XCARCITY: Almere Pampus Use Case – report

Report: Almere Pampus Use Case
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1. Almere use case specifications

XCARCITY is a five-year research initiative aimed at developing a federation of digital twins to support the design of 'car-low' urban areas, including the integration of smart mobility services. Almere Pampus ("Pampus") is one of the use cases within XCARCITY. Almere Pampus Master Plan provides a vision for the development of Pampus. There are 4 key themes highlighted in the plan, namely: *Mobility, landscape and ecological design, water system, energy system and circular economy.* As outlined in the Master Plan, Pampus will be developed in two phases: phase one will include the first phase of houses and corresponding jobs for Pampus, while phase two proposes three different scenarios for housing opportunities across varying densities and corresponding jobs.

Through the XCARCITY programme, the *mobility* theme (as described in the master plan) is interrogated in more detail through a car low perspective. Given that 'car-low' areas typically have lower parking standards, the goal of this report is to provide insights into how building with reduced parking provisions—across different housing densities (the three housing scenarios) —affects car ownership, car usage and air quality.

The three housing density scenarios are detailed below. Each scenario will be explored in relation to the three car ownership and parking variants:

Housing Density Scenarios:

- Phase one - *Scenario 1*: 7500 houses and 4000 jobs.
- Phase two - *Scenario 2*: 15000 houses and 16000 jobs.
- Phase two - *Scenario 3*: 30000 houses and 16000 jobs.

Three variants related to car ownership and parking:

- **Low car ownership and parking standard**: This is the lowest standard in Almere for a household, considering a standard of a 0.6 parking bay per household.
- **Medium car ownership and parking standard**: This is based on the expected standard for Pampus, considering a standard of a 0.9 parking bay per household.
- **Almere business as usual car ownership and parking standard**: This is based on the existing parking standards in Almere, considering a standard of 1.5 parking bays per household.

The phases, housing density scenarios and car ownership and parking variants investigated are summarized in Table 1. In these scenarios the distribution of houses and jobs across the Pampus area will be based on the Master Plan.

Table 1 Phases and variants

Housing density scenarios and corresponding jobs	**Variants**		
	Low car ownership and parking standard (0.6)	Medium car ownership and parking standard (0.9)	Almere business as usual car ownership and parking standard (1.5)
Phase 1 (without IJmeerlijn)			
7500/4000	X	X	X
Phase 2 (with IJmeerlijn)			
15000/16000	X	X	X
30000/16000	X	X	

Owing to the fact that the primary focus of this work is on parking, the rest of the mobility system—including the road and bicycle network, bus routes, and metro lines—is kept consistent across all the scenarios. Designing the system to make alternative modes of transport more attractive instead of the car, such as (shared) bikes and public transport, with reduced parking capacity, falls outside the scope of this report. However, the digital twins developed within XCARCITY offer potential to support such design considerations in the future.

Figure 1 provides a flow chart for the federated set of digital twins for Pampus which tests the above scenarios. The purple blocks contain the input. The green blocks include modelling steps to distribute jobs and households across Pampus, and to determine their car ownership. With this information the Omnitrans model is used to setup the basis for the digital twin environment (red blocks). OmniTRANS is a software package that contains a traffic and transport model for Almere including socio-economic zonal information, origin and destination matrices with trips between different zones and networks for the different modes. The digital twin uses these matrices and networks in combination with the population characteristic to assess the impact of the different scenarios.

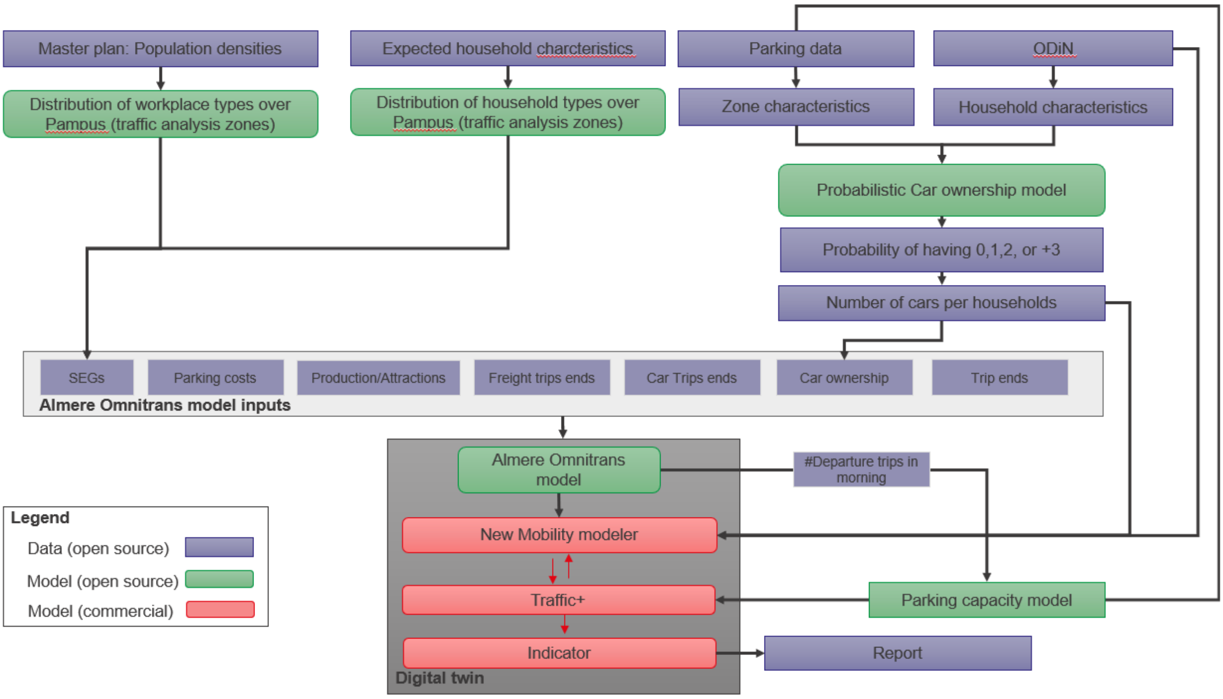


Figure 1 Digital twin flow chart for Almere Pampus use case

The report is structured as follows: Chapter 2 describes the digital twin components, Chapter 3 describes how the input for the digital twin for Almere is derived including the sociodemographic input, the distribution of people over Pampus and their car ownership status, Chapter 4 describes the results and Chapter 5 provides the conclusions and recommendations.

2. Digital twin description

The Digital Twin is a comprehensive framework designed for scenario-based analysis in the mobility domain. It integrates multiple models capable of simulating a wide range of travel modes, including private cars, freight transport, bicycles, and public transportation. These modes are assigned to the transport network using specialized assignment algorithms. For motorized traffic, the model employs a multi-user class volume-averaging algorithm for cars, and an all-or-nothing assignment approach for freight transport.

The Digital Twin can be used interactively to modify urban characteristics, enabling users—such as city authorities or municipalities—to actively simulate a wide range of policy scenarios. Example applications include assessing the impact of road closures, city-wide speed reductions, population growth, or increased parking fees. Each simulated scenario can be evaluated using a comprehensive set of indicators. In addition, the framework includes models to assess environmental and mobility-related outcomes, such as air quality, emissions, noise pollution, vehicle kilometres travelled, modal split, health impacts, and accessibility.

2.1. OmniTRANS

OmniTRANS is a professional traffic and transport simulation software package developed by Dat.mobility (Goudappel) in the Netherlands. It is widely used in research, consultancy, and government projects to analyse and predict the effects of mobility policies, infrastructure changes, and urban developments. OmniTRANS supports the entire modelling workflow—from data input and preprocessing, to simulation, analysis, and visualization. It is designed for regional, urban, and corridor-scale studies, and integrates both passenger and freight transport modelling.

Core Functionalities:

1. Multimodal Traffic Simulation
   - Models' car, public transport, cycling, and walking.
   - Allows scenario comparison (e.g., impact of new infrastructure, policy measures, or housing developments).
2. Four-Step Transport Modelling
   - Trip generation: Estimation of travel demand based on population, employment, and land use data.
   - Trip distribution: Allocating trips between origins and destinations.
   - Mode choice: Selecting transport modes (car, public transport, bicycle, walking).
   - Traffic assignment: Routing demand across the transport network.
3. Public Transport Modelling
   - Integrated modelling of bus, tram, metro, and train services.
   - Supports timetable-based simulations with transfer penalties and waiting times.
4. Scenario Analysis & Policy Testing
   - Evaluates infrastructure projects (e.g., new roads, bridges, rail).
   - Tests policy measures like road pricing, parking strategies or emission zones.
   - Models the impact of urban expansion (e.g., new housing or commercial developments).

5. Environmental & Safety Indicators
    - Estimates emissions (CO_2, NOx, PM).
    - Analyses noise, safety risks, and accessibility.
    - Useful for sustainability impact assessments.
6. Visualization & Reporting
    - Interactive maps, charts, and dashboards for presenting results.
    - Compatible with GIS systems and external tools for further analysis.

The OmniTRANS model for Almere is used for trip generation and destination choice. The resulting aggregated origin-destination matrices are used for disaggregated mode choice modelling for a large number of population groups using the New Mobility Modeller as described below.

2.2. New Mobility Modeller

At TNO, a population generator is available to create a synthetic population for the Netherlands. This population can be projected for a future year—2030 in this case—and is based on CBS (micro)data and demographic trends. The synthetic population comprises agents with diverse individual characteristics (e.g., age, gender, driver's license status) as well as household attributes (e.g., income, location). This 2030 population serves as input for the heterogeneous mode choice model known as the New Mobility Modeller (NMM).

