HARMONY
SPATIAL & TRANSPORT PLANNING FOR A NEW MOBILITY ERA

Holistic Approach for Providing Spatial & Transport Planning Tools and Evidence to Metropolitan and Regional Authorities to Lead a Sustainable Transition to a New Mobility Era

D2.5 Spatial and Transport Planning Scenarios Simulation Results

Submission date: 03/04/2023

SUMMARY SHEET

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Table of Contents

LIST OF TABLES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

LIST OF FIGURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
HMS	HARMONY Model Suite
KPI	Key Performance Indicator
UCH	Urban Consolidation Hub
AR	Autonomous Robots
EB	Electric Bicycle
VKT	Vehicle Kilometres
HGV	Heavy Good Vehicles
GHG	Greenhouse Gases
LEV	Light Electric Vehicle
ZEZ	Zero Emission Zone
DFM	Demographic Forecasting Model
LUTI	Land-Use and Transport-Interaction
REM	Regional Economy Model
LDM	Land Development Model
TPS	Tactical Passenger Simulator
TFS	Tactical Freight Simulator
OD	Origin-Destination
GIS	Geographic Information System
PA	Primary Activity

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HBW	Home-based work (Home – Work – Home tour)
HBO	Home-based other (Home – Other – Home tour)
NHB	Non-home-based Tour
WBO	Work-based Tour
RW	Remote Work
MC	Mode Choice
DRT	Demand Responsive Transit
MaaS	Mobility-as-a-Service

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EXECUTIVE SUMMARY

Metropolitan areas are currently responsible for over two thirds of greenhouse gas emissions and energy consumption and are therefore at the heart of any attempt to address climate change. With transport being a key sector in carbon emissions and travel demand reaching pre-pandemic levels, there is an immediate need to decarbonise the transport sector. However, expanding urban sprawl in metropolitan areas has led to a growth in private car ownership and its use with widespread congestion becoming the norm in many cities, thereby reducing people's quality of life through negative externalities, such as pollution or increased travel times. While public transport systems could massively reduce the carbon footprint of private motorised transport, efficient public transport requires large subsidisation with the traditional line and frequency-based services suffering low ridership from low-demand areas; thus, warranting an innovative approach to its planning and operation. Additionally, administrative boundaries do not always cover entire metropolitan areas, resulting in disjointed mobility policies and transportation systems. This often leads to inefficient services, poor regional connectivity and accessibility, and inconsistent fares or schedules within metropolitan areas.

The rapid ICT advancements over the past decade has enabled the emergence of several innovative mobility systems which has the potential to make the urban mobility landscape more efficient. However, public authorities face several challenges when it comes to harmoniously integrating these systems into spatial and transport plans to improve service efficiency, user satisfaction, and achieve environmental targets. Against this background, HARMONY's main goal is to develop the HARMONY Model Suite (HMS) – a spatial and transport planning tool, which will enable metropolitan planning organizations to conduct policy, investment, and new mobility concept analyses, leading the transition to a low carbon new mobility era in a sustainable manner. The HMS is a software-agnostic, web-based integrated land-use, and transport model system, capturing the transport system dynamics that new services and technologies introduce; based on state-of-the-art behavioural and operational modelling approaches. The HMS is entirely developed within the HARMONY project with the main purpose of assisting transport modelers and planners and allows the combination of different transport models –at different levels of abstraction including strategic, tactical, and operational – and provides an intuitive way of running the combined models and comparing their results. Lastly, it presents the process of integrating new modelling components to the platform and details on the interface between the HMS and three existing widely-used transport modelling tools-simulators –AIMSUM Next, PTV Visum, and SUMO.

In this context, the focus of this report is to present and describe the modelling use-cases, simulation scenarios, and results that were produced through the HMS in four of the project's pilot areas, namely Rotterdam (NL), Oxfordshire (UK), Turin (IT) and Athens (GR). The simulation scenarios were chosen for each city that pertain to the three interdependent levels, namely the *strategic level*, *tactical level and operational level.* The *strategic, tactical, and operational* levels are respectively focusing on modelling i) land-use, demographics evolution and economic growth, ii) daily passenger and freight mobility patterns and iii) multimodal networks with within-day supply-demand interactions. Specifically, at the *strategic level*, land-use, regional economy, and demographic forecasting models generate aggregate population, employment, housing, and education information which are being translated into a synthetic population of households, travellers, firms and commodities. At the *tactical level*, state-of-the-art activity and agent-based modelling frameworks generate habitual demand estimates in the form of activity schedules and freight tours (trip chains). Finally, at the *operational level*, demand estimates for individuals are loaded into multimodal networks, generating traffic volumes, travel times and other network impedances. The chosen scenarios for each city focus on their integration, extent of information exchange and interaction between the three levels. The simulation scenarios along with the generated results for each city demonstrate the various functionalities at play for each of the three levels, the required input data, key performance indices, and how to interpret the results. Most importantly, the report demonstrates how the HMS can be used by researchers, practitioners, and planners to better design their cities and make the urban mobility landscape more efficient, equitable and sustainable.

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1. Introduction

Project Summary

HARMONY's main vision is to develop a new generation of harmonised spatial and multimodal transport planning tools, which comprehensively model spatial organization and the changing transport sector's dynamics, enabling regional and urban planning organizations to lead the transition to a low carbon new mobility era in a sustainable manner. HARMONY's objective is to assist metropolitan areas with evidence-based decision making, by providing a state-of-the-art model suite that quantifies the multidimensional impact of various policies, investments, and mobility concept applications, while simultaneously identifying the most appropriate solutions and recommending ways to exploit the disruptive mobility innovations. As illustrated in Figure 1, the fundamental complexity of such an endeavour was addressed by disentangling and organizing the workload into six main axes (A1-6). This deliverable focuses on presenting how the outcomes of A4 – namely the HARMONY Model Suite (MS)- were utilised to support the HARMONY metropolitan areas with decision making.

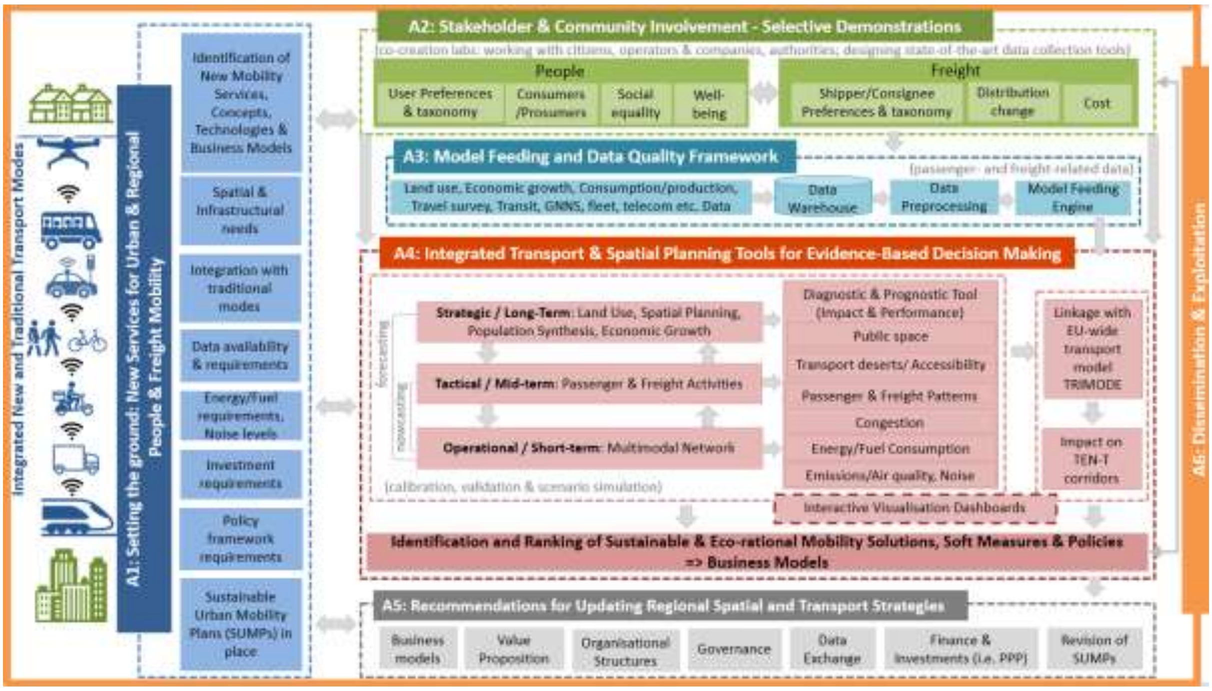

Figure 1: The HARMONY conceptual architecture

Deliverable Objectives

The objective of D2.5 is to present the results of the co-created scenarios' simulation for the trailblazing (Rotterdam and Oxfordshire) and aspiring (Athens and Turin) metropolitan areas. Its ultimate objective is to showcase how the HARMONY Model Suite (MS) was utilised to simulate the scenarios/use cases that the four metropolitan areas provided; verifying as such at the same time the delivery of the HARMONY MS to a TRL7. In addition, this deliverable acts as a report where the four HARMONY metropolitan areas can find all the results of the use cases they provided, as well as how the HARMONY MS was utilised.

Given the scenarios/use cases co-created by the metropolitan areas, the below HARMONY MS simulators were utilised for each area:

- Rotterdam: Strategic and Tactical-Freight simulators;
- Oxfordshire: the Strategic, Tactical-Passengers, and Operational simulators;
- Athens: the Strategic simulator;
- Turin: the Strategic and Tactical-Passengers simulators.

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2. Use Cases Simulations: Rotterdam

2.1 The use cases for Rotterdam

Metropolitan areas are facing fast-growing and innovative mobility services to address inefficiencies in the freight and passenger transport system. City managers and policymakers are now obliged to cope with associated pollution, increased travel times, poor regional connectivity, and accessibility. Therefore, the main goal of the HARMONY project is to develop spatial transport planning tools, which enable metropolitan planning organizations to develop and evaluate policies, prioritize policy measures, and analyse new mobility concepts that would ease the transition to a low-carbon new mobility era.

The Tactical Freight Simulator (TFS) is the component of the HARMONY MS that simulates the demand for urban freight transport. The TFS is a multi-agent simulator that represents the decision-making of freight agents on the level of individual firms and individual freight shipments and can be applied to quantify the effect of future scenarios on the urban freight transport system. It aims to support local authorities such as the City of Rotterdam to ensure sustainable development of city logistics. The general policy objective of metropolitan planning organizations is to ensure the accessibility and liveability of the city. And this needs to be achieved in a dynamic environment of city logistics with many innovations in new technologies and services such as deliveries by drone or automated robot, or the growth of e-commerce demand. Challenge in developing a simulator for city logistics is the wide scope of technological developments. In this paper, we provide a synthesis of four different simulation case studies with the TFS that are introduced as follows.

2.1.1 Use case 1: Micro-hubs

The increasing competition for urban space has driven logistics facilities outside of city centres to peripheral locations (Dablanc, et al., 2014), increasing the vehicle kilometres for logistics. To defragmentise the B2C last-mile delivery streams, micro hubs are introduced as a possible solution as they can increase the consolidation of inner-city deliveries (Aljohani & Thompson, 2016). As per the definition of the Urban Freight Lab (2020), micro hubs are “logistics facilities inside the urban area boundaries where goods are bundled, which serve a limited number of destinations within a bounded spatial range and allow a mode shift to low (or zero) emission vehicles or soft transportation modes (e.g., walking) for last yard deliveries.

The objective of this use case is to explore the impact of nine different scenarios of the large-scale implementation of micro hubs on the transportation system. Although it is a well-studied topic in city logistics, it is not completely clear how different configurations of a micro hub concept will affect the transportation system in terms of transport movements, number of travelled kilometres, etc. The case study explores three different design aspects: location, type of vehicles (delivery robots, cargo bike, LEV), and the business model (individual/full collaboration). Assumptions in the simulation scenarios are based on the Rosie demonstration in the HARMONY project, retrieved from the literature, as well as other recent Living Labs in Rotterdam (van Duin, et al., 2022).

2.1.2 Use case 2: Zero-emission zone for City Logistics

Rotterdam has announced the introduction of a Zero-Emission zone as part of the Green Deal Zero Emission City Logistics that aims at reducing CO2 emissions and improving both air quality and accessibility in the city. The zero-emission zone implies restricted access to the city centre (only with zero-emission vehicles are allowed) and consolidation of shipments in urban consolidation hubs (UCCs) on the outskirt of the city. The ZE-emission zone spans a ± 40 km2 area of the city within the orbital ring road. The simulations are based on the transition scenario presented in the Road Map zero-emissions City Logistics. Two types of behavioural responses are considered: a shift from the conventional vehicle to vehicles with a zero-emission driveline, or a shift of distribution structure where shipments are first consolidated via an UCC and distribution within the ZEZ takes place using LEVV, cargo bikes or small electric vans or trucks.

2.1.3 Use case 3: Crowd shipping

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Crowd shipping is one of the new opportunities and business models for last-mile logistics, that links parcel carriers to individual travellers on digital platforms. Crowd shipping is considered a solution to make use of the capacity of passenger transport in delivering parcels to customers. It could work in parallel with traditional delivery methods (conventional carriers) to make last-mile delivery more sustainable and efficient (Punel et al.,2018 & Rai et al., 2017). Although crowd shipping seems to be beneficial in terms of capacity utilization in the transport system, its pros and cons have not yet been explored thoroughly due to its complexity. In this use case, the TFS module is used to simulate the impacts of different implementation scenarios of crowd shipping services in the study area. With this simulation experiment, the viability of crowd shipping is explored by assessing its positive and negative impacts on both freight and passenger transport systems.

