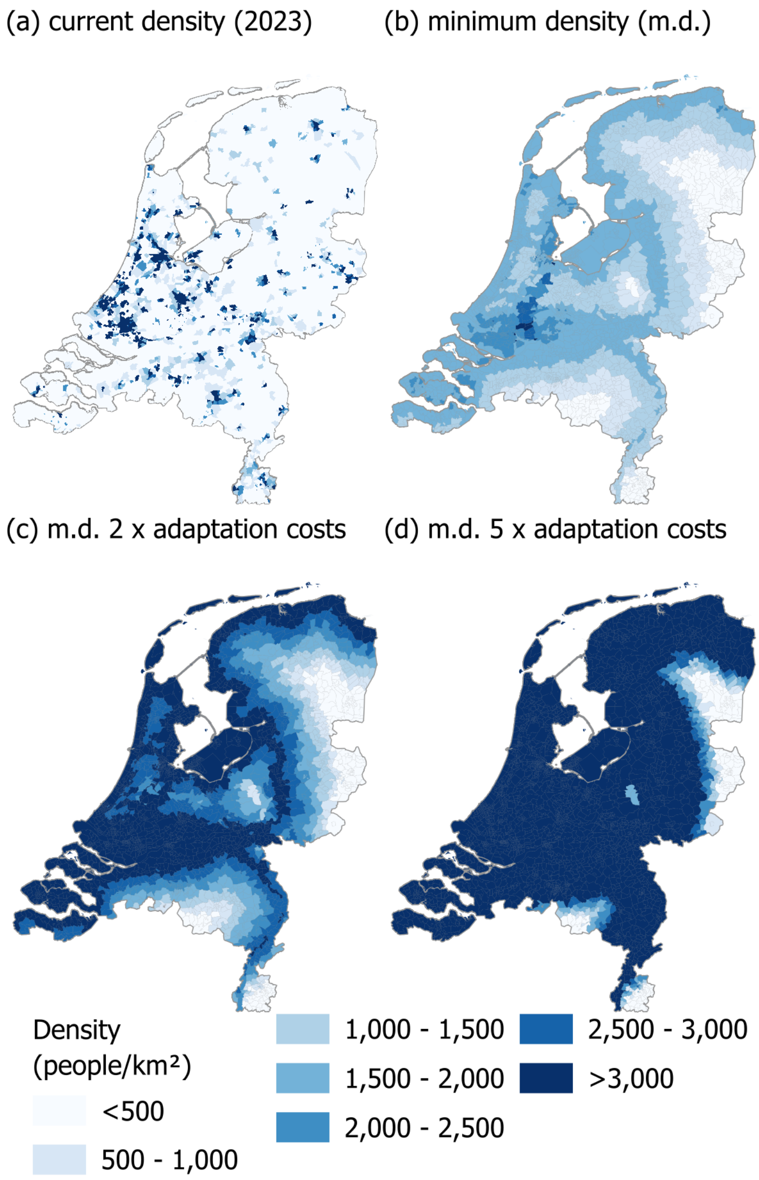

Figure 9: Minimum density needed for economically feasible urban development under different cost scenarios.