The New Mobility Modeller (NMM) assesses how mode choice shifts in response to changing conditions—such as rising public transport fares—or the introduction of new mobility options, like shared vehicles. These changes are evaluated relative to a baseline scenario generated by the transport model.

NMM relies on the synthetic population data and travel behaviour probabilities derived from the OViN and ODiN datasets. During preprocessing step, trips from the original origin-destination (OD) matrices are linked to specific population groups. For each OD pair and population segment, a logit model—estimated and calibrated using OViN and ODiN data—is applied to determine the updated mode choice based on utility functions.

The model assumes static population groups, including car ownership levels. However, this assumption is adjusted in advance to reflect specific scenario inputs (See 3.3 Car ownership model).

2.3. Traffic assignment and parking

The Traffic+ module assigns all car, bicycle, and freight traffic from the OD matrices to the transport network. This assignment process takes into account the capacities and speeds defined for each network link to calculate travel times for the different modes of transport. This means that travel time increases as traffic volume on a link grows. For freight transport, it is assumed that the fastest route is always taken, using an all-or-nothing assignment method. For car traffic, a volume-averaging equilibrium assignment algorithm is used, which distributes traffic across multiple routes. This approach accounts for congestion-related delays, making alternative routes more attractive for some travellers. The result is a traffic equilibrium where no traveller can reduce their travel time by switching routes. Additionally, Traffic+ supports the inclusion of new transport modes, such as shared cars, and can assign them to the network using a multi-user class assignment algorithm.

To incorporate parking into the static assignment, dedicated parking links are added to the transport network. Each zone (centroid) is assigned a parking link with a defined capacity, representing the number of available parking spaces. As more vehicles use a particular parking link—i.e., park in that zone—the associated travel time increases, reflecting the growing difficulty of finding a parking spot. Once the parking capacity nears its limit, the travel time becomes so high that it may be faster to park in a neighbouring zone and walk to the destination, rather than parking directly in the intended zone. This mechanism is modelled by introducing four types of parking-related links into the network: parking connector links, parking links, walk parking links, and interzonal walk links. The parking links have limited capacity and simulate increased search time using a BPR (Bureau of Public Roads) travel time function.

In general Parking capacity for traffic analysis zones is based upon Parking places in The Netherlands - Dataset - Metadata (tno.nl). To understand how parking capacity is determined for Pampus, as a future residential zone, please refer to section 3.4.

2.4. Public transport assignment

The Public Transport module assigns public transport trips. Based on the origin and destination zones, suitable stops are first identified—these can be reached by walking or cycling. Between these stops, various public transport routes (including transfer options) are then explored. This is done using a backward search approach, where the system works backward from the destination to the origin, identifying which public transport lines can be used to reach the destination and where transfers are possible. Throughout this process, the total travel time for each route is calculated. Once the possible routes are identified, travellers are distributed across them. Walking and cycling are considered as access and egress modes.

2.5. Indicators

The indicator module in the digital twin generates key performance indicators. After running the models on each scenario, the indicator module compares the scenarios using particular KPIs like modal splits, vehicle kilometre travelled, traffic intensities, air quality, CO_2, noise emissions and many more.

3. Digital twin input

3.1. Distribution of household types over Pampus

This section describes how the households are distributed across Pampus. Table 2 shows the generic distribution over household types for the expected population of Pampus as provided by Almere. The Master Plan also contains information on the different types of neighbourhoods in Pampus as illustrated in Figure 2. Figure 3 shows the expected population density in each zone.

Table 2 Expected population distribution in Pampus

ID	Household type	Age	Annual household income	Number of households	%
1	Small	<30	<35000 euro	2500	11%
2	Small	<30	35.000-75.000	1500	7%
3	Small	<30	>75.000 euro	1500	7%
4	Small	30-54	<35000 euro	1000	4%
5	Small	30-54	35.000-75.000	900	4%
6	Small	30-54	>75.000 euro	2500	11%
7	Small	55-74	<35000 euro	1000	4%
8	Small	55-74	35.000-75.000	800	4%
9	Small	55-74	>75.000 euro	1900	8%
10	Small	≥75	<35000 euro	600	3%
11	Small	≥75	35.000-75.000	300	1%
12	Small	≥75	>75.000 euro	300	1%
13	Family	family	<35000 euro	900	4%
14	Family	family	35.000-75.000	950	4%
15	Family	family	>75.000 euro	5800	26%
				22450	

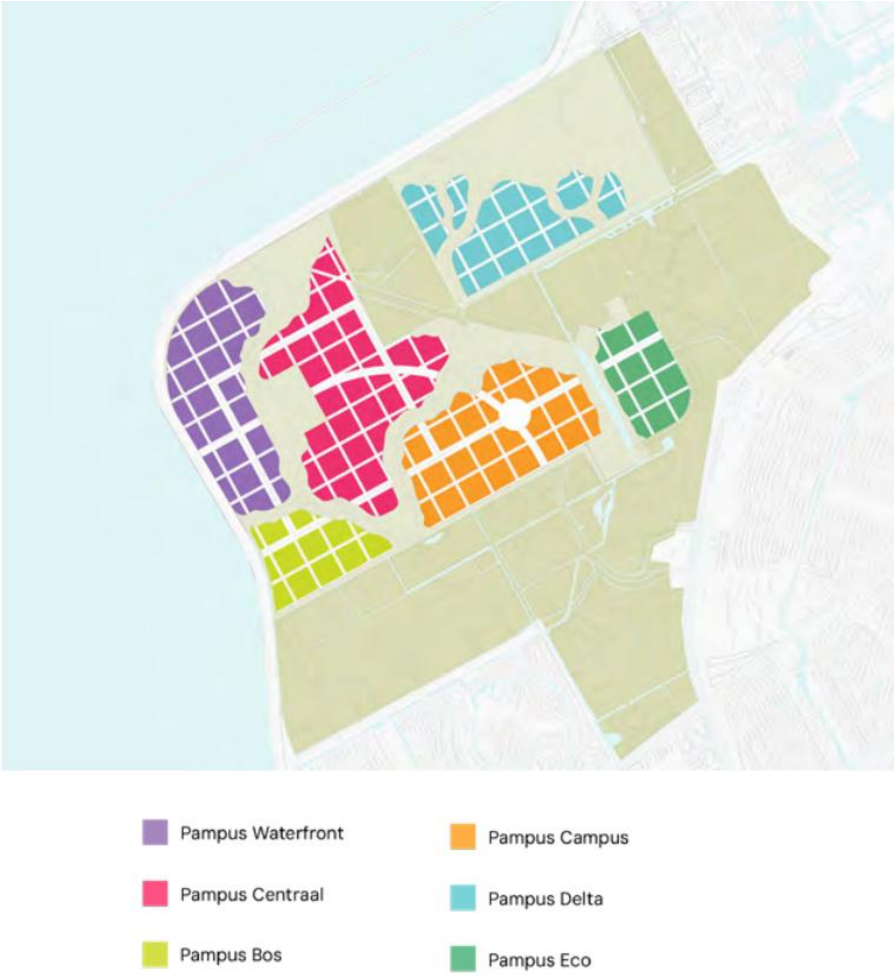


Figure 2 Almere Pampus neighbourhood types

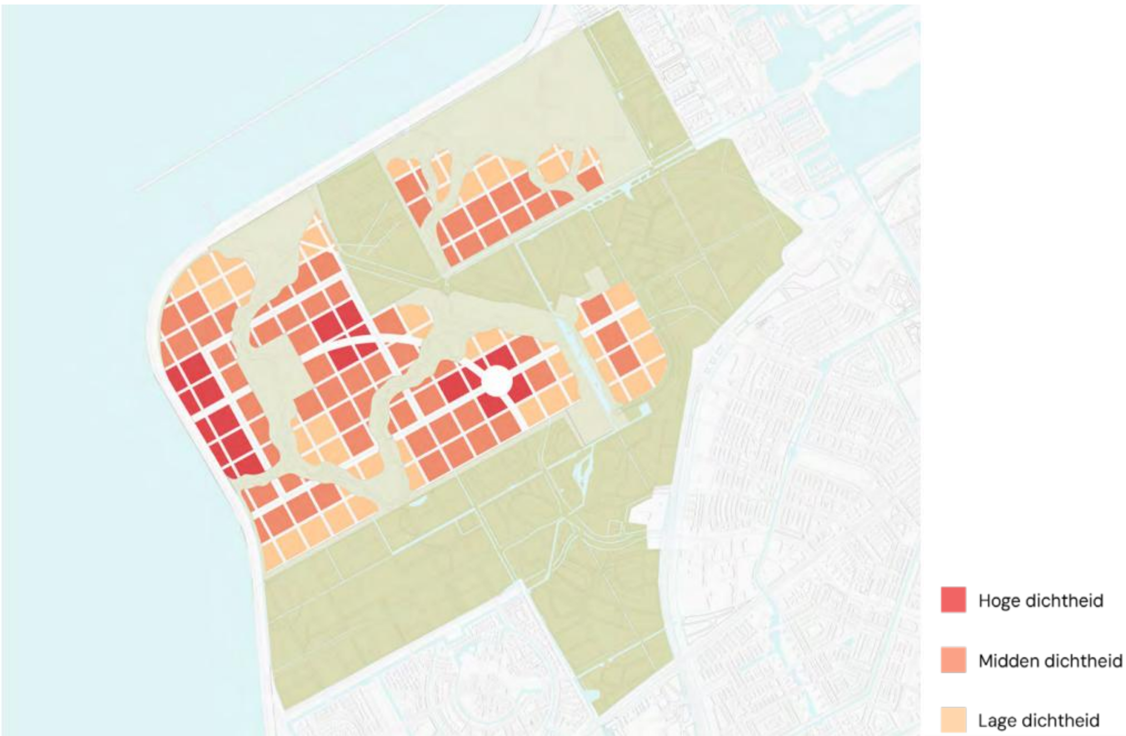


Figure 3 Density distribution across neighbourhood types

To allocate the population across the different neighbourhoods, the available squares for each coloured neighbourhood are counted (see Table 3). These squares are weighted by assuming different building heights: 12 storeys for high-density, 7 storeys for medium-density, and 3 floors for low-density areas. The results are displayed in Table 4.