2.1.4 Use case 4: Land use planning of logistic and industrial sites

The increasing competition in urban space has driven many logistic activities outside of the city centres into peripheral locations, also referred to as logistic sprawling (Dablanc et al., 2014). In addition, the size of logistic facilities is scaling up: almost half of the total logistic surface area is hosted by large distribution centres of >20.00 m2 (Onstein et al, 2021). The locations of these facilities have a direct impact on accessibility, liveability, and sustainability, including visual intrusion of the landscape. Regional coordination of the location planning of logistic facilities can be an effective tool to mitigate the external impacts of new logistic facilities but policies are lacking. In this use case, the TFS was used to simulate the impacts of two different land use planning scenarios for logistics facilities on local traffic flows and emissions.

2.2 Application of the HARMONY MS simulators

The use cases are explored with the TFS, a multi-agent urban freight transport demand model developed in HARMONY to simulate the decision-making of freight agents on the level of individual firms and individual freight shipments. It allows policymakers to quantify the effects of future scenarios on the freight transport system. The TFS distinguishes three main segments of urban commercial vehicle movements: Freight Shipments, Parcels, and Services. The model also distinguishes two phases. The first phase is the long-term tactical level that simulates shipment- and parcel demand in the shipment synthesis or demand modules. The second phase is the daily scheduling of the final transport movements in the scheduling modules. Separate scheduling modules are developed for freight shipments and parcel delivery because the size and consolidation of individual products (shipments or parcels) are inherently distinct.

Most of the inputs to the TFS are based on standard data from conventional transport models: networks, socio-economic data, and additional data on the location of logistic nodes. The firm population is synthesized from the zonal employment by industry sector. Aggregate commodity demand forecasts are derived from an external source, preferably an intermodal freight transport demand model.

2.3 Tactical models template: simulation results and evaluation

In this section, we elaborate on the results and evaluation of each use cases.

<u>2.3.1 Micro Hubs:</u>

The impacts from the 9 microhub scenarios are evaluated using a variety of indicators. The following key performance indicators (KPIs) were selected to evaluate the aspects of the performance of each examined scenario:

1. Number of tours per vehicle
2. Capacity usage of vehicles:
3. Number of tours using full capacity per vehicle
4. Average capacity utilization per tour per vehicle
5. Total number of kilometres travelled when capacity utilization is 0% per vehicle
6. Vehicle kilometres
7. Average tour distance per vehicle

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8. Total number of kilometres travelled in/out of the ZEZ per vehicle

The next Figure shows a snapshot of the simulation use cases implemented in the simulator.

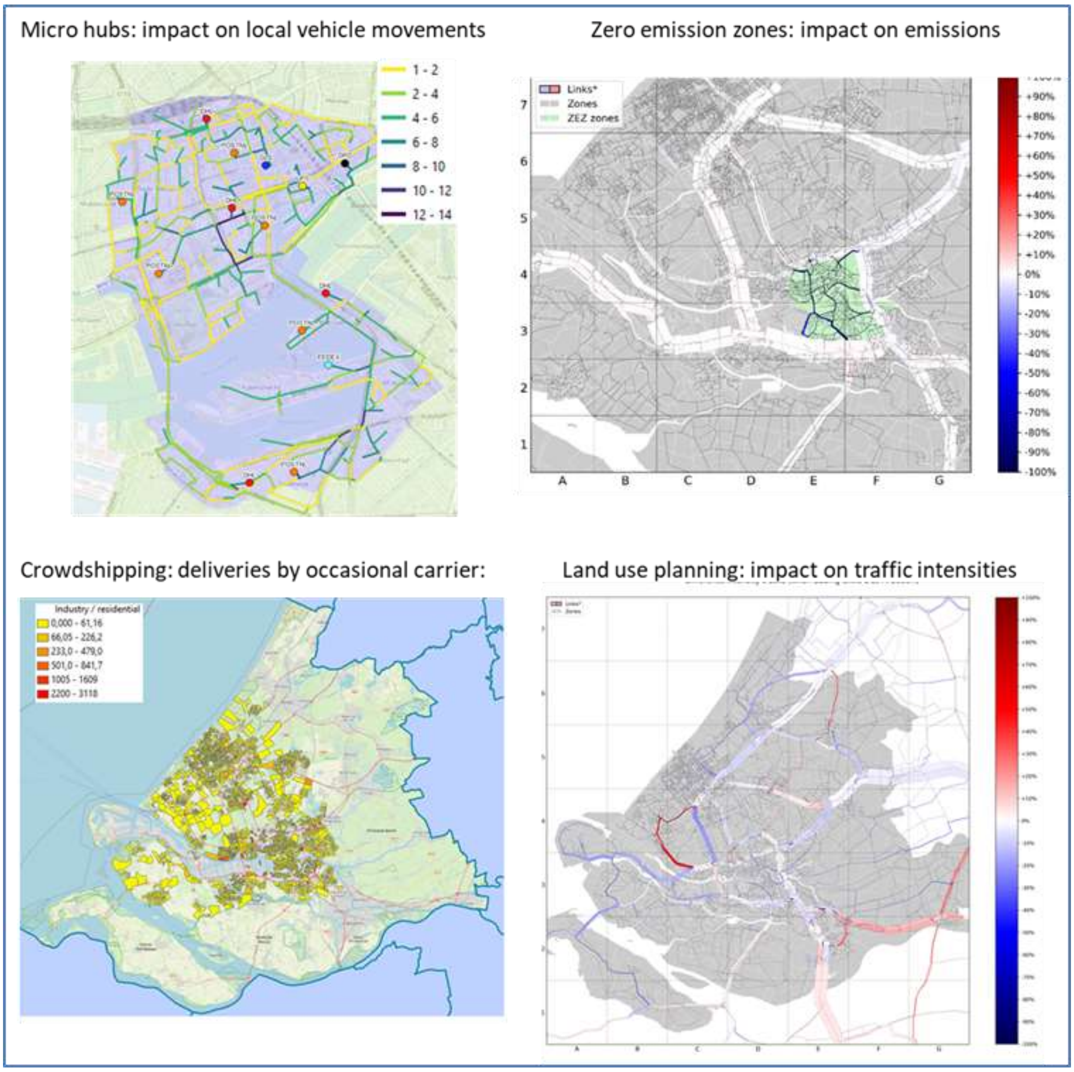

Figure 2 Examples from the simulation use cases

<u>Number of tours</u>

Every CEP has multiple depots spread around the region which can act as the supply chains' origins. Multiple depots from the same CEP can serve the same study area as they are assigned to microhubs based on their proximity. At the same time, every selected depot is responsible for its last-mile delivery, meaning that a truck does not visit other selected depots to collect parcels before arriving at the assigned microhubs. This indicates that, regardless of the number of parcels that need to be transported, a minimum of one tour is guaranteed per selected depot. It can be understood then that the higher the number of microhubs per CEP, the higher the possibility that a larger number of different depots is selected, which indirectly translates to a larger number of truck tours, for example in the individual CEP and full-collaboration models (see Table 1). In contrast, a lower number of microhubs per CEP, as in the hybrid model, can lead to a higher consolidation potential of parcels which can sequentially affect the final number of constructed tours

Table 1 Number of tours indicator per vehicle types

Scenario	Business model	Mode Abb.	TRUCK	VAN	AR	EB	LEV

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0	Reference scenario	VAN	-	44	-	-	-
1	Individual CEP model	AR	9	-	176	494	-
2		EB	9	-	-	559	-
3		LEV	9	-	-	-	47
4	Hybrid model	AR	8	-	120	511	-
5		EB	8	-	-	556	-
6		LEV	8	-	-	-	44
7	Full-collaboration model	AR	9	-	324	430	-
8		EB	9	-	-	556	-
9		LEV	9	-	-	-	44

Looking at Table 1, the full-collaboration model appears to favour the usage of autonomous robots (AR), which should be reminded to operate only on a 500m radius around each microhub. This can be explained as the flexibility to operate every available microhub means that the parcels are already delivered to their closest microhub by truck. This consequentially leads to microhubs attracting a higher number of parcels which have as a final destination the zones around it. Considering the 500m radius rule, it is clear in this case that the AR usage for the last-yard delivery will be increased. Considering the low capacity of the AR, it is understandable why the number of tours is so high in comparison to other modes.

At the same time, the AR usage for the individual CEP model is higher than for the hybrid business model even though no facility sharing takes place, which can be explained by the fact that the number of considered microhubs is almost double. A higher number of microhubs indicates that they occupy more urban space, and in this case, CEPs like PostNL or DHL are assigned the majority of microhubs (10 out of 14) as they are the largest market shareholders. This factor in combination with the above reasoning of microhubs attracting more local demand, explains the increased AR usage. Nevertheless, this mode's usage for the individual CEP model is almost half of that in the full-collaboration model due to the decreased degrees of freedom.

It is straightforward that the higher the AR usage is, the lower the electric bicycle (EB) usage becomes when they operate simultaneously. For this reason, when the main mode is AR, the full-collaboration model presents the least number of EB tours, but simultaneously the largest number of zero-emission vehicle movement s. In contrast, the hybrid model presents the largest number of EB tours but at the same time the lowest total number of green vehicle movements.

As regards the number of tours per EB when the main mode is EB, all the models seem to perform similarly. Only the Individual CEP model constructs three additional routes for this mode which may be attributed to the fact that the bicycles carry only parcels from the CEP they are assigned to. Therefore, parcels assigned to the same destination but originating from different CEPs cannot be transported by the same bicycle, as could be witnessed partially in the hybrid model and to its full extent in the full-collaboration model. This indicates that the micro-consolidation potential for the last-yard delivery is

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lost, hence requiring the construction of additional routes. The fact that the biggest shareholders are assigned to the majority of the microhubs in the Individual CEP model, meaning they have a large proportion of the clients and sequentially carry the majority of the parcels, compensates for the loss of the micro-consolidation potential.

Similarly, to the EB, the LEV usage per examined model is similar as the number of constructed tours is almost the same for every examined model. It is important to recognize nevertheless that the number of tours with the LEV is almost twelve times lesser than the number of tours with the EB, which may provide considerable operational advantages.

Capacity usage of vehicles

Table 2 Number of tours using full capacity per vehicle

Scenario	Business model	Mode Abb.	TRUCK	VAN	AR	EB	LEV
0	Reference scenario	VAN	-	38	-	-	-
1	Individual CEP model	AR	1	-	165	480	-
2		EB	1	-	-	545	-
3		LEV	1	-	-	-	33
4	Hybrid model	AR	0	-	114	503	-
5		EB	0	-	-	548	-
6		LEV	0	-	-	-	36
7	Full-collaboration model	AR	1	-	320	424	-
8		EB	1	-	-	549	-
9		LEV	1	-	-	-	36

The truck utilized for the last-mile delivery has the largest capacity among the examined modes at 1800 parcels. Due to this reason, it is logical that its capacity will not be easily fully utilized, especially for CEPs which don't occupy large shares in the market. From Table 2 it can be seen that for the hybrid model not even one tour utilizes the full vehicle capacity, while one tour does so for the rest of the models. Nevertheless, looking back at Table 1 it can be seen that the hybrid model constructs one lesser tour than the rest of the models. This may indicate that the parcel demand is more evenly distributed among tours, which limits the necessity for that additional tour. Evidence of this is provided in Table 3, where the average truck capacity utilization per tour for the hybrid model is at 50%, while for the rest of the models is at 44%.

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Table 3 Average capacity utilization per tour per vehicle

Scenario	Business model	Mode Abb.	TRUCK	VAN	AR	EB	LEV
0	Reference scenario	VAN	-	91%	-	-	-
1	Individual CEP model	AR	44%	-	97%	98%	-
2		EB	44%	-	-	99%	-
3		LEV	44%	-	-	-	85%
4	Hybrid model	AR	50%	-	99%	99%	-
5		EB	50%	-	-	99%	-
6		LEV	50%	-	-	-	91%
7	Full-collaboration model	AR	44%	-	99%	100%	-
8		EB	44%	-	-	99%	-
9		LEV	44%	-	-	-	91%

For the scenarios where the main mode for last-yard delivery is the light electric vehicle (LEV), it can be observed that the hybrid and full-collaboration models perform better than the individual CEP model. More specifically, they both construct 44 tours of which 36 start their first trip utilizing the full vehicle capacity, while the individual CEP model constructs 47 tours of which only 33 use their full capacity (see Table 1 and Table 2). Looking at Table 3, we can also observe that the average LEV capacity utilization for the hybrid and full-collaboration models stands at 91%, while for the individual CEP model at 85%. Since the parcel demand is distributed differently in each business model, it is important to acknowledge the gains that can be achieved with the hybrid and full-collaboration models when a lower number of tours can transport the same number of parcels by utilizing their capacity better. Of course, this can be attributed to the micro-consolidation that takes place in the aforementioned models. Similar results can be observed for the scenarios where the main mode for last-yard delivery is the electric bicycle, fact which enhances the above observation.

Regarding the scenarios that have as a main mode the AR, the above observation cannot hold as each business model affects this mode's usage very differently. It can be observed, nevertheless, that the full-collaboration model provides the best results in terms of capacity utilization as 320 out of the 324 AR tours and 424 out of the 430 EB tours are fully utilized (see Table 2). Table 3 supports this observation as the average capacity utilization for both these vehicles stands respectively at 99% and 100%. This concludes that the full-collaboration model, even though constructing the highest number of tours in the scenarios where the main mode is AR, and similar number of tours for the rest of the vehicles, still promotes a higher vehicle capacity utilization than the rest of the business models.

<u>Vehicle kilometres</u>

Table 4 shows for every examined scenario the total number of kilometres travelled in and out of the ZEZ per vehicle. If we set aside the zero-emission vehicles', it is easy to see that by implementing the concept of microhubs, the total number of movements with large vehicles in the ZEZ can be reduced. This is very important if we consider the fact that those movements are currently performed with diesel vehicles. To be more specific, the total number of kilometres travelled in the ZEZ with vans for the

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reference scenario is 776, while the corresponding number of kilometres travelled with a truck in the worst performing model, which is the full-collaboration model, is around 140. If we compare the scenarios where the LEV is used as the last-yard mode, as it is equivalent to the van in terms of capacity, we can still see that the total travelled kilometres in the ZEZ are reduced. More specifically, the combined total number of kilometres of trucks and LEVs for the worst performing model, which is the Individual CEP model is 416, which is still almost half of the reference scenario.