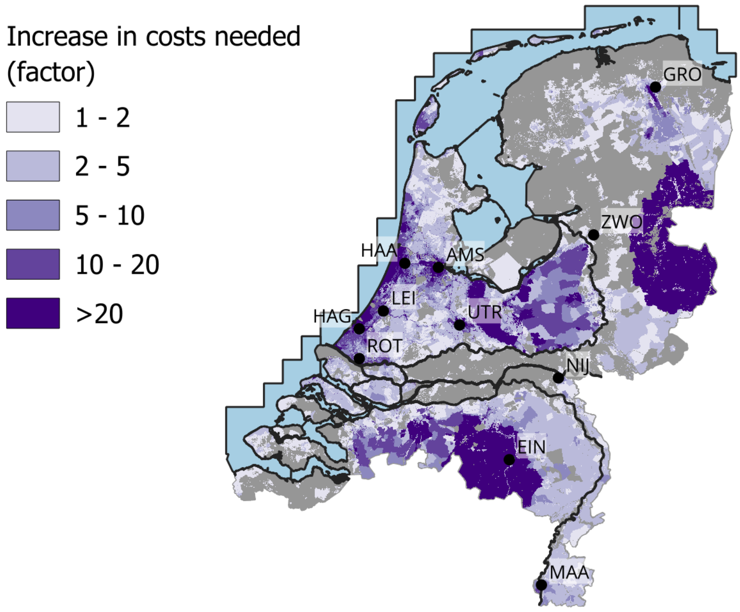

Figure 10: Increase in costs needed before net benefits become negative.

Table 5: Minimum density and rules of thumb for the Netherlands.

	Costs κ (€/m^2)	$\Delta\kappa$ (€/m^2)	d_{min} (people/km^2)	Δd_{min} (people/km^2)
Average location	117		1375	
Next to water	150	33	1753	$\sim$ 378
-5.8 m below sea level	133	15	1550	$\sim$ 175
Peat soil	222	105	2564	$\sim$ 1189
Clay/peat soil	151	34	1766	$\sim$ 391
Most exposed	270	153	3101	$\sim$ 1726
Marginal effect (evaluated at average location):				
+1 km away from water		-2.87		$\sim$ 32
+1 m elevation		-0.93		$\sim$ 11
Peat soil (vs good soil)		111.23		$\sim$ 1265
Clay/peat (vs good soil)		40.78		$\sim$ 468

Notes: $d_{\text{min}}(\kappa) = \frac{(q-\alpha)+\sqrt{(\alpha-q)^2+4\rho\kappa}}{2\rho}$ with $\alpha - q = 0.084$ and $\rho = 10^{-6}$. "Average location" is the reference with means taken from Table 2 (distance to water = 11.49, elevation = 11.43, peat = 0.017, and clay/peat = 0.118). Changes (Δ) are differences versus the reference. Approximations in the last column use $\sim$, as the exact marginal effect depends on location because the formula includes a square root.

6 Discussion and conclusion

This paper has developed and applied a framework that explicitly weighs the economic benefits of urban density against the geographically determined costs of climate adaptation. Using Dutch data on land values as a proxy for net agglomeration benefits and engineering-based estimates of flood and subsidence protection, we show that dense cities continue to yield strong welfare gains, even in highly exposed areas, while low-density settlements in exposed locations quickly become unviable.

Our results underscore three key points. First, climate exposure alone is a misleading guide for spatial planning. Dense cities with high adaptation costs can generate higher welfare than safe but sparsely populated regions, because agglomeration forces are powerful enough to offset substantial adaptation investments. Second, we identify minimum density thresholds for viable development in areas with climate hazards and derive simple rules of thumb that link required densities to geographical features such as distance from water, elevation, and soil type. Based on our findings, places located simultaneously near water, below sea level, and on weak soils only become viable once density exceeds thresholds of roughly 3,000 people per km^2. A simple rule of thumb is that every kilometer farther from the coast or a major river lowers the required density by about 32 people per km^2, while each additional meter of elevation reduces it by around 11. By contrast, building on peat soils raises the minimum density dramatically—by about 1,265 people per km^2—already included in the 3,000 threshold. Third, we demonstrate that the Netherlands already has many medium-sized and large cities that exceed these thresholds. Concentrating new housing in such places is more welfare-enhancing than expanding into peripheral areas where adaptation costs outweigh modest agglomeration benefits.