Table 3 Squares available as seen in Figure 2 and Figure 3

Density	Purple	Pink	Blue	Dark green	Orange	Green	Total
High	7	4	0	0	4	0	15
Middle	11	17	12	3	12	5	60
Low	5	6	6	7	6	5	35
Total	**23**	**27**	**18**	**10**	**22**	**10**	**110**

Table 4 Weighted squares based upon building layers

Density	Purple	Pink	Blue	Dark green	Orange	Green
High	84	48	0	0	48	0
Middle	77	119	84	21	84	35
Low	15	18	18	21	18	15

These tables help to determine which percentage of the total amount of households are going to live in Pampus, see Table 5. For example, in the case of 30000 households, refer to Table 6.

Table 5 Percentages to distribute the households over the Pampus area

Density	Purple	Pink	Blue	Dark green	Orange	Green
High	12%	7%	0%	0%	7%	0%
Middle	11%	17%	12%	3%	12%	5%
Low	2%	3%	3%	3%	3%	2%

Table 6 Case of 30000 households

Density	Purple	Pink	Blue	Dark green	Orange	Green
High	3657	2090	0	0	2090	0
Middle	3353	5181	3353	914	3657	1524
Low	653	653	784	914	653	522
Total	**7663**	**7925**	**4136**	**1829**	**6401**	**2046**

To determine the household types across the different neighbourhoods, the following two assumptions have been made:

1. For household types 10 through to 15 (elderly and families), it is assumed that 5% reside in pink neighbourhoods, 5% reside in orange neighbourhoods and the remaining 90% are distributed across the purple, blue, green, and dark green neighbourhoods.
2. Household types 1 through to 9 (small) are more likely to live in the orange and pink neighbourhoods. This is automatically accounted for by first allocating household types 10 through to 15, and then distributing household types 1 through to 9 based on the remaining estimated capacities per neighbourhood.

For example, in the case of 30000 households, this would lead to the distribution of household types as shown in Table 7.

Table 7 Distribution of household types over Pampus for 30000 households

Household types	%	Households	Purple	Pink	Blue	Dark green	Orange	Green
1	11%	3341	452	1348	244	108	1068	121
2	7%	2004	271	809	146	65	641	72
3	7%	2004	271	809	146	65	641	72
4	4%	1336	181	539	98	43	427	48
5	4%	1203	163	485	88	39	384	43
6	11%	3341	452	1348	244	108	1068	121
7	4%	1336	181	539	98	43	427	48
8	4%	1069	145	431	78	35	342	39
9	8%	2539	344	1024	185	82	812	92
10	3%	802	353	40	190	84	40	94
11	1%	401	176	20	95	42	20	47
12	1%	401	176	20	95	42	20	47
13	4%	1203	529	60	286	126	60	141
14	4%	1269	559	63	302	133	63	149
15	26%	7751	3410	388	1841	814	388	911
		sum of 10 until 15	2460	7333	1328	587	5809	657

In a next step, a match is made with traffic zones in the OmniTRANS model, as shown in Figure 4 by identifying the number of traffic zones intersecting with each colour segment in Figure 2. Using Table 7, the distribution of household types across the traffic zones is computed.

Figure 4 Almere Omnitrans traffic zones

Finally, Omnitrans requires more detailed information on inhabitants per traffic zone than provided above:

- Number of 1 person households.
- Number of 2 person households.
- Number of 3 or more person households.
- Number of people.
- Number of inhabitants between 0 until 17 years old.
- Number of inhabitants between 18 until 29 years old.
- Number of inhabitants between 30 until 44 years old.
- Number of inhabitants between 45 until 65 years old.
- Number of inhabitants 65 and older years old.

Individuals under the age of 30 are all categorized as 18–29 years. Those in the 30–54 age group are evenly divided between the 30–44 and 45–64 categories. People aged 55–74 are evenly split between the 45–64 and 65+ categories, while individuals aged 75 and older are fully assigned to the 65+ category.

Based on data from StatLine - Huishoudens; samenstelling, grootte, regio, 1 januari (cbs.nl) household types are allocated to households with one, two, or more persons (see Table 8). This allows for the estimation of the average number of people per household. For example, a type 1 household consists of approximately 74% single-person and 26% two-person households, resulting in an average of about 1.26 persons per household. In the case of families, the national average of 1.7 children per family is used. These individuals are then distributed across the relevant age categories.

Table 8 Constructing OmniTRANS input

Household ID	Household type	Age	Household_1p	Household_2p	Household_3emp	Average people	inw_0_17	inw_18_29	inw_30_44	inw_45_64	inw_65eo
1,2,3	Small	<30	74%	26%		1.26		1.26			
4,5,6	Small	30-54	67%	33%		1.33			0.66	0.66	
7,8,9	Small	55-74	46%	54%		1.54				0.77	0.77
10,11,12	Small	≥75	57%	43%		1.43					1.43
13,14,15	Family	Family			100%	3.70	1.19	0.51	1.25	0.75	0.77

3.2. Distribution of student places and jobs over Pampus

First student places are distributed over Pampus based on national statistics, Almere's Master Plan, and distribution of age groups (0-17, 4-12, 12-18) across entire Pampus (see previous section). The statistics are presented in Table 9.

Table 9 Statistics used to distribute number of students over Pampus

values	**unit**	**Source**
Primary school		
3.5	m2 per student	https://oudersenonderwijs.nl/kennisbank/schooloverkoepelend/het-schoolgebouw/grootte-van-het-klaslokaal/
209	students per school	Vergelijk de basisscholen in de woonplaats Een (bijgewerkt 2024!) | AlleCijfers.nl
732	m2 per basis school	
8	fulltime teachers per school	
88	m2 per teacher	
277	Foundation standards Almere (minimum number of students to start a school)	Staatscourant 2022, 28567 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)
Secondary school		
9	m2 per student	Grootte van het klaslokaal - Ouders & Onderwijs (oudersenonderwijs.nl)
424	students	Aantal leerlingen - Voortgezet onderwijs - DUO Open Onderwijsdata
3816	m2 average secondary school	
17	fulltime teacher per school	
225	m2 per teacher	
732	The foundation standards for a school community for mavo, havo and vwo are 195 pupils for mavo, 244 pupils for havo and 293 for vwo.	Stichten school - Voortgezet onderwijs - DUO Zakelijk

The maximum number of primary and secondary schools per zone is calculated based on Almere's foundational standards, combined with the number of children in each relevant age category.

Similarly, to distribute jobs over Pampus, data was used from the Master Plan as presented in Table 10.

Table 10 Distribution of number of jobs over different job categories

Field name	**description**	**Phase 2 (16500)**	**Phase 2 (4000)**	**Factor (see Master Plan)**
arb_benz	Jobs at petrol station	0	0	
arb_dfood	Jobs in retain food	600	145	1/5 jobs,
arb_dienst	Jobs in services	1433	347	1/3 facility jobs
arb_dnfood	Jobs in retail non-food	600	145	1/5 business jobs
arb_grhndl	Jobs in wholesale trade	600	145	1/5 business jobs
arb_horeca	Jobs hospitality	1433	347	1/3 facility jobs
arb_indus	Jobs in industry	600	145	1/5 business jobs
arb_kant	Jobs in offices	9200	2230	Total
arb_overig	Job in others	600	145	1/5 business jobs
arb_warenh	Jobs in warehouses	1433	347	1/3 facility jobs

3.3. Car ownership model

The number of cars varies depending on the scenario: a low car ownership scenario, a medium car ownership scenario, and a business-as-usual scenario. The model's estimation is based on ODIN data from 2018 to 2022 combined with a dataset containing the address density for each PC4 area, obtained from CBS. The table below presents the available features, with the second column indicating how each feature is derived.

Table 11 Data sources car ownership model

Feature	Source
Standardized income of household	Directly from ODiN.
Kids in household	Directly from ODiN
Number of driving licenses in household	Directly from ODiN
Factor of household	Directly from ODiN. This scalar is used to make households representative for the entire population.
Parking norm in the area of the household	This feature is not available by default, but the custom approach described in Section 2 is used to estimate it.
Number of cars in household	Directly from ODiN
PC4	Directly from ODiN

Based on these data a car ownership model was estimated that predicts how many cars a household is likely to own based on factors such as income, presence of children, number of driving licenses, and parking availability. To do this, the model groups households from the ODiN dataset into bins with the same feature values. If a bin has enough households (at least 50), the model directly uses the observed distribution of car ownership in that group as the prediction. From this distribution, it can also calculate the expected number of cars.

The model also estimates feature importance, which reflects how much each factor influences the prediction. For example, if income levels lead to noticeable differences in car ownership within otherwise similar households, income is assigned a higher importance. In the analysis, driving licenses and parking availability turned out to be the most influential factors, followed by income and the presence of children. If a bin does not contain enough households, the model relaxes the feature requirements step by step (starting with the least important feature) until enough data is available. This ensures predictions can always be made, though with reduced accuracy in sparse cases.