Table 4 Total number of kilometres travelled in/out of the ZEZ per vehicle

Scenario	**Business model**	**Mode Abb.**	**TRUCK**			**VAN**			**AR**			**EB**			**LEV**		
			TOT KM	IN ZEZ	OUT ZEZ	TOT KM	IN ZEZ	OUT ZEZ	TOT KM	IN	OUT	TOT KM	IN	OUT	TOT KM	IN	OUT
0	Reference scenario	VAN	-	-	-	958.4	776.0	182.4	-	-	-	-	-	-	-	-	-
1	Individual CEP model	AR	284.8	82.9	201.9	-	-	-	94.1	94.1	-	1623.2	1623.2	-	-	-	-
2		EB	284.8	82.9	201.9	-	-	-	-	-	-	1663.1	1663.1	-	-	-	-
3		LEV	284.8	82.9	201.9	-	-	-	-	-	-	-	-	-	333.0	333.0	-
4	Hybrid model	AR	270.3	69.7	200.6	-	-	-	59.6	59.6	-	1664.5	1664.5	-	-	-	-
5		EB	270.3	69.7	200.6	-	-	-	-	-	-	1689.6	1689.6	-	-	-	-
6		LEV	270.3	69.7	200.6	-	-	-	-	-	-	-	-	-	218.5	218.5	-
7	Full-collaboration model	AR	278.9	139.4	139.5	-	-	-	155.9	155.9	-	893.4	893.4	-	-	-	-
8		EB	278.9	139.4	139.5	-	-	-	-	-	-	953.4	953.4	-	-	-	-
9		LEV	278.9	139.4	139.5	-	-	-	-	-	-	-	-	-	101.3	101.3	-

As previously observed in Table 1, 9 truck tours are constructed for both the individual CEP model and the full-collaboration model, with their total number of travelled kilometres almost matching, if we look at Table 4. Nevertheless, the road network usage for each of these models is very different when we compare their activity in and out of the ZEZ. The full-collaboration model makes more use of the road

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network inside of the ZEZ zone (see Figure 2-2), which can be explained by the fact that the trucks have to travel to all 8 microhubs to deliver their assigned parcels. It is interesting to point out that for this model, the trucks visit the closest microhub to their origin depot first, thus decreasing the number of kilometres travelled outside of the ZEZ. In contrast, the individual CEP model makes more use of the network outside of the ZEZ zone (see Figure 2-3) as the trucks must visit first only one of their closest *assigned* CEP microhubs, therefore they lack the flexibility of the full-collaboration model.

The hybrid model exhibits characteristics of the Individual CEP model but proves that the number of microhubs can be of trivial importance in the travelled kilometres inside or outside the ZEZ. From Table 4 it can be seen on one hand, that they hybrid model leads to almost the same number of truck kilometres outside of the ZEZ as the individual CEP model, even though the latter has 6 additional microhubs. On the other hand, even though they hybrid model has the same number of microhubs as the full-collaboration model, it can be seen that it leads to almost half of the number of kilometres travelled inside the ZEZ. In comparison to the Individual CEP model, it leads to just 13 lesser kilometres which again indicates that the number of microhubs is not an important factor.

Table 5 Average tour distance per vehicle

Scenario	Business model	Mode Abb.	TRUCK	VAN	AR	EB	LEV
0	Reference scenario	VAN	-	21.78	-	-	-
1	Individual CEP model	AR	31.64	-	0.53	3.29	-
2		EB	31.64	-	-	2.98	-
3		LEV	31.64	-	-	-	7.09
4	Hybrid model	AR	33.78	-	0.50	3.26	-
5		EB	33.78	-	-	3.04	-
6		LEV	33.78	-	-	-	4.97
7	Full-collaboration model	AR	30.98	-	0.48	2.08	-
8		EB	30.98	-	-	1.71	-
9		LEV	30.98	-	-	-	2.30

Table 6 Total number of kilometres travelled when capacity utilization is 0 % per vehicle

Scenario	Business model	Mode Abb.	TRUCK	VAN	AR	EB	LEV
0	Reference scenario	VAN	-	366.8	-	-	-
1	Individual CEP model	AR	134.9	-	24.2	730.3	-

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2		EB	134.9	-	-	744.0	-
3		LEV	134.9	-	-	-	63.2
4	Hybrid model	AR	134.6	-	7.9	792.8	-
5		EB	134.6	-	-	799.1	-
6		LEV	134.6	-	-	-	60.7
7	Full-collaboration model	AR	99.8	-	19.8	416.6	-
8		EB	99.8	-	-	425.0	-
9		LEV	99.8	-	-	-	35.2

As expected, for every green vehicle the total travelled kilometres match the kilometres travelled in the ZEZ, as they only operate in that designated area (see Table 4). Combining Table 1 and Table 4 shows that the total kilometres travelled with the AR are relative to the number of tours performed for each by almost a factor of 2, a fact which can also be supported by Table 5 as the average tour distance with an AR fluctuates at around 0.5 km for every examined scenario. This can be explained as they only deliver parcels which fall into a 500m radius around each microhub. The hybrid model seems to lead to the least total travelled kilometres for this mode, but also to the least kilometres when it travels completely empty (see Table 6).

Regarding the EB that complement the AR operations, it is interesting to notice that for the full-collaboration model 430 tours are constructed, in comparison to the 494 of the Individual CEP models, which result in a total of 894 kilometres which is almost half of the corresponding kilometres travelled in the Individual CEP model (see Table 1 and Table 4). This of course is affected by the increased usage of the AR (almost 90 additional AR kilometres), but it nevertheless proves that micro-consolidation even in such a small scale can still lead to significant gains.

The full-collaboration model seems to be the most beneficial in terms of least total travelled kilometres and least total travelled kilometres when vehicle is empty as observed for both the EB and LEV operations. Operating with the LEVs under this business model, proves to be the most optimal scenario as also the least number of vehicle tours is constructed, with most of them starting under full capacity. By comparing Figure 2-2 and Figure 2-3, it can be seen that for the hybrid model only the roads close to the microhubs are mostly active, due to the overlap of the tours, while in the Individual CEP model, even though majority of the roads are used due to the spatial spread of the microhubs they still present of the highest frequencies of use. Table 4 proves this as the number of kilometres travelled by the LEVs for the Individual CEP is almost double the kilometres travelled for the hybrid model, and almost triple the kilometres travelled for the full-collaboration model. This explains why the average tour distance for the LEVs presents a similar pattern under each examined model (see Table 5).

Apart from the full-collaboration model, it has been observed that the individual CEP model favours more the EB, while the hybrid model favours more the LEV. More specifically, the EB for the individual CEP model constructs 559 tours, in comparison to the 556 tours of the hybrid model, which still lead to 26.5 less total kilometres, almost 55 less kilometres travelled when the vehicle is empty and simultaneously a shorter average tour distance of around 3 kilometres. The LEV for the hybrid model constructs 44 tours, in comparison to the 47 tours of the individual CEP model, which lead to 114.5 less total kilometres, 2.5 less kilometres travelled when the vehicle is empty which is trivial, and a shorter average tour distance of around 5 kilometres. It appears then that when the parcel concentration at microhubs is high, as in the case of the full-collaboration model (parcel micro-consolidation as all CEPs

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share the same vehicle) or the hybrid model (lesser number of microhubs attract higher number of parcels) the LEV performs better due to its higher capacity, but in the opposite case modes with smaller capacity such as the EB present an advantage.

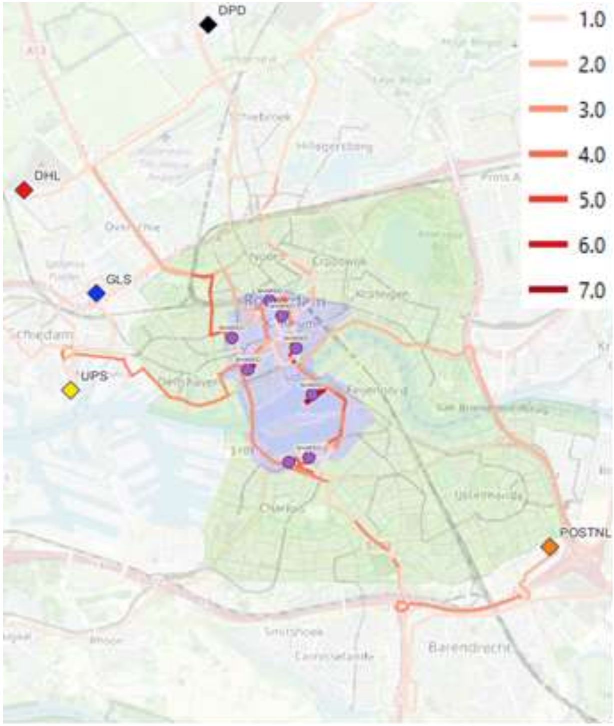

Figure 2-2 Full-collaboration model: truck road network usage

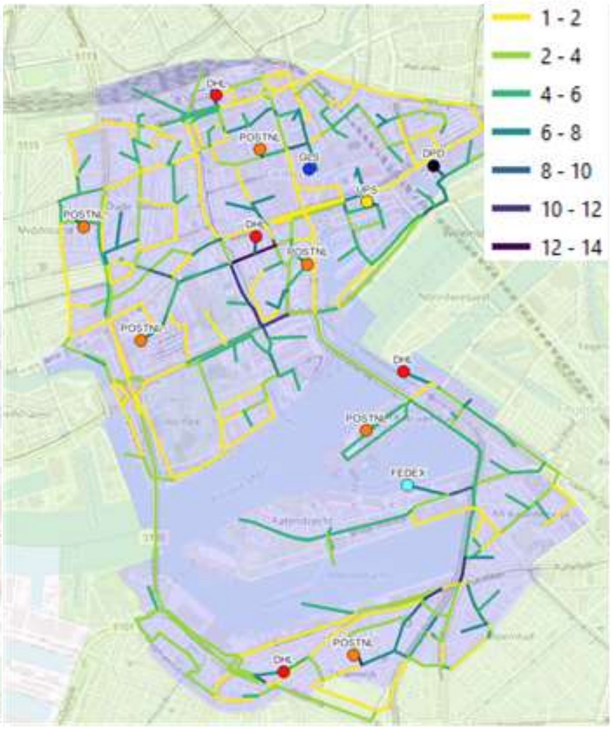

Figure 2-3 Individual CEP model - LEV road network usage

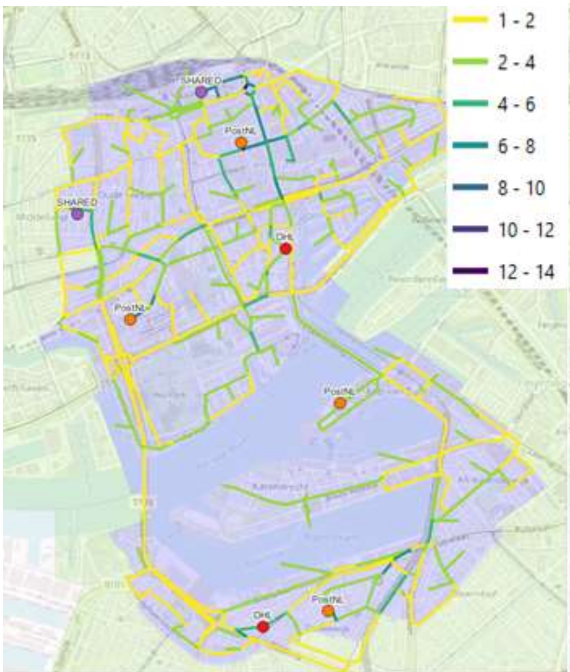

Figure 2-4Hybrid model - LEV road network usage

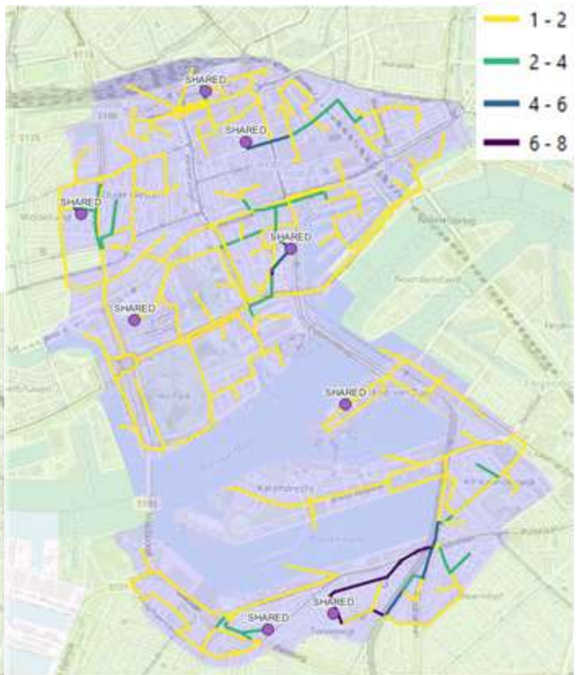

Figure 2-5 Full-collaboration model - LEV road network usage

Figure 3 Model results comparison

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2.3.2 Zero emission zone

This scenario is applied on the simulated shipments from the Shipment Synthesizer, the first module in the TFS. The results of zero emission use case are compared to a reference case where there is no zero-emission zones in the Rotterdam city. In the Reference scenario 12 thousand shipments and 61 thousand parcels are transported per day to/from the area of the planned ZE-zone. In the zero-emission scenario, part of the shipments are rerouted through the seven UCCs and distributed/collected inside the ZE-zone. The other shipments are carried in the original tour but using a ZE-vehicle. This leads to a small increase of 0.25% in the total Vehicle Kilometres (VKT) in the study area compared to the reference scenario. This is an unexpected, but realistic finding and can be explained by the extra leg that was added to the deliveries that are routed through the UCCs.