While our estimates provide consistent benchmarks across the country, they inevitably simplify reality. We rely on standardized cost estimates for a representative terraced house, which allows adaptation costs to be compared across locations but masks variation by housing type. Apartments are typically cheaper to protect, while detached houses in rural areas may face higher per-unit costs. Our approach, therefore, likely overstates adaptation costs in dense places and understates them in sparsely populated regions, providing a conservative bound. Moreover, we restrict attention to floods and land subsidence, the hazards that the Dutch government uses as guidance for new housing development, while excluding other hazards such as heat stress or drought. Including such hazards could raise costs further in specific regions, though it would not alter the fundamental insight that viability depends jointly on geography and density.

Notwithstanding these caveats, a broader implication is that climate adaptation strengthens rather than weakens the case for urban densification. While some literature emphasizes managed retreat to safer ground, our results show that the combination of density and geography is what matters. In contexts like the Netherlands, where dense cities remain below the point at which negative externalities dominate, further concentration can both sustain economic performance and justify large-scale adaptation.

At the same time, densification as a climate strategy raises distributional questions. The economic gains of urban concentration accrue mainly to households and firms, while the costs of adaptation are often borne collectively through public investments in defenses. Ensuring that these costs are shared fairly is critical for political and social feasibility. Future research should therefore examine financing mechanisms and institutional arrangements that distribute adaptation costs equitably, so that the economic rationale for densification is matched by social legitimacy.

Our findings suggest that the economic geography of climate adaptation is not about whether cities should stay, but at what densities and under what conditions they remain viable. For the Netherlands—and likely for other countries facing rising climate hazards—the answer is clear: densification in existing cities remains both feasible and desirable, supporting cost-effective climate adaptation.

Acknowledgment

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A Derivation of adaptation costs

We derive the costs of climate adaptation from EIB (2025), with some additional calculations. For extra investments at the building level for flood protection, EIB (2025) uses the yearly chance of a flood of a minimum of 20 centimeters water depth, as presented in Table 6. Dutch public flood maps, available via Klimaateffectatlas, report the chances of such floods occurring per year, allowing us to link the data with these maps. We estimate our land values as the price per m². Hence, we convert the costs per house to m² prices to make the benefits and costs comparable. This conversion relies on specific assumptions. For single-family houses, EIB (2025) reports an average ground floor area of 89 m², allowing us to derive the m² prices in Table 1.

Table 6: Costs of flood-prone buildings (EIB, 2025).

Flood of min 20 cm		Single family	
Development	chance/y (%)	House (€)	€/m²
Yes	0	0	0.00
Yes, accept risk	< 0.01	0	0.00
Yes, minor investment	0.01–0.1	2700	30.34
Yes, large investment	0.1–1	7700	86.52
No, huge investment	> 1	11 800	132.58

Note: Assumes 89 m² for single-family houses.

EIB (2025) reports general costs for land subsidence, without a distinction per building type, as shown in Table 7. Most buildings constructed after 1970 use timber piles that transform the building's weight to deep and stable soil layers resistant to land subsidence effects. This means damage only occurs in the public space, such as subsiding roads, sewage, and utility cables. These costs depend on the number of buildings, and EIB (2025) reports per building numbers for different rates of subsidence. As we need a per-m² price for comparison with the benefits, we use the same trick as before by dividing by the average unit size of a single-family house.

Table 7: Extra costs in public space of development in land subsidence zones (EIB, 2025).

Land subsidence risk		Total cost (€)	Cost per m² (€)
Development	Subsidence (cm)	Per building	Single family
Yes	0	0	0
Yes, accept risk	<5	0	0
Yes, small investment	5–30	4000	44.94
Yes, average investment	30–60	7000	78.65
Yes, large investment	60–90	10 000	112.36
No, huge investment	>90	20 000	224.72

Note: Assumes 89 m² for single-family homes.