Using the car ownership model in combination with the distribution of households over traffic analysis zones results in scenario-specific updates to the Almere OmniTRANS input file for socio-economic input (SEGs) and car ownership for the Pampus zones (529 to 566). OmniTRANS uses cars per household on zonal level. To get insight into the average cars per household type, Table 12 is provided. In Table 13 the input per scenario per zone is shown.

Table 12 Output of car ownership model as number of cars and cars per household ratio

			Low		Medium		High	
Household type	**Age**	**Annual income**	**cars**	**Cars/hh**	**cars**	**Cars/hh**	**cars**	**Cars/hh**
Small	<30	<35000 euro	906	0,27	2023	0,61	2285	0,68
Small	<30	35.000-75.000	940	0,47	1645	0,82	1792	0,89
Small	<30	>75.000 euro	967	0,48	1765	0,88	1965	0,98
Small	30-54	<35000 euro	384	0,29	850	0,64	954	0,71
Small	30-54	35.000-75.000	587	0,49	1018	0,85	1106	0,92
Small	30-54	>75.000 euro	2062	0,62	3298	0,99	3903	1,17
Small	55-74	<35000 euro	454	0,34	983	0,74	1085	0,81
Small	55-74	35.000-75.000	591	0,55	997	0,93	1074	1,00
Small	55-74	>75.000 euro	1754	0,69	2810	1,11	3270	1,29
Small	≥75	<35000 euro	251	0,31	549	0,68	610	0,76
Small	≥75	35.000-75.000	208	0,52	356	0,89	385	0,96
Small	≥75	>75.000 euro	218	0,54	384	0,96	428	1,07
Family	Family	<35000 euro	1055	0,88	1439	1,20	1645	1,37
Family	Family	35.000-75.000	1394	1,10	1808	1,42	1913	1,51
Family	Family	>75.000 euro	8337	1,08	11595	1,50	12533	1,62

Table 13 Average cars per household ratio per zone for different parking standards in 30000 houses scenario

	Parking standard		
zones	**High**	**Medium**	**Low**
529	1.3	1.2	0.8
530	1.1	1.1	1.1
531	0.5	0.5	0.4
532	1.8	1.6	1.2
533	1.1	1.0	0.8
534	1.4	1.3	1.0
535	0.7	0.6	0.5
536	0.6	0.5	0.4
537	1.1	1.1	1.1
538	4.1	3.7	2.4
539	0.6	0.5	0.4
540	1.0	1.0	1.0
541	1.1	1.1	1.1
542	1.1	1.1	1.1
543	1.1	1.1	1.1
544	1.0	0.9	0.7
545	0.8	0.7	0.5
546	1.0	1.0	1.0
547	1.1	1.1	0.9
548	1.1	1.0	0.8
549	1.1	1.1	0.9
550	1.2	1.2	0.9
551	1.1	1.1	1.1
552	0.6	0.6	0.5
553	0.5	0.5	0.5

554	1.0	1.0	1.0
555	1.2	1.1	0.9
556	1.2	1.1	0.9
557	0.8	0.8	0.6
558	1.0	1.0	1.0
559	1.1	1.1	1.1
560	1.1	1.1	1.1
561	1.0	1.0	1.0
562	1.5	1.5	1.5
563	1.0	0.9	0.6
564	1.0	1.0	1.0
565	0.6	0.6	0.5
566	1.0	1.0	1.0

Important to note: it is assumed that there are two ways travellers may react to parking pressure. On one hand some households with car possession may decide to have no car due to limited parking standards. Since car possession is part of household characteristics, this leads to changes in household type. This can be captured using the car ownership model. For example, Table 14 compares how the percentage of car owned households in each zone changes due to high or low parking standards as compared to regular parking standards.

Table 14 Changes in percentage of Household categories due to the changes in parking standards

household	Changes in percentage of household with car possession	
	Parking standard = 0.6	Parking standard = 1.5
1	-16%	4%
2	-13%	3%
3	-51%	12%
4	-33%	6%
5	-38%	8%
6	-22%	5%
7	-43%	9%
8	-24%	6%
9	-51%	11%
10	-33%	7%

In scenarios with a low parking standard, 10 new household categories are introduced to represent those who previously owned a car under the medium parking standard scenario but no longer own a car under the low parking standard. The percentage of car-owning households was reduced based on the figures provided in Table 14 and the difference was reallocated to the new household categories. Conversely, in scenarios with a high parking standard, the proportion of households owning one or more cars increases, while the share of car-free households decreases, relative to the medium parking standard scenario. These changes affect the number of cars per zone and per household that are provided as input to the Omnitrans model.

On the other hand, parking standards can influence traveller behaviour by affecting the time spent searching for parking. This, in turn, impacts overall car travel time and subsequently influences households' mode choice. However, the mode choice model used in the Omnitrans model for Almere does not account for these effects at the level of individual household types. To account for these behavioural effects, the TNO Digital Twin is used as explained in the previous chapter.

3.4. Parking capacities per zone for the digital twin

In this study, the focus is on parking standards associated with household activities. To support this analysis, three types of parking capacities have been defined, as presented in Table 15.

Table 15 Definition of parking types

Parking type	Description
1 – home bound parking (private parking for houses)	This is based upon parking standards associated with the number of households in a zone. For this there are three scenarios: - 0.6 bays per household, - 0.9 bays per household, - 1.5 bays per household
2 – destination bound parking	This parking capacity is for the visitors of Pampus, for example for work
3 – free public parking areas	This is a total number of free multipurpose parking bays: - 0.06 bays per household, - 0.09 bays per household, - 0.15 bays per household

To analyse how individuals respond to parking pressure within a zone, the evening peak period is the most relevant for modelling. To ensure that trips are matched with appropriate parking options, the Digital Twin incorporates mechanisms that regulate parking behaviour based on trip purpose. It enables the definition of prioritization rules (see Table 16), allowing users to specify the order in which parking locations should be considered.

Table 16 Parking priority rules

Trip purpose	Type 1 – home bound parking	Type 2- destination bound parking	Type 3: free public parking areas
Work-home Education-home Shopping- home Etc.	1		2
Home – work Home – Education Shopping – home etc		1	2

The parking capacities available in Pampus during the evening peak are estimated by multiplying the number of households by the applicable parking standard, with an adjustment for vehicles that have left the area in the morning. Parking capacity for other areas in Almere is based upon [Parking places in The Netherlands - Dataset - Metadata (tno.nl)] and the parking capacities outside the study area have been set to 99999. These are considered not to be relevant for the study.

Table 17 illustrates the variation in parking capacities by parking type under high, medium, and low parking standard scenarios, using the 15,000-household scenario as an example.

Table 17 Parking capacity variations in Pampus area

	Low parking standard			Medium parking standard			High parking standard		
Zone/ Parking Type	Type1	Type2	Type3	Type1	Type2	Type3	Type1	Type2	Type3
529	560	463	75	578	772	125	827	1158	188
530	0	0	0	0	0	0	0	0	0
531	1627	945	213	2971	1575	355	4654	2362	532
532	368	445	51	373	742	85	377	1113	127
533	939	1374	187	1736	2290	311	3022	3435	467
534	415	285	54	421	475	90	646	712	135
535	1053	814	179	2167	1358	299	3558	2037	448
536	812	445	125	1520	742	209	2405	1113	313
537	0	0	0	0	0	0	0	0	0
538	294	123	42	298	205	70	300	307	104
539	497	294	67	906	490	112	1416	735	168
540	208	123	30	208	205	50	458	307	75
541	0	0	0	0	0	0	0	0	0
542	0	0	0	0	0	0	0	0	0
543	0	0	0	0	0	0	0	0	0
544	302	123	52	414	205	87	750	307	131
545	1212	765	227	2487	1275	379	4045	1912	568
546	0	445	30	0	742	50	250	1113	75
547	315	123	43	318	205	72	612	307	108
548	343	123	54	404	205	90	748	307	135
549	380	3783	43	383	6305	71	677	9457	107
550	564	1982	80	576	3304	133	989	4956	199
551	0	0	0	0	0	0	0	0	0
552	1016	765	172	2096	1275	287	3435	1912	431
553	994	765	151	1998	1275	252	3251	1912	378
554	211	123	30	211	205	50	461	307	75
555	386	2115	45	389	3525	74	688	5287	111
556	0	445	48	0	742	79	304	1113	119
557	1126	1536	198	2285	2560	331	3734	3840	496
558	215	123	30	215	205	50	465	307	75
559	0	0	0	0	0	0	0	0	0
560	0	0	0	0	0	0	0	0	0
561	225	123	30	225	205	50	475	307	75
562	116	94	14	116	157	23	116	235	34
563	1137	285	222	2015	475	370	3011	712	555
564	215	123	30	215	205	50	464	307	75
565	1107	765	163	2151	1275	272	3454	1912	408
566	0	123	30	0	205	50	250	307	75

3.5. Omnitrans network

This section describes how the networks for the different modes are derived from and adjusted in OmniTRANS. Figure 5 and Figure 6 display the original car and transport network in the OmniTRANS version which was provided by Almere on 30 September 2023. Figure 7 includes the mobility plans from the Almere Master Plan. These plans have been integrated into OmniTRANS. The results are shown in Figure 8.

Road Infrastructure: The road infrastructure is mainly focused on the car network with additional bike links to include sufficient roads for the macroscopic models to get a good connection out of the traffic zones.

Metro line: For public transport, the metro line has been moved to the planned location in the Master Plan and the new metro stops have been added. The metro has a frequency of 6 metros per hour. The old placement of the metro line is still drawn in the model, but the frequency is set to 0.