The transitions change the composition of vehicle movements in the ZEZ. Figure 4 shows the evolution of the fleet kilometers by vehicle type before and after the scenario application. New smaller vehicles such as e-scooters and electric cargo bikes travel around 10% more vehicle kilometers. These types of vehicles are introduced more frequently because they are the predominant vehicle used for last mile deliveries from the UCCs. The results also show that the composition of vehicles driving in the city center do not change dramatically. Of course, this is the result of the scenario assumptions: the Roadmap outlines how many shipments will be delivered using heavy goods vehicles (HGVs) but with alternative driveline type. This assumption is conditional to the availability of ZE- or hybrid vehicles. The outputs of these case studies can also be used as a prediction for the number of vehicles required to see if these numbers can be met by the truck manufacturers. We assume that carriers will use the available ZE- and hybrid HGVs in city logistics.

Emissions are calculated from the route of each freight trip: this means that the calculation can take into account the vehicle type and load, but the route as well (location, link type, congestion). This is necessary for an accurate calculation of emission of hybrid trucks that have zero-emissions driveline based on their location. As expected, the implementation of the ZEZ led to a significant decrease in emissions in the ZEZ as it can be seen Table 2-7. All Greenhouse Gases (GHG) had a 90% decrease inside the ZEZ and were reduced by almost 10% in the rest of Rotterdam area. Results also show that the reduction of impacts is very small at regional (or national) level. Most of the freight traffic in this study area is unaffected by the zero-emission zone. In the area of Rotterdam most freight related traffic is generated by the port and involves long haul HGV transports that do not enter the city center: these transports remain unaffected. This case study shows that zero-emission zones are not the silver bullet in reducing greenhouse gasses. Additional measures are required to reach more ambitious climate goals. Future case studies with the presented simulation model will address the effectiveness of a combination of measures, both at local and national scale.

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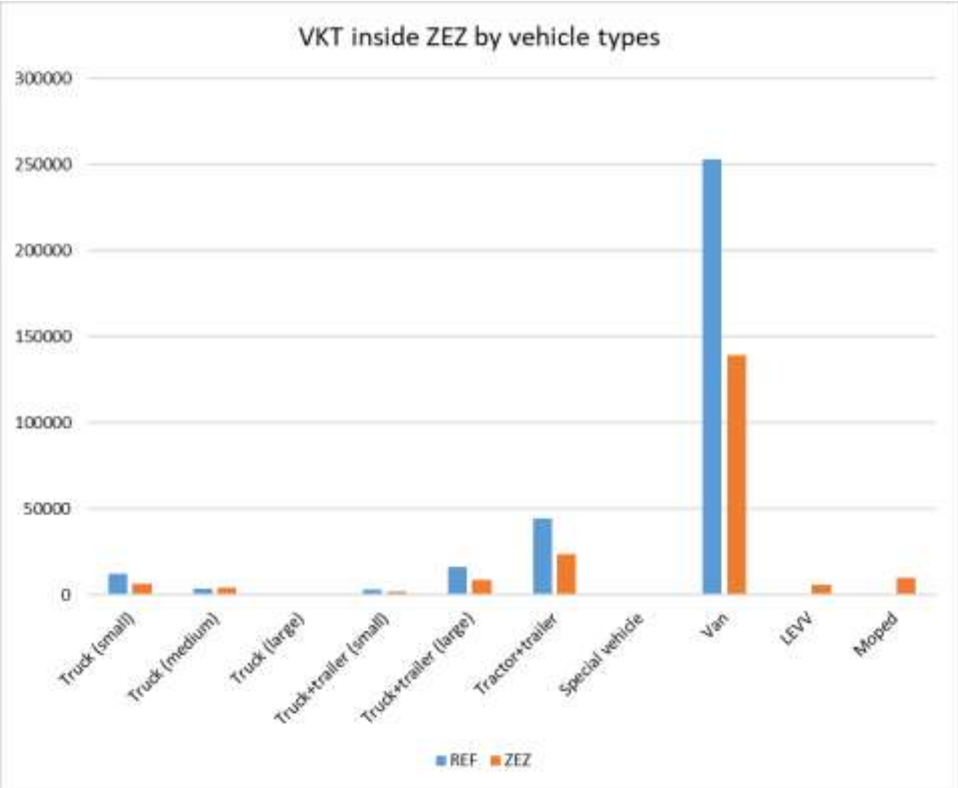

Figure 4 Vehicle kilometres by vehicle type before and after introduction of the zero-emission zone

Table 7 Reduction in emissions at different scale levels

Type	In the ZEZ	Rotterdam	Study area (prov. South Holland)
CO2	-91%	-4%	-1%
SO2	-91%	-4%	-1%
PM	-86%	-6%	-1%
NOX	-93%	-5%	-1%

The implementation of the ZEZ in Tactical freight simulator provides an insight into the magnitude of the impact of the ZEZ in the study area.

This case study shows that the impact of UCCs is not trivial: emissions within the ZEZ are reduced (because all transport takes place with ZE-vehicles) but we can see a small increase in vehicle kilometers travelled (VKT) outside the ZEZ: +0.25% which can be attributed to the rerouting of shipments through the UCCs. Calculations confirm that emissions are reduced dramatically, by 90%, inside the ZEZ. At the city scale this corresponds to a reduction of almost 10%, as most freight related traffic is generated by the port and involves long haul HGV transport that do not enter the city center. At a regional level the reduction of impacts is very small. The impacts on city level are significant and a good step towards the ambition from the current municipal coalition agreement to reduce CO2 emissions by 49% by 2030. However, to achieve this policy objective more measures are needed for

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instance measures to decarbonize long-haul freight transportation, that make up for a large part of the emissions in the study area.

We also present the effectiveness and possibilities of the HARMONY Tactical Freight Simulator to address a complex zero emission city logistics scenario, with UCCs and vehicle type transitions. The level of detail in the multi-agent model also permits the assessment of different transition paths to ZE – vehicles for each logistics segment, to better account for heterogeneity in preferences of different actors. This provides a better empirical basis for informed decision making, e.g. on the planned size of the zero-emission zone, and to plan to support UCCs to provide accessibility for all stakeholders.

2.3.2 Crowd-shipping:

To simulate the crowdshipping system, the crowdshipping simulator uses the output of V-MRDH traffic model for acquiring travel patterns (bike and car) in the metropolitan area of Rotterdam and Den haag. Additionally, it interacts with the HARMONY tactical freight simulator (TFS) simulator. More specifically, it uses the parcel demand module and parcel scheduling module of TFS to distinguish parcels that are eligible for crowdshipping.

the parcel demand for crowdshipping simulation is generated by the parcel demand module in TFS. See for a description the deliverable 6.3. This module generates the B2B parcel demand to workplaces and B2C parcels to households. These demands are distributed over zones of the study area (South Holland, in the Netherlands, light pink polygons in 5) based on their socio-demographic characteristics. The origin of these parcels is assigned to the depots of the corresponding parcel carriers (in total 6 in the study area). The location of these depots is collected from Openstreetmap (see Figure 5). The crowdshipping module first of all calculates the proportion of parcel demand eligible for CS. For this demand, the module simulates the origin and destination of these parcels. Destinations of the parcels are the zones for which the parcels are generated. To identify the origin of the parcels, first the simulator assigns each parcel to one of the 6 parcel carriers based on the market share of these carriers. Then the origin of each parcel is assumed to be the closest depot of the corresponding parcel carrier.

To calculate the supply of travellers, the simulated trip patterns from the traffic model V-MRDH for the study area is used. Within the study area, 2.3 million car trips are made, over 450,000 public transport users and just below 1.8 million cycle trips each day. For these modes, an origin-destination matrix for all 5925 zones is available. The travel times for car trips is known using the skim matrix. The time skims matrix for cycling trips could easily be computed by dividing the distance by the average cycling speed of 12 km/h (Molnár, 2002). For public transport, however, no travel time skim matrix is available and for this reason, public transport travellers are not considered in this research. Please note that the traveller supply is considered to be a static input: no feedback loop is simulated from the changing travel patterns evoked by crowdshipping, back into the traffic model. It is expected that the impacts of the changes in travel patterns will be marginal on the traffic flow conditions.

The TFS with an enabled crowdshipping setting requires a set of specifications for running each scenario. A list of specifications of the TFS for crowdshipping scenario is listed in the table below. These specifications are parameters that control either demand or supply side of the crowdshipping platform. For the rational and references behind these parameters, refer to the Deliverable 6.4.

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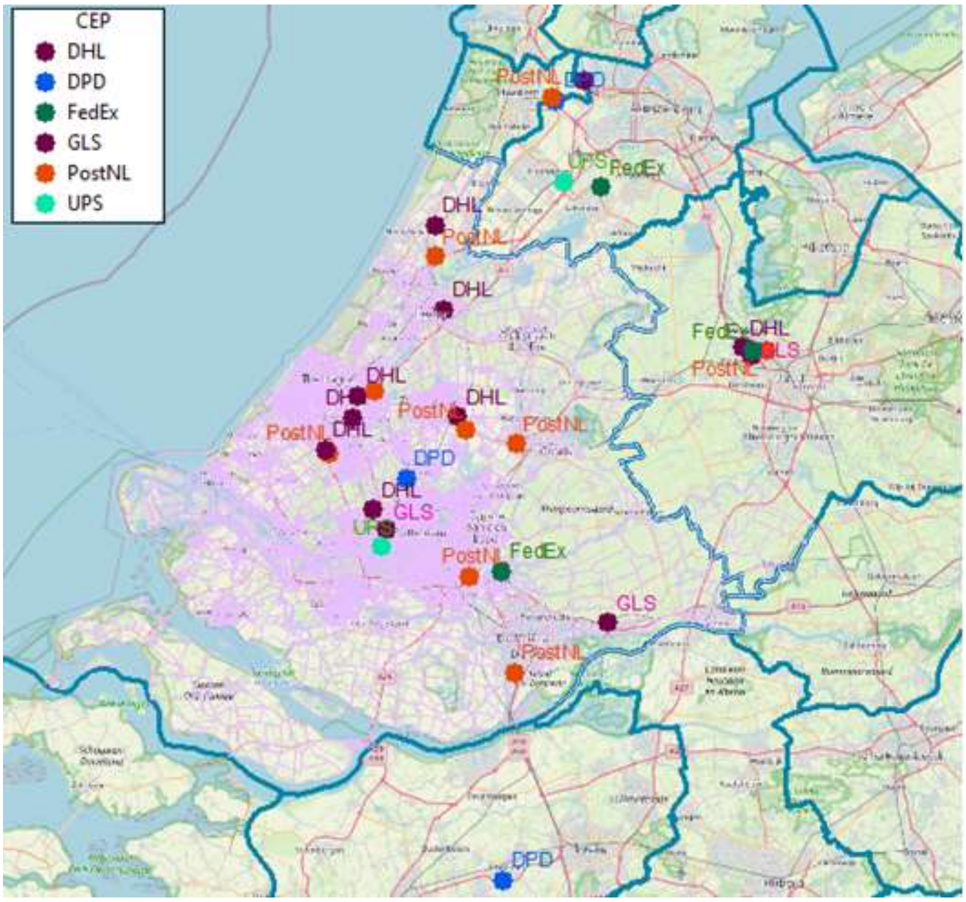

Figure 5 Pickup location of parcels

Table 8 Model specifications

Specification	Side of the system	Crowdshipping (Base)
Parcel per employee	Demand	0.041
B2B success rate	Demand	0.95
B2C success rate	Demand	0.75
Crowdshipping willingness	Demand	0.06 (6%)
Van max parcel load	Supply	180 (parcels)
Bike max parcel load	Supply	1 (parcel)
Car max parcel load	Supply	1 (parcel)
Bike willingness to ship	Supply	0.3 (30%)
Car willingness to ship	Supply	0.3 (30%)
Bike value of time	Supply	8.75 euro/h

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Car value of time	Supply	9 euro/h
Bike idling time	Supply	0.0167 (60 seconds)
Car idling time	Supply	0.033 (120 seconds)
Van idling time	Supply	0.033 (120 seconds)
Bike Detour threshold	Supply	0
Car Detour threshold	Supply	0
Compensation scheme	Supply	Log(parcel distance+5)

To assess the impact of the crowdshipping scenario on passenger and freight system, we run the TFS, first without (REF), and then with crowdshipping settings.

In addition, we have run several crowdshipping scenarios for sensitivity analysis of the parameters and assumptions made for crowdshipping simulation setups. Within these scenarios we could explore the impact of detour threshold on freight and passenger transport systems. We also could test the compensation policies. In the next sections we elaborate on crowdshipping simulation experiment and compare it with the reference and base-case scenarios.

Parcel delivery without crowdshipping (Reference case)

In the REF case, all the parcels are scheduled and delivered by conventional carriers (using Van vehicle type). In the passenger transport system on one hand, 4.1 million trips are simulated by V-MRDH model, of which 57% are made by car and the other 43% by bike. Travellers have driven a total distance of 15.5 million kilometres (6.6 km/trip) by car while the total driven distance of bike travellers is 7 million kilometres (3.9 km/trip). In the freight system on the other hand, 243000 parcels are delivered by customers on a daily basis. The total distance travelled by vans to deliver these parcels in the study area is 90 thousand km. Table 2-9 summarizes the indicators of both passenger and freight transport system in the reference case resulting from simulation of the study area without crowdshipping.

Table 9 Simulation result of parcel delivery without crowdshipping for the study area

Indicator	Freight system	Passenger system
Total number of parcels	242866	-
Vans' number of tours	1362	-
Vans' number of trips	33259	-
Vans' VTK (km)	89718.05	-
Bikes' number of trips	-	1763000
Bikes VTK (km)	-	6,917,000 (3.92 km/trip)

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Cars' number of trips	-	2337000
Cars' VTK (km)	-	15,468,000 (6.6 km/trip)

In the reference case (see Table 9). All the 242866 parcels are delivered by conventional carriers which resulted in 89718.05 km travelled by van. The kilometre per parcel ratio in this case is 0.37.