B Costs of dike reinforcements

The regional costs mostly concern reinforcing the primary flood defenses, which include dikes, dunes, and storm surges along the sea and major rivers. These can be classified as public costs as they are executed by the local water authorities and the national government. AT Osborne and Witteveen+Bos (2023) have researched the additional investments per water authority needed to comply with all safety norms for the expected situation in 2050, as mapped in the First Assessment Round for Primary Flood Defenses by Rijkswaterstaat and the local water authorities. Figure 11 shows high total costs in water authority districts where the major rivers flow through. These are also the districts where the costs per house are the highest. Although Figure 2 shows that flood risk is also high in the western part of the Netherlands, this region is already well defended, and maintenance works are up to date. Therefore, additional investments are limited. In combination with a higher urban density in this region, the costs per house are relatively low in the western part. This emphasizes that both scale effects and lower total costs result in a lower cost per house ratio than the rest of the country.

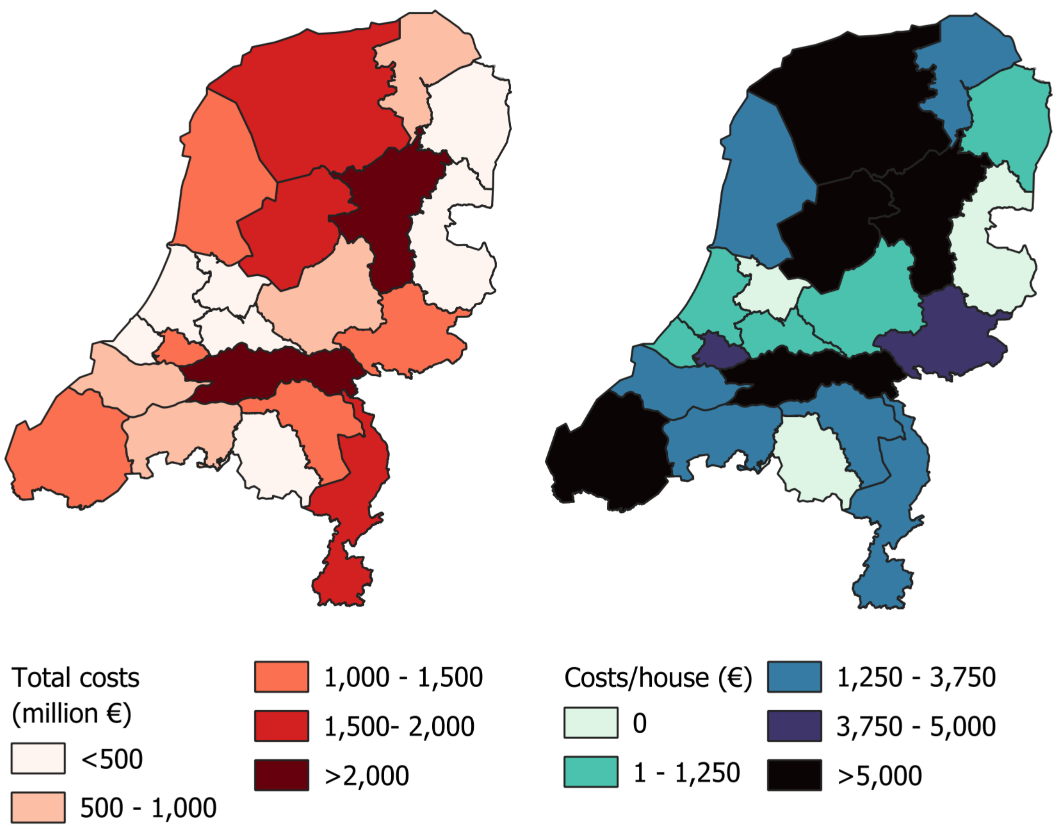

Figure 11: Investments needed per water authority district to comply with safety norms for primary flood defenses by 2050 (AT Osborne & Witteveen+Bos, 2023).

C Geography

We look at the geographical characteristics of the Netherlands in Figure 12. The maps show the average distance to primary water, elevation, and soil type at the neighborhood level. Distance to primary water is defined as the nearest primary water body, which consists of the sea, and the major rivers Meuse, IJssel, and all large branches of the Rhine (Waal and Lower Rhine). Elevation is defined as the average number of meters above or below sea level per neighborhood. There is a correlation between distance to water and elevation, with neighborhoods close to water also being characterized by lower elevation levels. For soil type, we only focus on the weak clay, clay/peat, and peat soils that may result in land subsidence. These soils also correlate with lower elevation levels.