Bus stops: In the public transport network, the planned bus stops are also included. There is no information on how the bus would pass these stops therefore three bus lines have been created (see Figure 8). Bus line 1 runs between train station Almere Poort and train station Almere Centrum in both directions, which is also applicable for phase 1. Bus line 2 runs from Almere Centrum to Almere Poort. Bus line 3 runs in the opposite direction from Almere Poort to Almere centrum. All the buses have a frequency of 4 buses per hour.

Figure 5 Car network

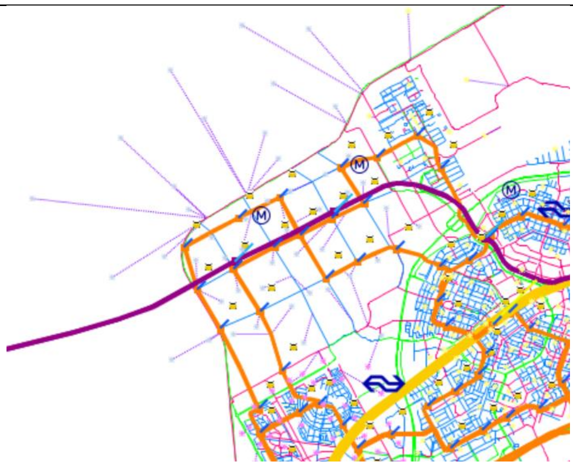


Figure 6 Public Transport Network

Road infrastructure | Car connections | Public transport network | Bike routes

Figure 7 Master Plan mobility network Pampus

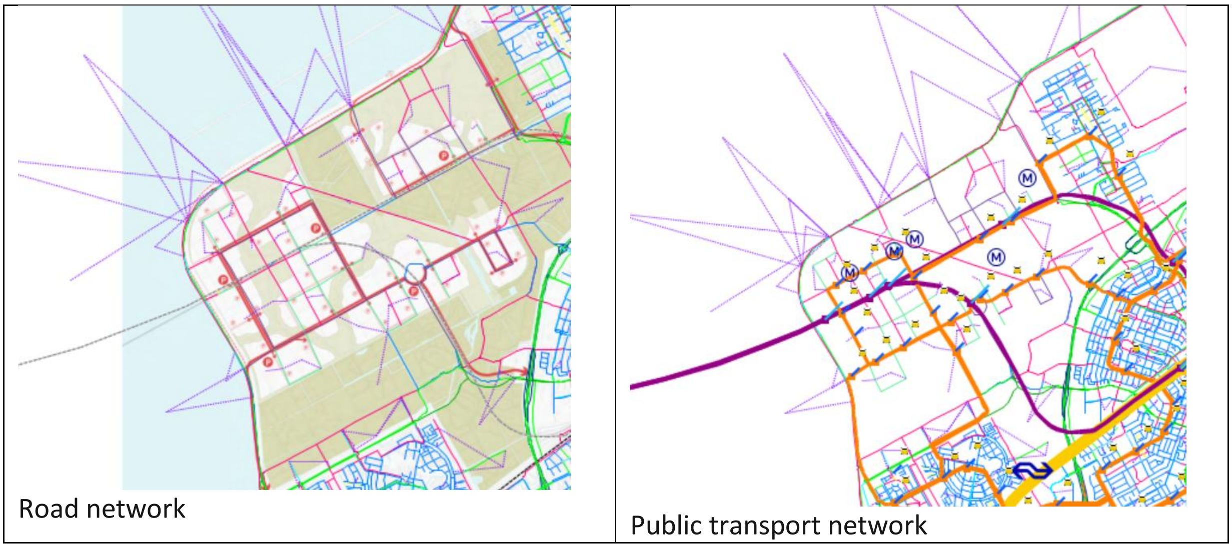


Figure 8 New OmniTRANS transport network for Pampus

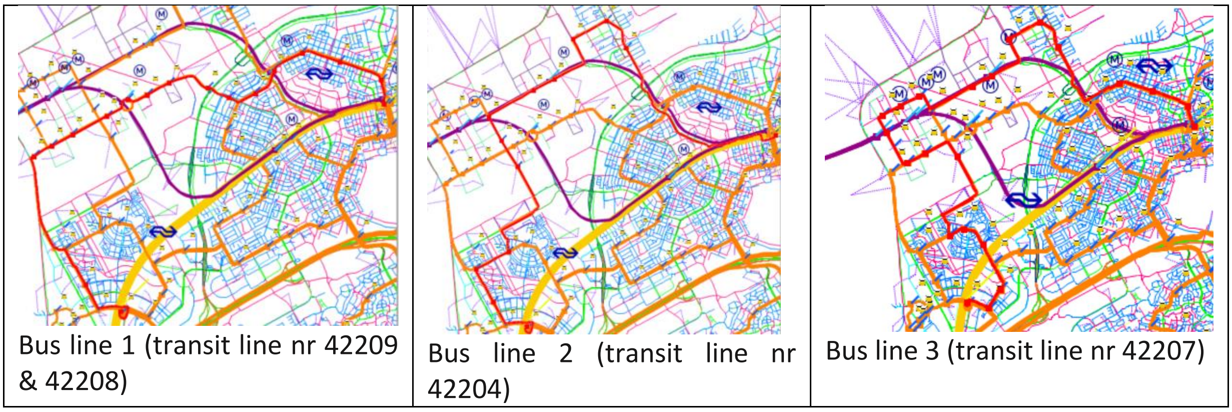


Figure 9 Highlighted in red the added bus lines servicing the bus stops from the Master Plan

To use these networks in the digital twin, the networks (car& freight network and bike & public transport network) are combined in one scenario in OmniTRANS.

4. Results and discussions

In this section, the findings are presented from simulations assessing the impact of various development scenarios in Pampus. First traffic-related key performance indicators (KPIs) are examined, followed by an evaluation of environmental impacts through emission KPIs. Finally, noise emission indicators across the different scenarios are discussed and compared.

4.1. Traffic-Related Indicators

4.1.1. Intensity

Figure 10 compares the total link-level intensities (i.e., across all travel purposes) for each development scenario. In this figure, the intensities are benchmarked against the scenario with a medium parking standard. Green indicates a reduction in link intensity compared to the medium parking standard scenario, while red signifies an increase. As expected, the higher parking standard results in higher traffic intensity on the road network.

To a large extent, these differences are explained by work trips. Figure 11 illustrates the differences in work trip intensities across Almere's road network under high, low, and medium parking standards for various development scenarios. The figure clearly shows that in the high development scenario (i.e., 30,000 inhabitants), the low car setting leads to a decrease in traffic intensity in Pampus and Almere Port, while traffic intensity increases in Almere Buiten. This suggests that under dense housing conditions, a low car scenario may shift traffic pressure to other districts, potentially increasing congestion in areas like Almere Buiten.

Figure 10 Differences in link level intensities between low/high car and medium scenarios for all travel purposes

Low parking standard | High parking standard

7500

15000

30000

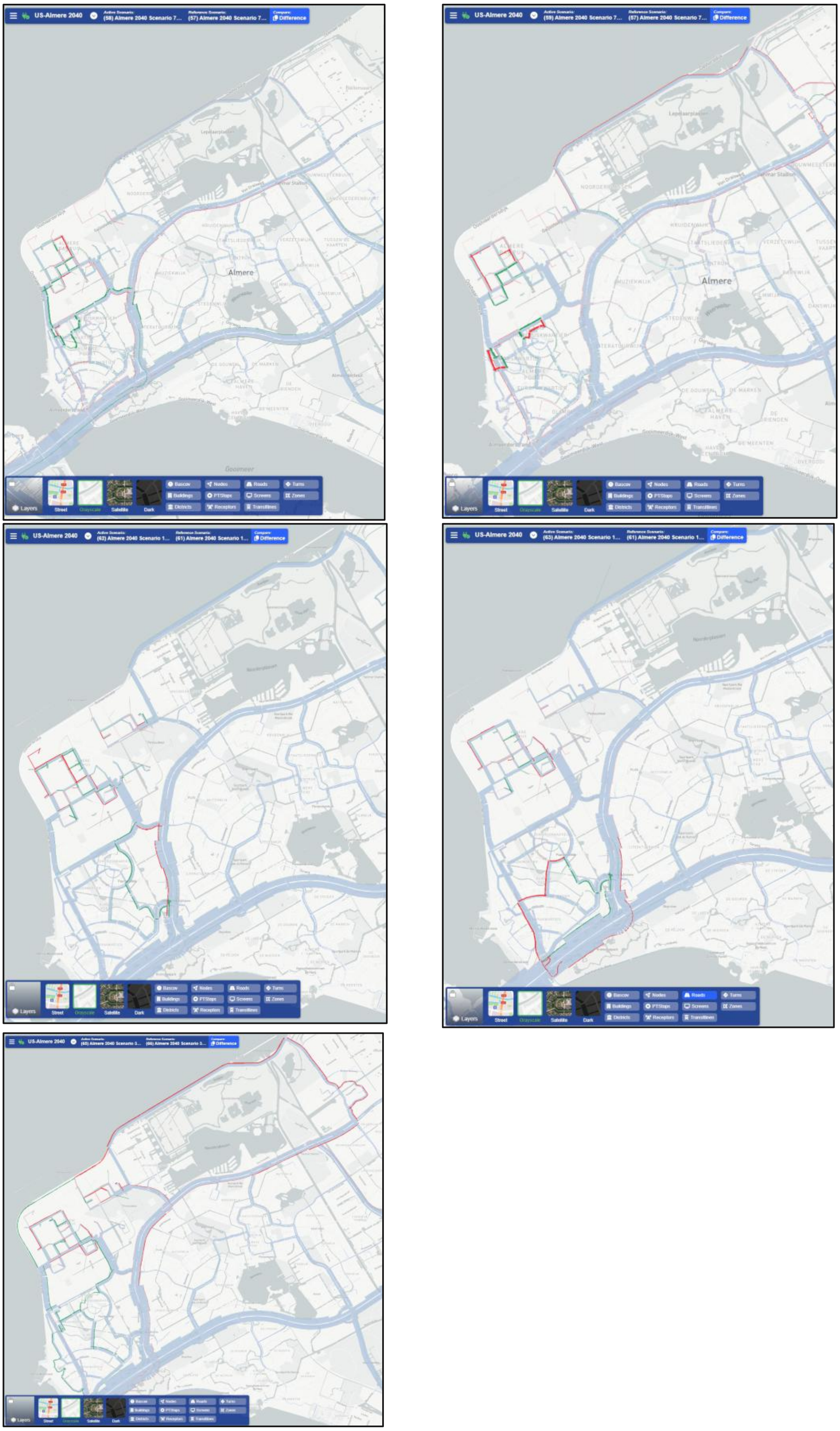


Figure 11 Difference in link intensities for work travel purpose.