Parcel delivery with Crowdshipping

The TFS demand module generates the parcel demand for 6625 zones in south holland. However, we could only simulate the crowdshipping in 5925 zones in the study area within which the travellers' origins and destinations are available from V- MRDH model. That means that from 242866 parcel demand in the reference case, 148790 parcel demand is considered for the simulation. The result of simulation shows that from the total 148897 ordered parcels, 9569 parcels are eligible for crowdshipping of which 8311 parcels (86.85%) have been delivered by occasional travellers. From the delivered parcels by crowdshipping, 5163 parcels are delivered by bikes with the total of 8230 km extra travelled distance and 3148 parcels are delivered by passenger cars with the total of 12450 km extra travelled distance. A comparison between the reference and crowdshipping scenarios shows that the crowdshipping system can decrease vans' travelled distance by 1553.19 km. This, however, is at the cost of cars' extra 12450 km travelled distance that is imposed to the transportation system by occasional carriers. The kilometre per parcel ratio for the crowdshipping scenario is 2.16 (9569/(12450+8230)). This ratio is relatively high as compared to the reference case. This is due to the inefficiency of the occasional carriers as compared to the efficiency of professional parcel delivery companies. These inefficiencies mostly arises from the fact that professional delivery companies bundle parcels into one vehicle and hence can derive less to deliver the same number of parcels.

As Figure 6 shows, detour length is on average 3.95 km per parcel for cars and 1.59km per parcel for bikes. The distribution of detour length of bike users is denser around the average as compared the car users. This logically shows that car users are more flexible for larger detours as compared to the bike users. Regardless of their model, occasional travellers have made 2.49 km detour on average to deliver these parcels.

Figure 6 Distribution of detour distances per modes

Looking at the distribution of Cars' detours in figure above, we can observe some occasional carriers with negative detours (minimum detour is –11.95 km). That means less distance is travelled when a traveller delivers a parcel. This is because travellers usually use the fastest route in their trajectory not the shortest route. Therefore, when occasional carriers make a delivery, it might be a case that they travel shorter distance while the path will take longer. This leads to a negative detour. Figure 7 shows a representation of this issue.

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Figure 7 Representation of negative detours

In general, the average provided compensation for the occasional carriers is 2.32 euro. Figure 8 compares the distribution of compensation for car and bike users. The average compensation provided for bike users is 2.12 euro and for car users is 2.44 euro.

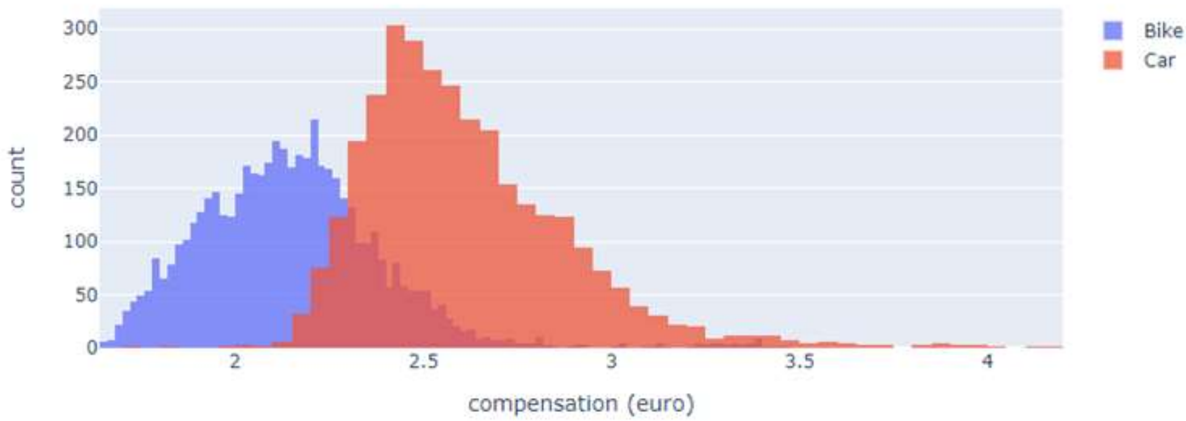

Figure 8 Distribution of compensation per modes

From the 9569 parcels that are eligible for crowdshipping, 8311 parcels are delivered by occasional carriers and 1258 parcels are delivered by conventional carriers because eighter the detour threshold or value of travel time constraints could not be satisfied for any travellers. Looking at the destinations of these parcels (Figure 9), it looks like that parcels that are carried by occasional carriers are more likely to belong to residential areas (B2C) while the crowdshipping parcels that are delivered by conventional carriers are more likely to belong to industrial areas (B2B).

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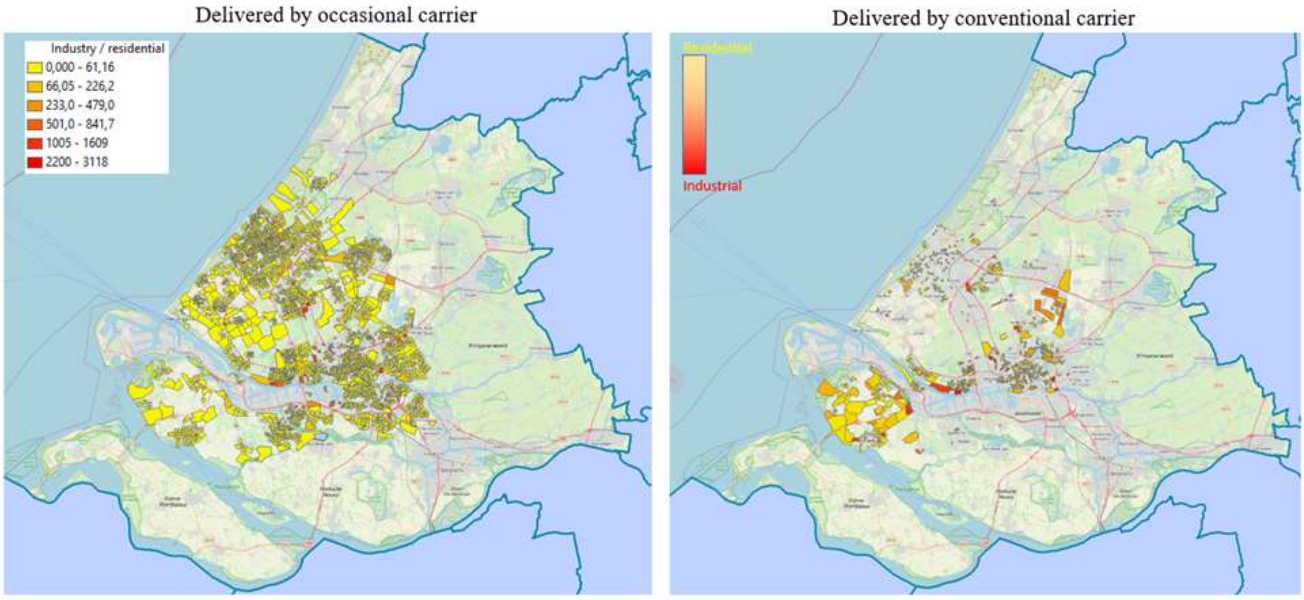

Figure 9 Distribution of compensation per modes

From this analysis, we could conclude that the crowdshipping has a marginal positive impact on freight transport system reducing van's vehicle kilometres meaning that carriers can reduce their fleet size and yet being able to deliver their parcels, hence this would reduce fixed and variable cost of having larger fleet size. The crowdshipping, however, has a negative impact on transport system since a large share of crowdshipping parcels will be delivered by travellers using personal cars and the extra detour cost imposes a surge of vehicles flows in the residential areas. Therefore, policy makers and municipalities in the metropolitan areas have to be aware of such side effects.

2.3.4 Spatial planning

The impacts of spatial planning scenarios are explored in a what-if-analysis. This means first scenarios are to be formulated that can be analysed in the TFS. For the use case we develop two scenarios. The two main uncertainties in the spatial planning scenario are: economic growth and the type of spatial planning policy. For economic growth the WLO Low and High scenario are considered. The WLO Low scenario assumes 0.5% growth per year and high 4% per year. For each scenario a different spatial planning policy is explored that differ in the degree of regulation in the allocation of logistic facilities.

This analysis consists of the following steps:

1. Estimate future demand
2. Allocate spatial demand
3. Impact assessment in the TFS

The first three steps are discussed in this section. The results from the impact assessment in the TFS are presented in the next section.

Estimation of future demand

For future demand a high- and a low growth scenario are formulated. The Table below first of all shows the recent development of demand for logistic real estate in the study area, and the Netherlands overall. The data are provided from a market report (NVM, 2021).

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Table 10 Surface area of logistic real estate between 2012-2020

	2012	2014	2016	2018	2020
South-Holland (M2)	4.420.000	4.687.500	4.883.000	5.538.000	6.944.500
The Netherlands (M2)	27.446.000	28.760.000	30.933.000	35.462.00	40.887.000
Growth SH (%)		+6,05	+4,17	+13,41	+25,40
Growth NL (%)		+4,79	+7,56	+14,64	+15,30

As can be seen over recent years the increase in logistic real estate was substantial and dynamic over the recent years. The trend between 2012 and 2020 is considered to be representative for a strong growth scenario. Therefore, the recent trend is used to extrapolate the demand for 2030 in the high growth scenario. This implies a growth of 49% of the current floorspace.

For the low scenario a much more modest increase is expected. The relative variation is assumed to be consistent with the difference in macro-economic growth scenario. This corresponds to a factor 8: there the growth in Scenario 1 with low growth is assumed to be (0.5/4.0)x49% = 6%.

Spatial planning scenario

For each scenario, WLO Low and High, a different spatial planning policy is explored that are distinctive in the degree of regulation in the allocation of logistic facilities. For the low scenario we assume less regulations, and in the high scenario we are assuming stronger regulation.

In case of unrestricted policies, it is assumed that the current trend would continue this means new logistic facilities will be planned in peripheral locations for lower land prices and near highways to lower transport costs. For the restricted scenario we assume that new logistic facilities will be planned on brownfield locations and existing industrial terrains and urban area.

A first step in the allocation of logistic facilities, is to define the search space. This is visualised in the following plots. In scenario 1 the DCs can be planned unrestricted. New locations are mostly considered to be placed beside the well-used highways. This is done for good accessibility and efficient transport costs. The red dots indicate the search area with potential new locations. The total demand of new logistic facilities (35 in total) is allocated to these dots.

For the second scenario, the new DCs are restricted to settle on already used industry areas. In this scenario, the DCs are more centralized because the new DCs are located in the already existing industrial area. Because there are already many DCs in these industrial areas, it is assumed to be attractive locations for logistic facilities and these areas are easily accessible because of the already existing infrastructure.

The following maps show the allocated floorspace of new DC's in both the unrestricted low growth scenario (1) and restricted high growth scenario (2).

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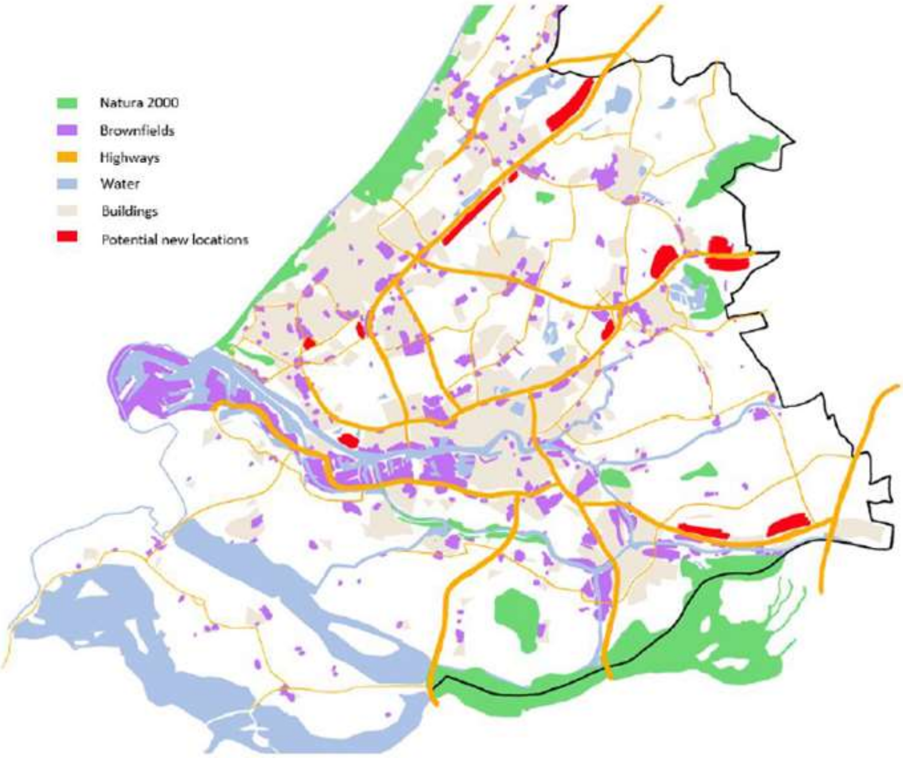

Figure 10 Search area for Scenario 1 with unrestricted development

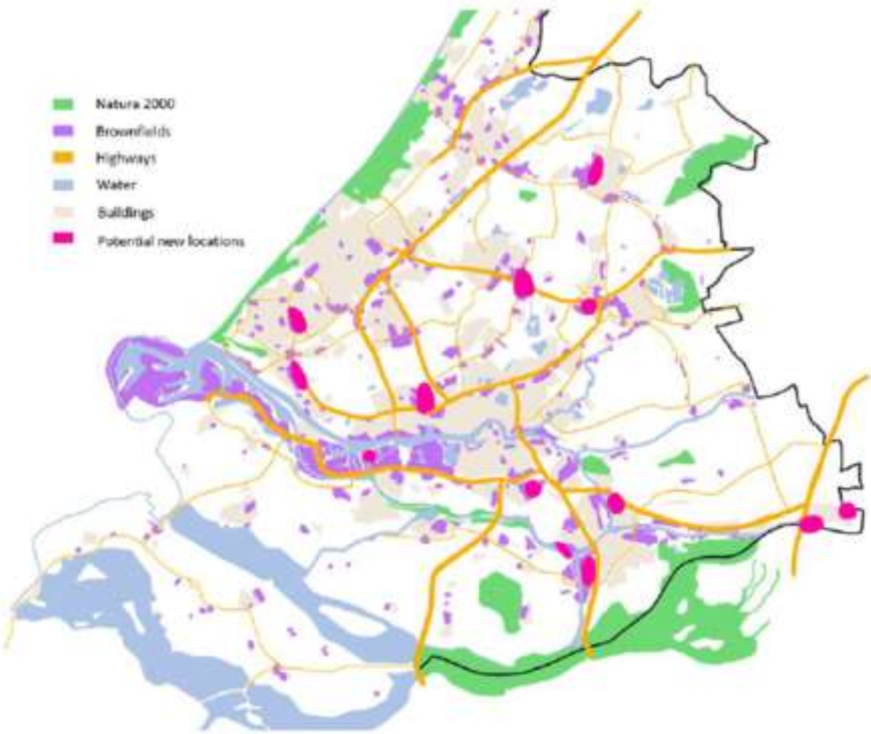

Figure 11 Search area for Scenario 2 with restricted development

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Figure 12 Allocated surface area of logistic facilities in Scenario 1 (unrestricted)

Figure 13 Allocated surface area of logistic facilities in Scenario 2 (brownfields)

Below an overview is provided of the assumptions in both scenarios. The impacts of the planned distribution centres in the scenarios are simulated by inserting the planned logistic real estate in the reference scenario for 2030. For both economic scenarios, the low and high scenario, a reference scenario is available for 2030 with the corresponding macro-economic growth of 0,5 % and 4 % annually. Scenarios 1 and 2 are developed as spatial alternatives in the WLO Low and High scenarios.