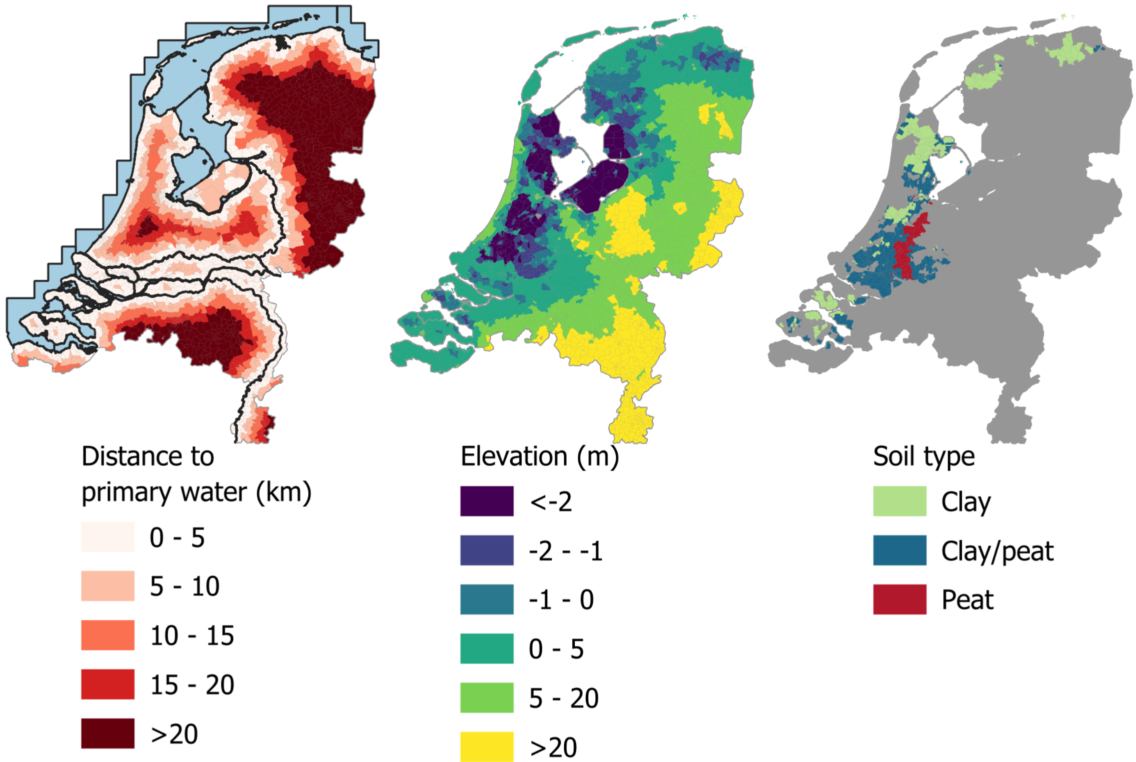

Figure 12: Different geographical characteristics of the Netherlands.

D Change in land values

Figure 13 shows the average land value between 2000 and 2007. During this period, we see the same pattern that arises between 2015 and 2023: land values are the highest in dense urban areas in the western part of the Netherlands. Over time, these places have also rapidly increased in land values, reporting growth rates over 30%, and in some cases, like Amsterdam, even exceeding 100%. On the other hand, large parts of the north and the province of Limburg have faced a decline in land values. This development shows the agglomeration power of the big cities, which attract economic activity and human capital from the more peripheral regions.