4.1.2. Trip kilometres

This section compares vehicle kilometres travelled (VKT) across different population groups under varying parking pressure scenarios. As expected, trip distances tend to decrease with higher parking pressure across all scenarios, because of reduced car ownership and a shift to other modes. On average, the low car setting leads to a reduction in trip kilometres (Table 18) by approximately 8% in the scenario with 7,500 houses, 9% with 15,000 houses, and 10% with 30,000 houses.

It is important to note that the impact of parking standards is not uniform across all population groups. The results clearly indicate that older age groups tend to experience a greater reduction in trip kilometres. Additionally, lower-income groups show more pronounced changes—either reductions or increases—depending on whether the parking setting is low or high. However, income level appears to have a more limited influence on this KPI compared to age category.

Table 18 Trip kilometres for combinations of different levels of housing development and parking standards

Population group		7500			15000			30000	
		LC	MC	HC	LC	MC	HC	LC	MC
		TRIPKM	TRIPKM	TRIPKM	TRIPKM	TRIPKM	TRIPKM	TRIPKM	TRIPKM
1	age class 1, household income 1	106830	117820	119786	112662	126488	126474	127132	143814
2	age class 1, household income 2	103564	114306	114276	109332	120852	120834	122872	136804
3	age class 2, household income 1	170218	186230	199924	178222	209304	209288	203698	241006
4	age class 2, household income 2	195520	213240	221098	204508	231276	231258	231552	263754
5	age class 3, household income 1	177276	193358	192568	185668	201802	201782	208116	227632
6	age class 3, household income 2	191308	208454	207432	200234	217212	217194	224366	244908
7	age class 4, household income 1	167246	182494	180488	175250	189262	189246	196116	213094
8	age class 4, household income 2	182688	199088	194908	191322	204266	204246	213534	229260
9	age class 5, household income 1	138660	151478	147578	145476	155004	154990	162230	173826
10	age class 5, household income 2	156182	170482	165474	163786	173720	173704	182466	194570
Total		1589492 -8%	1736950	1743532	1666460 -9%	1829186	1829016	1872082 -10%	2068668

4.1.3. Parking intensities

Figure 12 to Figure 14 present heatmaps of parking intensities by parking type across zones in Pampus, covering all housing–parking combinations. These visualizations illustrate how parking demand is distributed spatially within the area. Although similar figures can be generated per trip purpose using the digital twin, the aggregated results are presented here as a representative example. The findings indicate that in the high car setting, where parking standards are more generous, residents tend to park within Pampus, resulting in a high concentration of parking activity in that area. Conversely, in the low car setting, outer zones become more popular for parking, particularly for street parking. This suggests a shift in parking behaviour due to reduced availability within Pampus.

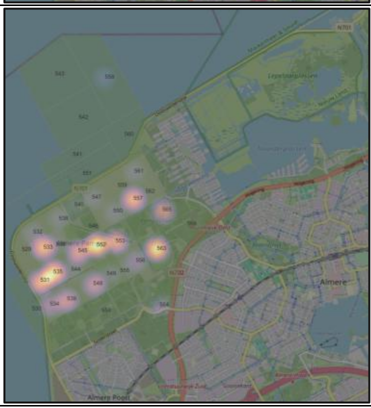
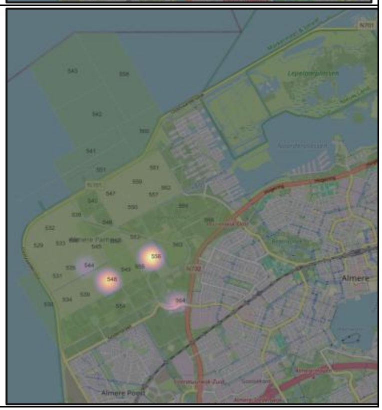
		Parking on own premises - residences	Parking on own premises - jobs	On street parking spaces
7500	Low parking			
	Medium parking			
	High car			

Figure 12 Comparison of parking intensities in each zone for 7500 scenario between high, low and medium parking standards

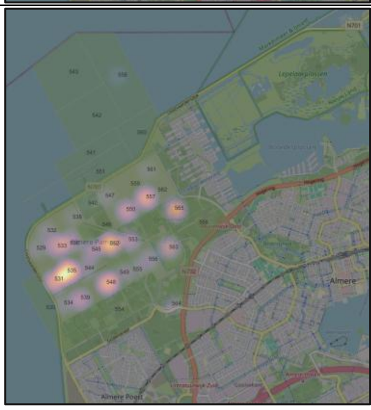
		Parking on own premises - residences	Parking on own premises - jobs	On street parking spaces
15000	Low parking			
	Medium parking			
	High car			

Figure 13 Comparison of parking intensities in each zone for 15000 scenario between high, low and medium parking standards

		Parking on own premises - residences	Parking on own premises - jobs	On street parking spaces
15000	Low parking			
	Medium parking			

Figure 14 Comparison of parking intensities in each zone for 30000 scenario between high, low and medium parking standards

4.2. Air quality

The digital twin is capable of calculating air quality (emissions and dispersion effects) within the study area. For each scenario, road traffic emissions—such as those for nitrogen dioxide (NO_2)—can be visualized. Figure 15 illustrates the NO_2 emissions for the scenario involving 7,500 housing units with a high parking standard as an example.

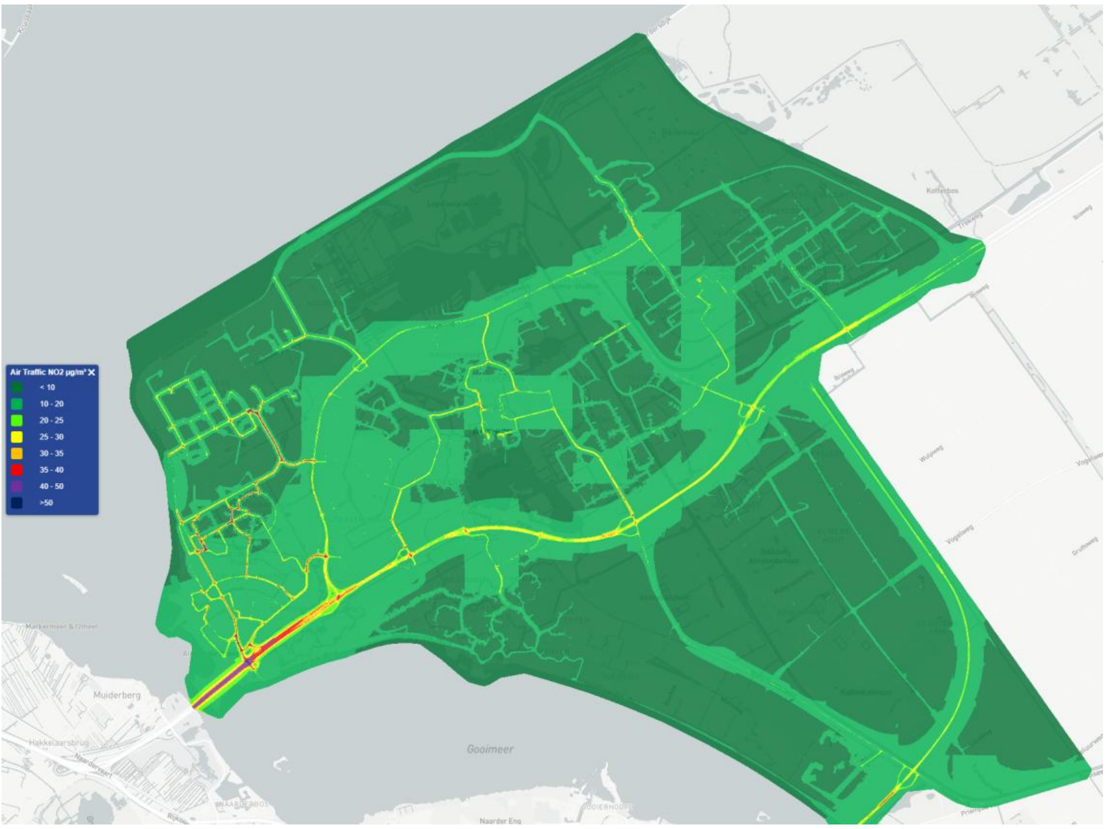
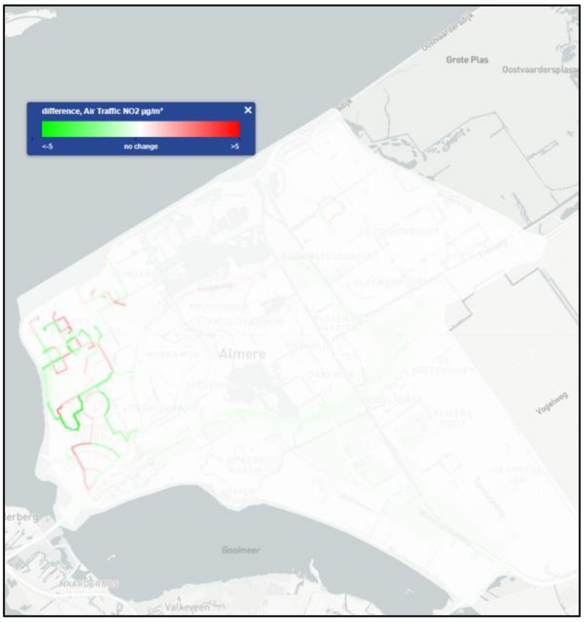