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In the first scenario with low economic growth, 35 DCs are expected and in the second scenario with high economic growth 297 new facilities are planned. Next, these scenarios are used as input for the TFS, and the impacts are simulated on the transport system.

Table 11 Overview of assumptions in the spatial planning scenarios

	Scenario 1	Scenario 2
Economic growth	Low economic growth of 0,5 %	High economic growth of 4 %
Location choice	Unrestricted	Only on brownfields
Growth rate	6,11 % (8 times lower than scenario 2)	48,9 %
New amount of DCs	35	297

The scope of the TFS is to simulate the impacts of policies on freight transport decisions, the freight demand patterns, and the generation of freight traffic. Doing so it provides information for the evaluation of impacts on accessibility and sustainability. The main KPI's it provides are vehicle kilometres and emissions.

The Table below summarises the global impacts. The WLO Low and High scenario show an increase of vehicle kilometres of 6 and 15 % totally for 2030. These scenarios include business as usual freight demand development, and no investments in new logistic facilities. In these scenarios it is assumed that all freight demand is handled through the existing logistic facilities, without capacity constraints. In the spatial scenario's the localization of new facilities have a redistributive impact on the pattern of freight shipments. The objective of scenario 1 and 2 is to explore what would be the impact of unrestricted allocation (peripheral and near highways) and restricted to brownfields (existing industrial terrains). From the results of scenario 1 it shows that the unrestricted policy leads to a marginal increase in vehicle kilometres, even though the distribution centres are allocated near highways. The peripheral locations contribute to longer transport distances.

Table 12 Global impacts of Scenario 1 and 2

Scenario	*Base year*	*Reference 2030 WLO*		*Spatial scenario*	
	2018	*abs*	*rel(%)*	*abs*	*rel(%)*
Vehicle kilometers (vkms):					
Scenario 1: Low - unrestricted	18429993	19522354	5.9%	19550301	0.14%
Scenario 2: High – restricted	18429993	21219772	15.1%	21078784	-0.66%
CO2 emissions(kg):					
Scenario 1: Low - unrestricted	19418441	21716025	11.8%	21706821	-0.04%

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Scenario 2: High – restricted	19418441	23816751	22.7%	23301287	-2.16%

The restricted policy in scenario 2 shows that the planned locations for logistic facilities contribute to a modest reduction in vehicle kilometres. This is a positive outcome as it shows that the redistribution of logistic activities can help in reducing freight transport. The impacts on CO2 emission shows that emissions increase stronger compared to the vehicle kilometres: in the High scenario the emissions increase by 23% while vehicle kilometres only increase by 15%. This can mostly be attributed to the higher congestion levels in the reference scenario's which effectively lead to higher emissions per kilometre. This occurs in particular on the highway links. As a result, the impacts of the spatial planning scenario on emissions are also slightly stronger: a reduction of 2% in the high scenario. Scenario 1 showed a modest reduction of vehicle kilometres due to the favourable allocation near highways, but since freight vehicle have higher emissions per kilometre on the highway the net impact is a modest increase of CO2 emissions. Results show it is necessary to have location specific calculation of emissions (see Deliverable 6.3 for details). In addition, it is important to investigate the local impacts. Therefor the impacts on freight traffic and emissions are also visualised in the following plots.

The network intensity plots show much stronger local differences in Scenario 2 as a result of the spatial planning scenarios. Of course, this scenario allocates much more logistic real estate, that attract and generate local traffic. As one of the hotspots for real estate development was in the 'Westland', a district west of the A4 highway, a significant rerouting of freight movements can be observed: a significant shift can be observed of much freight movements now going from the Westland to Rotterdam via the A20 instead of A4. Strong local increases can also be observed on the A15 and A16 South-East of Rotterdam where two designated hotspots were localized.

A DC has an impact on a local level. As can be seen in the results the emission is increased at new locations of the DCs. When there are a lot of new DCs in one place the changes can be significant. This can be seen in scenario 2 where the emission difference can be up to 20 % in Westland. However, overall, the emission in South-Holland increases only slightly. This is because the scenario only assumes redistributive impacts: the new DC's take a market share of all freight transport handled through distribution channels. The total freight trough distribution channels do not change in these spatial scenarios. For this the scenario should have to be increased with a logistical component: how does the opening of new distribution centres increase the use of distribution channels in the supply chain.

The scenarios that are developed here are a first sketch with the purpose to illustrate the use case of logistic facility planning. A general conclusion drawn from this analysis is that the growth of logistic real estate demand is above the trend and with a spatial planning policy for the allocation of logistic facilities, the freight transport demand and externalities on accessibility and emissions can be influenced. If the growth of the DCs is going in the same pace as now the demand for new DCs can be up to 300 in 2030. The arrival of these new DCs influences the local level and there is not enough space in South-Holland to continue this growth and for the DCs to build new industrial areas. However, it is seen that the centralization of the DCs has a positive influence on the vehicle kilometres. The validity of the spatial scenarios can be improved by developing scenario in cooperation with the main stakeholders: regional authorities, local authorities, logistic service providers and carriers. The development of such policy scenarios can be used to encourage the logistic sector to work together and bundle the DCs at already existing industrial areas. This influences the vehicle kilometre but also the demand for new facilities. Cooperation on the planning of logistic facilities can also be used as a step towards more innovative collaborative concepts and asset sharing.

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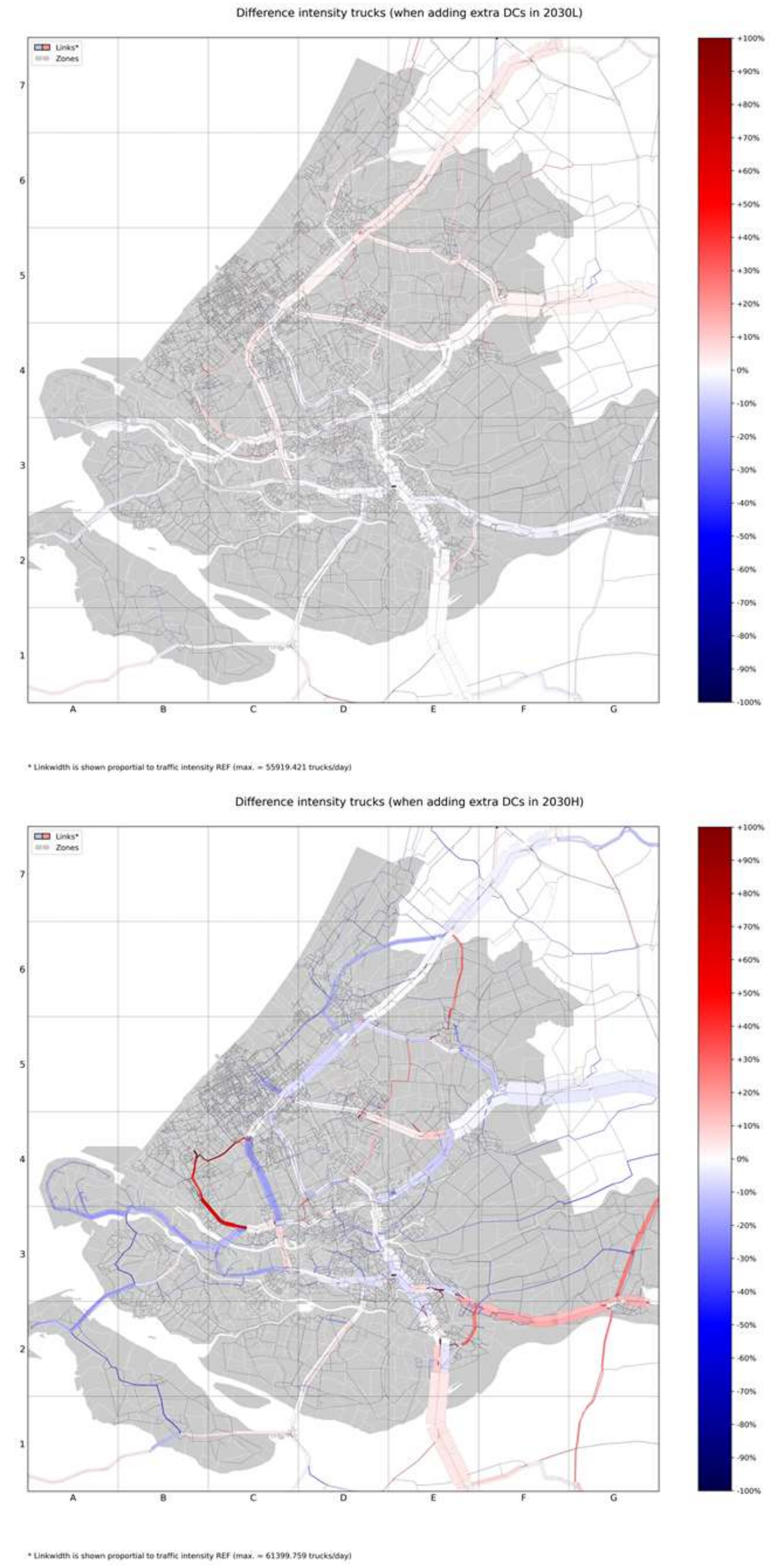

Figure 14 Traffic intensities in the Low scenario (Top) and High scenario (Below)

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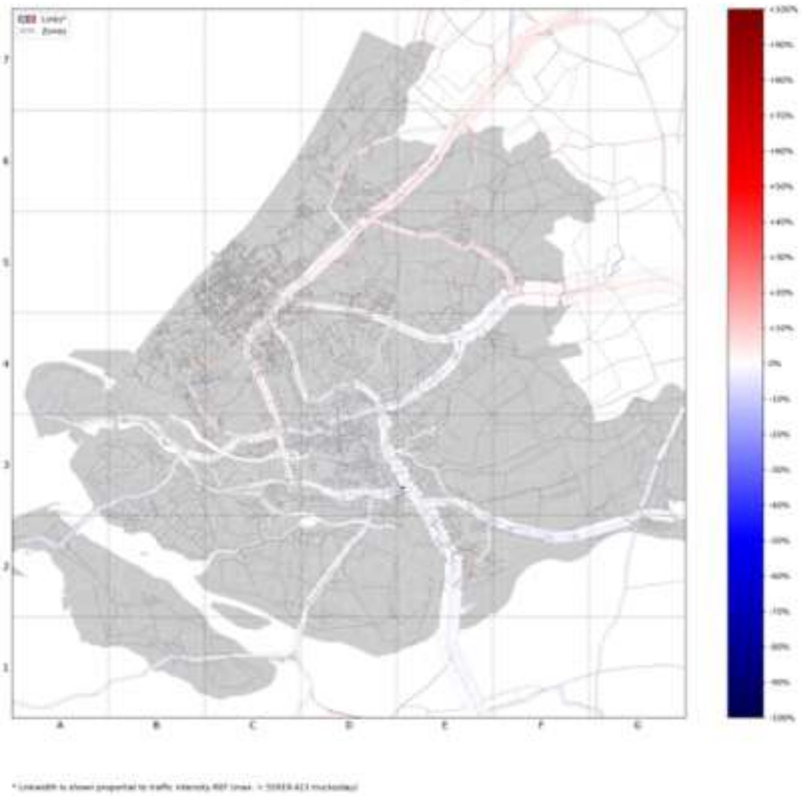

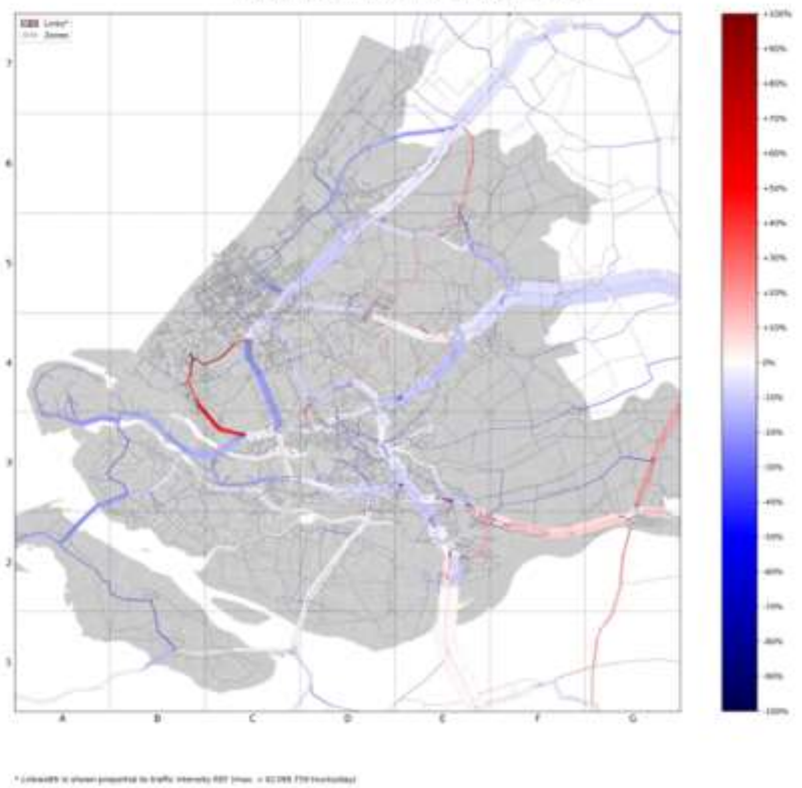

Figure 15 Emissions in the Low scenario (Top) and High scenario (Below)

2.4 Summary

2.4.1 Micro hubs:

The light electric vans have a higher capacity so on average have fewer tours from the micro hubs; this is considered an operational advantage. The hybrid and full-collaboration models show a better vehicle utilisation than the individual CEP model. The full collaboration model, with light electric vehicles lead to fewest vehicle kilometres in- and outside the study area.