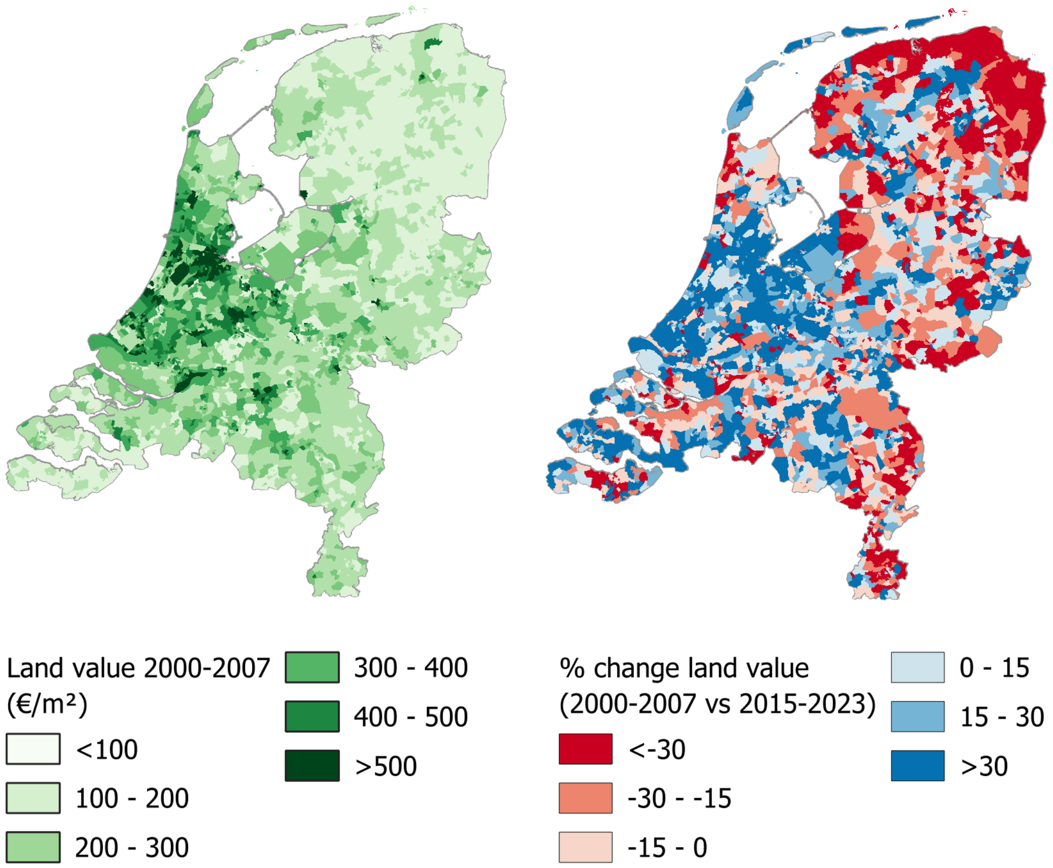

Figure 13: Change in land values between 2000–2007 and 2015–2023.

E Correlations of main variables

Figure 14 shows the effect of distance to primary water and elevation on density. Both graphs show that denser cities cluster close to water and at lower elevation levels. This supports Bleakley and Lin (2012) and Kocornik-Mina et al. (2020), showing that dense cities also cluster near water and in lower floodplains in the Netherlands.