Figure 15 NO2 emission for the 7500 housing scenario with high parking standard

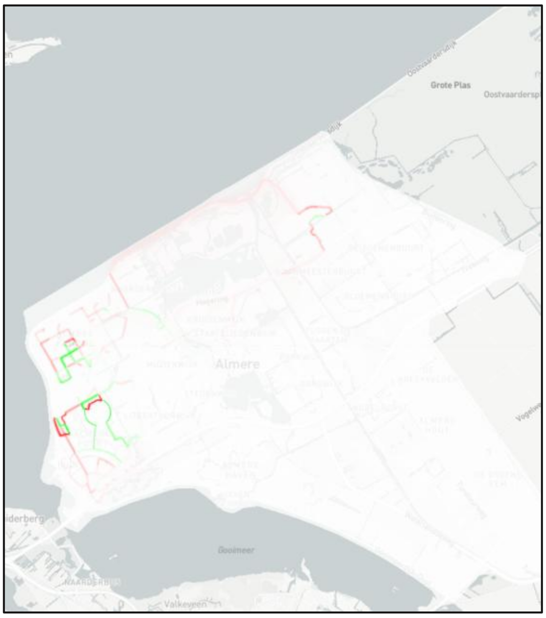
Similar to the comparison of road traffic intensities, air quality differences—such as variations in NO_2 concentrations—between high and low car scenarios are assessed. These comparisons can be extended across different development scenarios (see Figure 16). As expected, generally NO_2 emissions tend to be lower in scenarios with reduced car usage. However, in the highest development scenario (i.e., 30,000 inhabitants), emissions shift toward the areas surrounding Pampus. Table 19 shows that NO_2 levels are higher in the low-car setting compared to the medium-car setting for Almere_Spiegelhout_30000 and Almere_Hout_30000. Although Pampus is designed as a low-car area, some traffic appears to be diverted to surrounding areas, leading to increased emissions there.

For other pollutants, such as CO_2, no significant differences were observed between the scenarios.

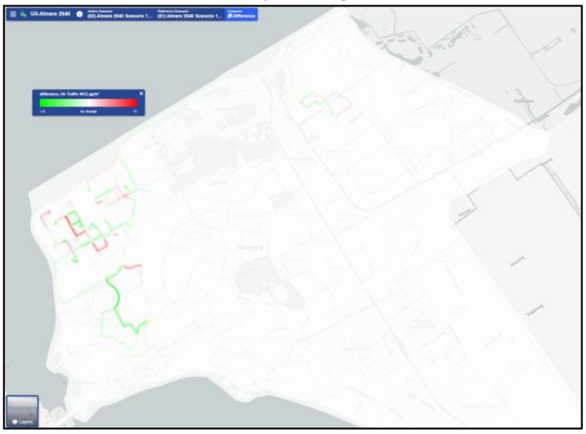
7500-Low parking standard



7500-high parking standard



15000-Low parking standard



15000-high parking standard

30000-Low parking standard

Figure 16 Difference in No2 emissions for low/high parking standard and medium scenarios

Table 19 district level No2 emission

DISTRICT_NAME	EMISSION_NAME	7500			15000			30000	
		LC	MC	HC	LC	MC	HC	MC	LC
Almere_Stad	NO2	4102	6157	6164	6175	6182	6182	6256	6256
Almere_Pampus	NO2	15944	30338	36699	19235	19257	19269	38040	37504
Almere_Centrum	NO2	15716	19025	30407	37563	37791	37807	19186	19162
Almere_Zuiderhout	NO2	809	795	1074	1169	1183	1202	1239	1163
Almere_Spiegelhout	NO2	4716	4716	4748	4748	4748	4748	4686	4716
Almere_Poort	NO2	13230	13339	18177	19066	19220	19190	18634	18256
Almere_Hout	NO2	12786	12797	14142	14106	14194	14200	14600	14660
Almere_Haven	NO2	104	106	260	262	273	274	273	267

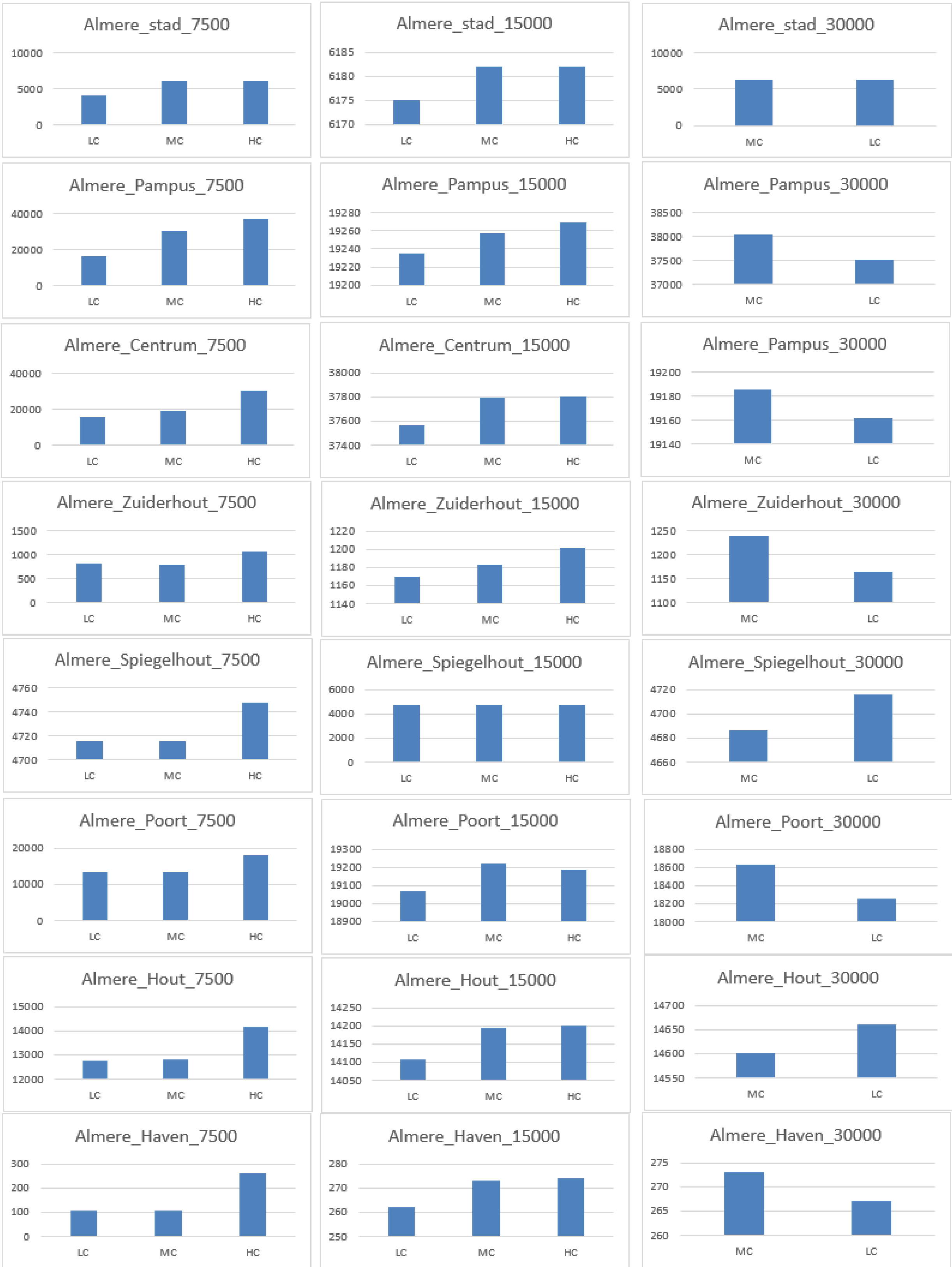


Figure 17 District level comparison for NO2 emissions

4.3. Noise

The digital twin can also compute inhabitants' annoyance levels due to noise emissions and dispersion effect, based on traffic intensities. The threshold for noise-related annoyance is set at 48 dB—the higher the noise levels, the greater the expected annoyance among residents. Figure 18 presents the noise levels in Almere for the scenario involving 7,500 housing units with a medium parking standard as an example.