2.4.2 Zero emission zone:

Calculations confirm that emissions are reduced dramatically, by 90%, inside the ZEZ. At the city scale this corresponds to a reduction of almost 10% of whole emissions produced by freight transport. At a regional level the reduction of impacts is marginal. Using UCCs reduces emissions within the ZEZ areas but slightly increases the vehicle kilometres travelled (VKT) outside the ZEZ. The rerouting of freight vehicles around the ZEZ or to and from the UCCs can lead to substantial increases in local freight traffic: this is an important side effect that needs to be mitigated.

2.4.3 Crowd shipping:

Crowd shipping could improve the efficiency of freight transport system in delivering parcels. However, since a large share of crowd shipping parcels will be delivered by travellers using personal cars, the net impact of crowd shipping is an increase in total vehicle kilometres in particular in the residential areas. The sides effects could be mitigated by applying control policies on the crowd shipping platforms and services.

2.4.4 Spatial planning:

Spatial planning policy for the allocation of logistic facilities influences the freight transport demand, accessibility and emissions. Centralisation of the DCs has a positive influence on the vehicle kilometres. Despite the increasing demand for the new DCs, there will not be enough space in South-Holland to build new industrial areas. Cooperation with the main stakeholders such as regional authorities, local authorities, logistic service providers and carriers is required to develop sustainable and efficient policies for new logistic facilities.

2.4.5 Conclusions

The application of a new city logistic simulator shows the possibilities of using simulation to study system wide impacts of new technologies and services in city logistics. The explorations learn that although the technology seems to be ready for innovative solutions, the logistical organisation or business models and policies are not yet well developed. Simulation tools can contribute to this by showing potential impacts of system wide impacts and get a common understanding about the pros and cons, and barriers and opportunities of new solutions. This can be a point of inspiration for further collaboration between the relevant stakeholders from logistics and local and regional authorities.

To create more value from the simulations with the TFS, future work can focus on the integration of the different use cases into broader logistic scenarios. The use cases are typically complementary. For instance: micro hubs can be considered in combination with a spatial planning scenario and extended in a scenario with a crowd shipping service where the micro hubs also serve as a location for pick-up or drop-off of parcels. By combining the use cases a holistic logistic scenario is created with consistent assumptions across the use cases. The development of broad logistic scenarios requires regional coordination and involvement of logistic stakeholders. The results from the individual use cases can be used to feed the discussion between these stakeholders.

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3. Use Cases Simulations: Oxfordshire

3.1 The use cases for Oxfordshire

In the metropolitan region of Oxfordshire, the HARMONY MS was deployed to assess the following two use-cases,

1. **Impact of new housing development in Oxfordshire**

Oxfordshire is a 2,605 km^2 county located in England, which consists of five district councils (Oxford City Council, Cherwell, South Oxfordshire, Vale of White Horse and West Oxfordshire). The case study area is divided in 86 Middle Layer Super Output Area (MSOA) zones. The total population in 2019 (the HARMONY reference year) was 687,524 inhabitants, with most of them residing in the city of Oxford. In the case study of Oxfordshire, the Strategic Simulator aims to assess the impact of a new housing development. The local plan of Oxfordshire foresees the building of 8,000 new homes by 2026 and 33.263 new dwellings in total by 2031.

2. **Demand responsive transport services for Oxfordshire**

This use case investigates the effect of a demand responsive transport (DRT) service in a realistic network. In particular, the transport network of Oxford, UK and its surrounding area. The DRT service operates a fleet of vehicles that respond to trip requests, mimicking real-world, on-demand transport services, such as Uber. For each scenario tested, a fraction of the background traffic demand is replaced with trip requests.

Trip schedules for the DRT service are generated before run-time, and are scaled, based on the origin-destination matrices of the network. Generated schedules are similar to those that could be created and made available from the tactical layer, without the inclusion of associated activity information.

Since the hourly number of trips in the Oxfordshire region is large (~35,000), it is unrealistic to expect that all trips could be replaced with a DRT service. Trip numbers range from 1-10% of total demand. As explained below, trips were randomly generated from the origin-destination matrices supplied with the network model without reference to activity type information. The other variable that can be modified is fleet size. However, in both case a minimum of about 100 vehicles (and up to 1000 vehicles) would be required to fulfil demand.

3.2 Application of the HARMONY MS Simulators

Strategic Simulator

The Strategic Model Suite for Oxfordshire case study is a suite of aggregate and disaggregate regional economic, demographic forecasting, land-use transport-interaction and land development models for spatial planning. These models consist of i) a population model, that generates the total population disaggregated into age-sex cohorts that define the overall size of the city systems in question. Ii) A regional economy model (REM) associated with the entire suite of models in HARMONY, that generates future employment and structures the demand for physical travel. Iii) A Land Use Transport Interaction (LUTI) model, that takes inputs from the aggregate economic and demographic forecasting models, allocating these activities to small zones using spatial interaction approaches consistent with the transport activity models at the tactical scale. Iv) A land development model for predicting land availability / suitability.

In Oxfordshire, the Demographic Forecasting Model (SPENSER) produces population and household projections at a high spatial resolution, using UKCensusAPI and UKPopulation programming libraries. UKCensusAPI extracts census tables and makes consistent census and mid-year population estimate data from a range of sources. UKPopulation extracts household estimate data and projection data and produces constraining projection results. Both packages help to generate the sum of total population each year from 2011 to 2030, population projections for each year from 2011 until 2030 containing the residential population per sex, age, ethnicity and ONS code for geographical area and household projections from 2011 until 2030 containing the households divided by build type, tenure, composition, occupants and Output Area.

REM takes population data from the DFM, but also public investments, National GDP, tourism and Income data as inputs and produces employment projections by economic sector per year, supplying the LUTI model with total employment data per zone.

LUTI models can evaluate the impact of significant changes in land-use and transportation. In Oxfordshire, a new housing development plan foresees the building of 33.263 new dwellings by 2031.

For the **new housing development use-case**, based on the 2011 census population and on population projections for the following years provided by the HARMONY Demographic Forecasting model, two different scenarios were developed, one for the reference year (2019) and one for the projection year (2030):

1. New Housing Development 2019: Oxfordshire region is divided in 86 zones and the model uses employment, number of dwellings and travel times from 2019 (journey to work model), population, supermarket floorspace and travel times from 2019 (journey to retail model), population data for primary and secondary pupils, schools' capacity and travel times from 2019 (journey to school model) and population data, hospital floorspace and travel times from 2019 (journey to hospital model).
2. New Housing Development 2030:

Journey to work model: The number of jobs and the travel times remain the same, while the number of dwellings has been increased by 33.263 dwellings in total from 2019 to 2031.

Journey to retail model: The square meters of supermarket floorspace and the travel times remain the same, while the population has been increased by 79.831 persons.

Journey to school model: For each educational level (primary, secondary) the population change has been increased by 79.831 persons in 2030, but the travel times and the schools' capacity stay do not change.

Journey to hospital model: The square meters of hospital floorspace and the travel times remain the same, while the population has been increased by 79.831 persons.

Operational Simulator

The **demand responsive transport services** use-case for Oxfordshire was developed at the Operational level of the HARMONY MS. The Oxfordshire network (Figure 25) consists of a subnetwork enclosing the road network of Oxford, as well as the surrounding region. The majority of the 1019 centroids are contained within the subnetwork that delimits the city of Oxford. (Origin-destination trips are defined between pairs of centroids in the network.) The network contains 10889 “sections” or road segments, 928 bus routes, 45 OD matrices (for combinations of vehicle type, scenario, and time period), and 15 control plans for signal control.

For each period of 15 minutes each, there is an OD matrix that specifies the number of trips between centroids. The trip schedule generation algorithm assigns a weighting to each cell for each OD matrix. The total number of generated trips is equal to the sum of all cells. For each trip, an origin-destination pair $(a,b)\in L2$ needs to be selected, where L is the set of location points. An OD matrix applies to a particular time period $p\in I$, where I is the set of time period intervals. The probability of selecting a trip, $t\in L\times L\times I$, is $\Pr(t=(a,b,p))=nabp\Sigma nijk(i,j,k)\in L\times L\times I$ where $nabp$ is the number of trips in the OD matrix for period p between the origin a and destination b. Rather than selected trips one by one, it is more efficient to select all trips in one function call. The trip generation code calls the Python random.choices() function to select trips, where the weightings are equal to the trip numbers in the OD matrices. However, activities are not included in the random trip schedule as there is no information about activities in the OD matrices.

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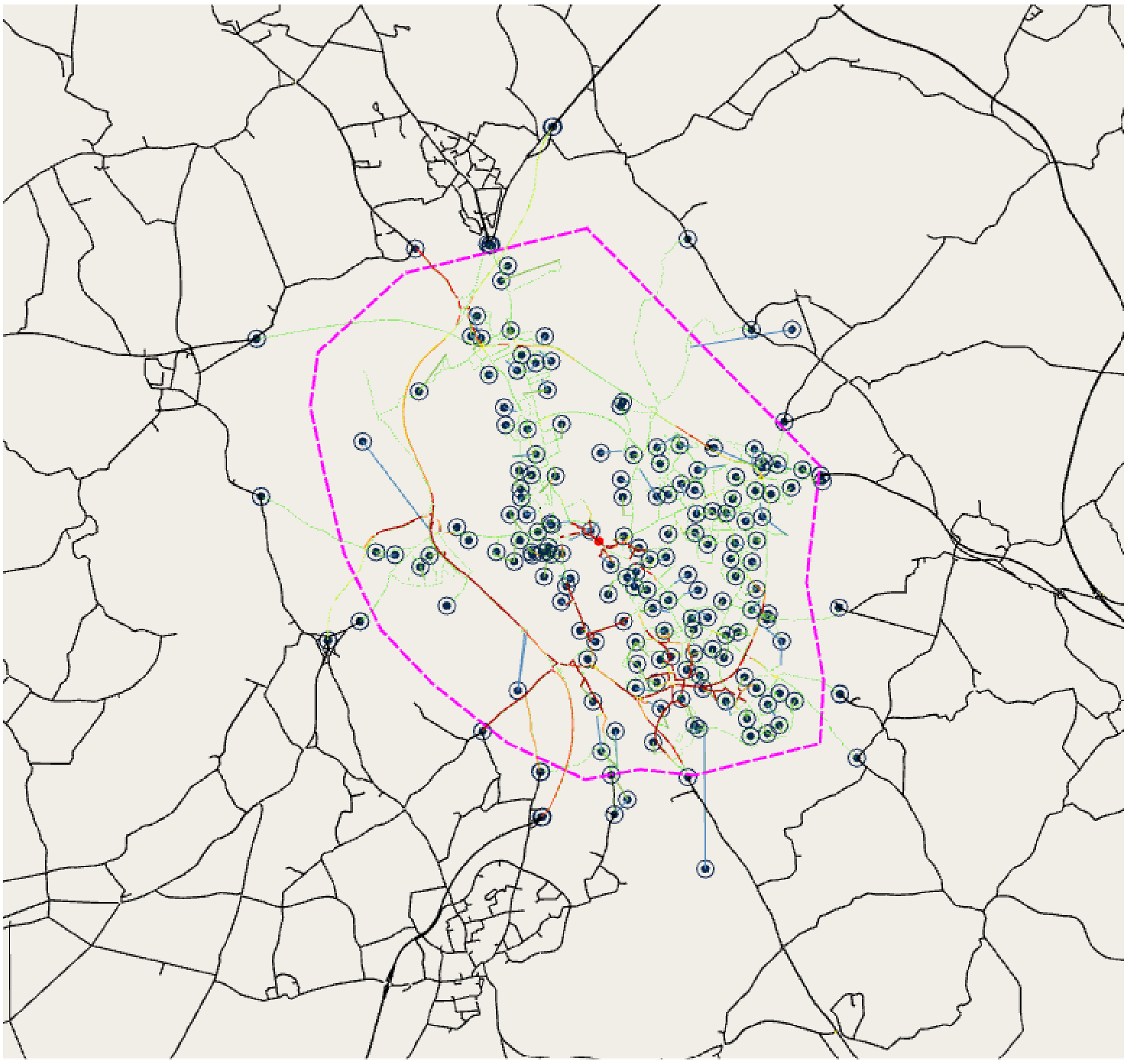

Figure 16: A portion of the Oxfordshire network in Aimsun with the Oxford subnetwork in the centre

3.3 Strategic models template: simulation results and evaluation

We first proceed to present the findings of the models utilized for the **housing development use-case**.