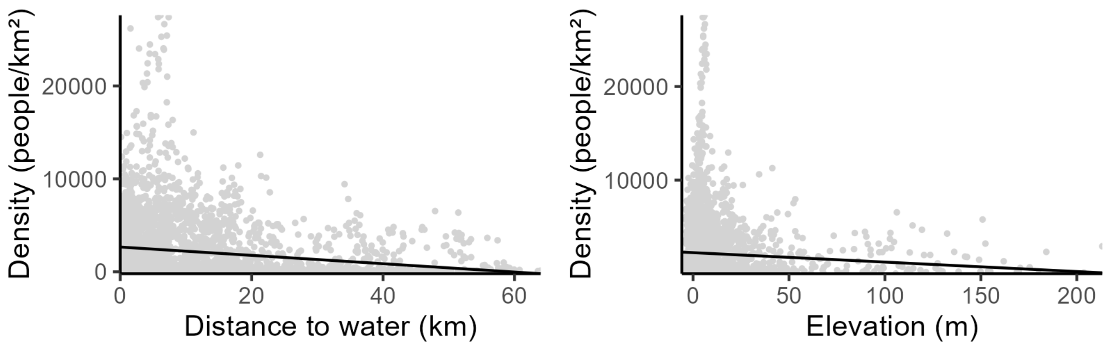

Figure 14: Geographical characteristics and density.

Figure 15 first shows the correlation between density and land values. The relationship follows a strong linear pattern. The plots also show the adaptation costs scale modestly with density, meaning that higher densities incur slightly lower adaptation costs. The distance to water (primary waters such as the sea and major rivers) also affects the adaptation costs. Places located further away from these water bodies are characterized by lower costs. The same pattern applies to elevation, where places located higher above sea level incur lower adaptation costs.

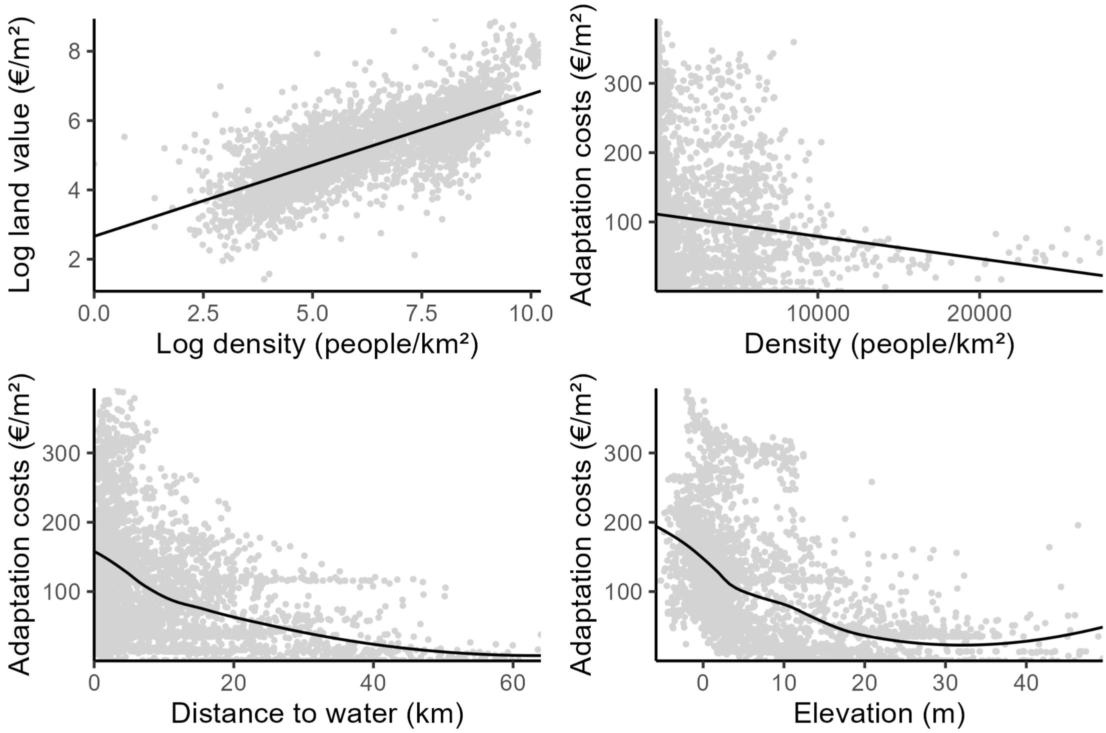

Figure 15: Correlations between density, geography, and adaptation costs (elevation cut off at 50 meters, as higher elevations barely incur any costs).