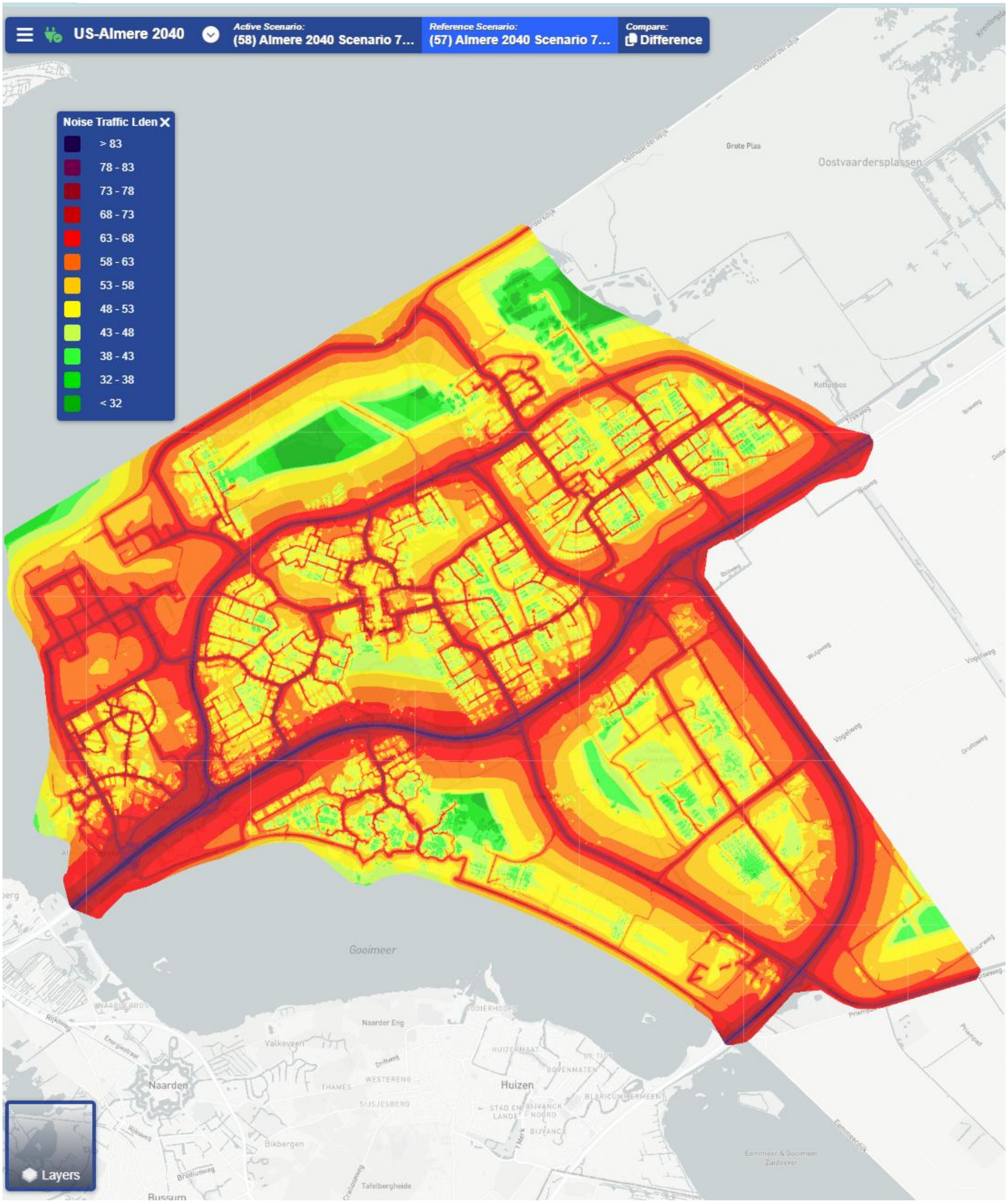


Figure 18 Traffic related noise for 7500 housing units and medium parking standard

Figure 19 compares the differences in noise emissions between the low and high parking standard scenarios, relative to the medium parking standard baseline. As shown in Figure 19, noise levels are generally lower in the low-car scenarios, reflecting reduced traffic intensities and associated emissions. A similar pattern can be observed here: in all scenarios with low car usage in Pampus, noise emissions tend to shift toward the surrounding areas.

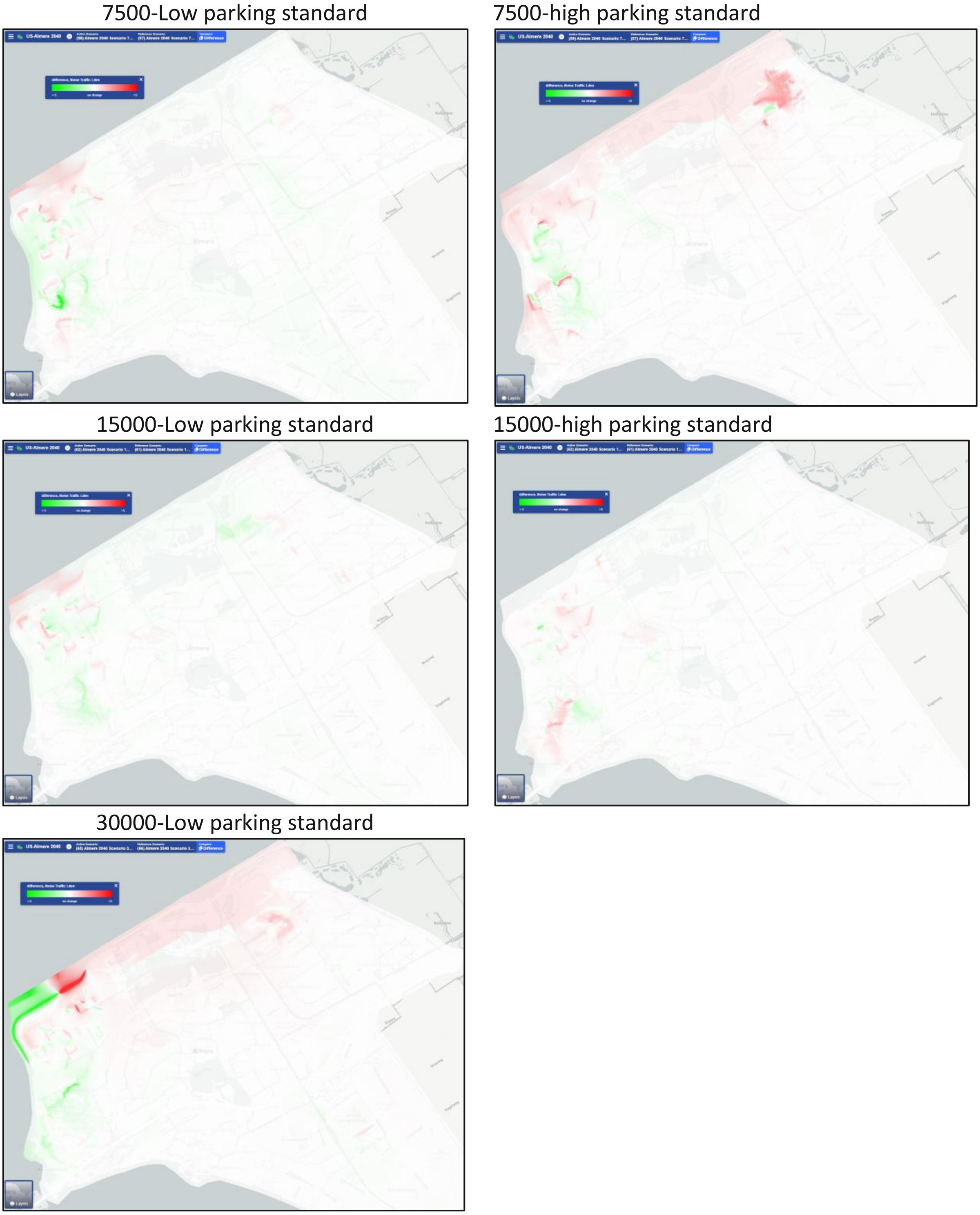


Figure 19 Differences in inhabitants' annoyance from noise emission

5. From Development to Deployment: Using the Models in Practice

In this section we explain how urban designers, spatial planners and policy makers at Almere municipality can utilize this developed toolset in practice.

- The car ownership model allows urban designers and/or spatial planners to select different parking standards and number of people in particular zones to calculate the number of cars per household types. This enables policy makers to see the potential behaviour adaptation of inhabitants under low car or high car pressure. The predicted number of cars then can be used in SEGs file to run Omnitrans model. The Omnitrans model then can predict the impact of these changes on the traffic system.
- The parking model allows urban designers and/or spatial planners to select different parking norms. The model then calculates the available parking capacities, per zone, accordingly. The traffic model then takes the predicted parking capacity as well as parking costs into account while assigning travelers' trips to the transport network. This would result in rerouting or reconsidering travel mode by travelers if not enough parking space is available in their destination. Designers can identify the high parking intensities at zone level. With this designers and/or planners can determine tradeoffs between parking standards, parking costs, and parking intensities or try to compensate that with adding shared mobility services out side the low car areas for mode transfer (e.g. car to bike) to inside the low car areas.
- The urban designer and/or spatial planners can change the number of inhabitants as well as number of jobs in the design area. The model can redistribute the new numbers across zones and use that as input to the Omnitrans model. The Omnitrans model can then predict the impact of these changes on the traffic system.

6. Conclusions and recommendations

In this report, the case of Almere Pampus for future housing developments is examined, with a particular focus on the impact of parking standards as a policy intervention to mitigate high car densities. The key findings include:

1. Parking standards affect population groups differently. For example, car ownership among older age groups is generally more sensitive to parking pressure, which highlights the potential for targeted mobility policies tailored to demographic segments.

2. In the highest development scenario (30,000 housing units), implementing a low car policy in Pampus improves air and noise quality within Pampus itself, but may lead to deterioration in surrounding areas. It is recommended to consider compensatory or preventive measures for these affected zones.

3. The low car scenario encourages a modal shift toward public transport and cycling, contributing to a reduction in car usage and supporting more sustainable mobility patterns.

4. In the low car setting, outer zones become more popular for parking, particularly for on street parking. This indicates a shift in parking behaviour due to restricted parking availability within Pampus.