The Land Development model uses as constraint layers the administrative boundaries of Oxfordshire, surface water, conservation areas, parks and gardens, areas of outstanding beauty, highways, flood zones, sites of special scientific interest and natural nature reserves. Slope, population density and 2500m distance from green spaces of Oxfordshire are considered as negative attractors, while job and housing accessibility for 2019 and 2030 for all modes of transport (car, bus, rail) as positive attractors. Based on these inputs and in accordance with LUTI model 4 scenarios for Oxfordshire were built:

1. Scenario 1: Land suitability and land desirability (for 2019 and 2030) are predicted considering Green Belt as constraint and allowing to build in Flood risk areas.
2. Scenario 2: Land suitability and land desirability (for 2019 and 2030) are predicted without allowing to build in both Green Belt and in Flood risk areas.
3. Scenario 3: Land suitability and land desirability (for 2019 and 2030) are predicted allowing to build in both Green Belt and in Flood risk areas.
4. Scenario 4: Land suitability and land desirability (for 2019 and 2030) are predicted allowing to build in Green Belt areas, but not in Flood risk areas.

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Figure 17 Locations of new houses in Oxfordshire by 2031

DFM (SPENSER)

First, Household Microsynthesis produces a single CSV file in which each row refers to an individual household. In addition, the user will find a series of JSON files including meta data outlining each characteristic and its numeric classification. This is because only numeric values are stored in the data. Each column name describes a category and a census table from which it came, e.g., column *LC4408_C_AHTHUK11* contains values from the *C_AHTHUK11* category in the *LC4408* table. The corresponding metadata for this tables reads[1]:

"C_AHTHUK11": {

"0": "All categories: Household type",
"1": "One person household",
"2": "Married or same-sex civil partnership couple household",
"3": "Cohabiting couple household",
"4": "Lone parent household",
"5": "Multi-person household"
},

and so, a value of “4” in the CSV file in column *LC4408_C_AHTHUK11* indicates that the respective household is a “lone parent household”. Table 1 provides an overview of each of the columns, their source census table as well as a description of what characteristic of the household population the column covers.

Table 13: Census-based categories of generated synthetic household population

Category	Table/Column Name	Description
Geography	Area	ONS code for geographical area (e.g. E00000001)
Build Type	LC4402_C_TYPACCOM	Type of dwelling e.g. semi-detached
Communal Type	QS420EW_CELL	Type of communal residence, e.g. nursing home
Tenure	LC4402_C_TENHUK11	Ownership, e.g. mortgaged
Composition	LC4408_C_AHTHUK11	Domestic situation, e.g. cohabiting couple
Occupants	LC4404EW_C_SIZHUK11	Number of occupants (capped at 4)
	CommunalSize	Number of communal occupants (estimated)
Rooms	LC4404EW_C_ROOMS	Number of rooms (capped at 6)
Bedrooms	LC4405EW_C_BEDROOMS	Number of bedrooms (capped at 4)
PPerBed	LC4408EW_C_PPBROOMHEW11	Ratio of occupants to bedrooms (approximate)
CentHeat	LC4402_C_CENHEATHUK11	Presence of central heating
SE Class	LC4605EW_C_NSSEC	Socio-economic classification of household reference person
Ethnicity	LC4202EW_C_ETHHUK11	Ethnicity of household reference person, e.g. Asian
NumCars	LC4202EW_C_CARSNO	Number of cars used by household (capped at 2)

Finally, Table 14 provides the header and first rows of an exemplary CSV output of a synthesised household population for the City of London. The CSV file can be found in the output folder and is titled according to area and spatial resolution, e.g. for “E07000180 OA11” *hh_E07000180_OA11_2011.csv*.

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Table 14: Exemplary rows of the output CSV for the "City of London"[2]

	Area	LC4402_C_TYPACCOM	QS420EW_CELL	LC4402_C_TENHUK11	LC4408_C_AHTHUK11	CommunalSize	LC4404EW_C_SIZHUK11	LC4404EW_C_ROOMS	LC4405EW_C_BEDROOMS	LC4408EW_C_PPBROOMHEW11	LC4402_C_CENHEATHUK11	LC4601EW_C_ECOPUK11	LC4202EW_C_ETHHUK11	LC4202EW_C_CARSNO
0	E00000001	5	-2	2	1	-2	1	2	2	1	2	14	4	2
1	E00000001	5	-2	2	1	-2	1	3	3	1	2	5	2	2
2	E00000001	5	-2	2	1	-2	1	4	3	1	2	5	2	2
	…													

Static microsimulation for people population produces a single CSV file for each year between the census reference year and the horizon year per LAD. Each row refers to an individual MSOA specifying sex, age and ethnicity of an individual.

Table 15: Exemplary output for people population microsimulation

PID	Area	DC1117EW_C_SEX	DC1117EW_C_AGE	DC2101EW_C_ETHPUK11
0	E02005921	1	1	2
1	E02005921	1	1	2
2	E02005921	1	1	2
	…			

The files are named according to the area code, geographic resolution, projection data and year and can be find in the defined output folder, e.g., '*ssm_E07000177_MSOA11_ppp_2011.csv*', '*ssm_E07000177_MSOA11_ppp_2012.csv*', '*ssm_E07000177_MSOA11_ppp_2013.csv*', etc.

Static microsimulation for household population generates a single CSV file for each year between the census reference year and the horizon year per LAD. Each row refers to an individual OA specifying build type, tenure, composition, occupants among others, as well as an ID column called 'HID' (Table 15). The files are named according to the area code, geographic resolution, projection data and year and can be find in the defined output folder, e.g., '*ssm_hh_E07000177_OA11_2011.csv*', '*ssm_hh_E07000177_OA11_2011.csv*', '*ssm_hh_E07000177_OA11_2011.csv*', etc.

Finally, projected population – household assignment produces an identical file to the result of the microsimulation for a people population, i.e., a single CSV file for each year between the census reference year and the horizon year per LAD. Each row refers to an individual MSOA specifying sex, age and ethnicity of an individual, but will also contain a new column called 'HID' which corresponds to the household ID of the microsimulation for a household population output. The files are named according to the area code, geographic resolution, projection data and year and can be find in the

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defined output folder, e.g., 'ass_E07000177_MSOA11_ppp_2011.csv', 'ass_E07000177_MSOA11_ppp_2012.csv', 'ass_E07000177_MSOA11_ppp_2013.csv', etc.

REM

The REM model is fed by exogenous trends, to represent the impacts of socio-demographic aspects related to national trends and regional components on the evolution of jobs in the metropolitan area.

With reference to the Oxfordshire County, GDP trend is aligned with the EU Reference scenario 2020[3] projection for United Kingdom between 2020 and 2030. Since the COVID disease is included in the period, an initial decrease (4.6%) is present in 2020. In the following years, a steady recovery is assumed, with a growth rate of 3% until 2025 and 1.7% until 2030. Tourism is also affected from the COVID disease, with a reduction of 60% in 2020, followed by the assumption of a rapid increase until 2023, to reach the pre-COVID values in 2024. Other input trends such as e-commerce index, public investments, residential and transport cost, etc. have been estimated based on past trends. On the other hand, population has been taken directly from the DFM (SPENSER) model.

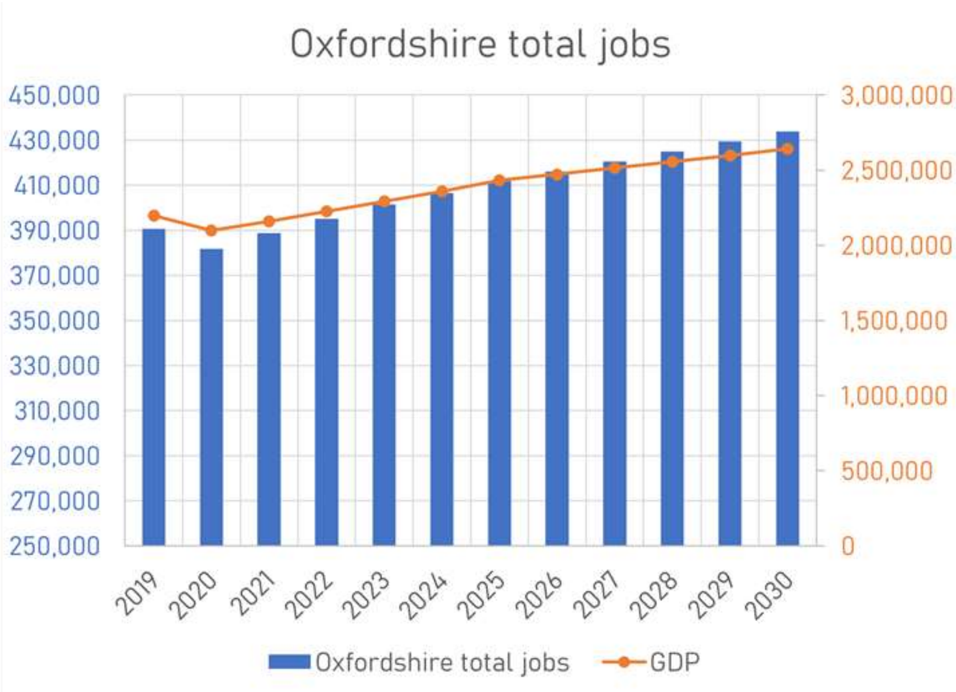

Figure 18: Total jobs trend in Oxfordshire between 2019 and 2030

Figure 17 represents the total jobs in Oxfordshire: following GDP and the other exogenous trends, the total number of jobs shows a decrease (-2.3%) in 2020, followed by a steady rise, leading to 13% additional jobs in 2030, with respect to 2020.

Considering economic sectors (Figure 18), four of them show a decrease until 2030: Information Technology, Communication, Utilities, and High-Tech Industry. This reduction is a continuation of trends observed in recent years. On the other hand, the Activity services shows the highest increase (32% with respect to 2019).

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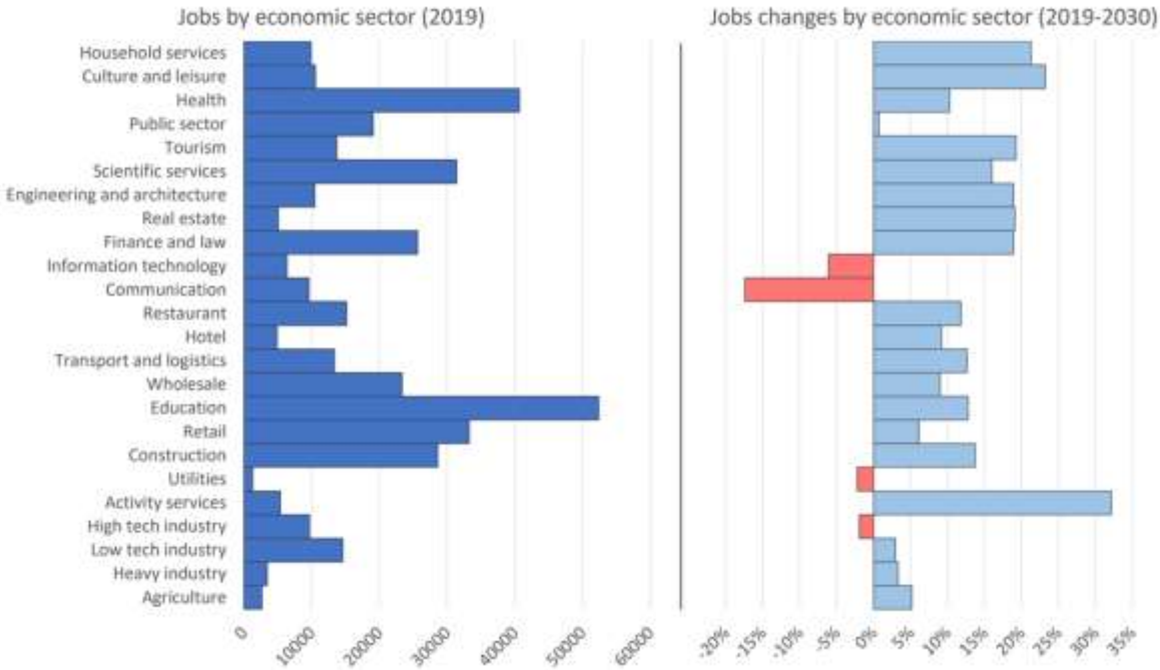

Figure 19: Jobs by economic sector, and jobs changes by economic sector in Oxfordshire from 2019 and 2030

LUTI

One of the main results of LUTI models are the prediction of people's flows. The flows of people travelling with car are much more intense than the ones travelling with bus. The majority of the flows are concentrated in the major roads of the city centre, close to Witney (west), close to Banbury and Bicester (north) and close to Abingdon, Didcot, Dorchester and Wallingford (south). In 2030, the flows of both cars and bus are predicted to increase in the western, eastern and some parts of the northern ring roads, while the flows in the local roads inside the town centers will decrease. A shapefile that contains commuter's flows can be easily downloaded from the HARMONY MS Dashboard and visualized on a map using any GIS software.

Population change from 2019 to 2030 in Oxfordshire is directly produced as a map by the HARMONY MS Dashboard. It is obvious that Witney faces the greatest population change, while Thame and some parts of the city of Oxford follows (Figure 19). Chipping Norton, Benson and Didcot also show a notable change.

Another important result of the LUTI model is the accessibility around job and housing locations. Regarding the jobs' accessibility, the scores stay relatively the same in 2019 and 2030. It is observed that the highest accessibility scores for people using car and rail are concentrated in the cities of Oxford, Banbury, Abingdon and Thame, while for people using bus high job accessibility have also the towns of West Oxfordshire, like Witney and Chipping Norton. Except for their absolute values in 2019 and 2030, Figure 20 also presents the difference between these years. For both car and bus the biggest difference of 4.5% occurs in the city of Thames. Additionally, a difference of around 3% (for bus) occurs in the regions near the cities of Witney and Chipping Norton. For the rail network the highest value of 2% is found only in the city of Bicester, while for bus network the city of Bicester and its surrounding area presents the highest negative change (-4.5%).

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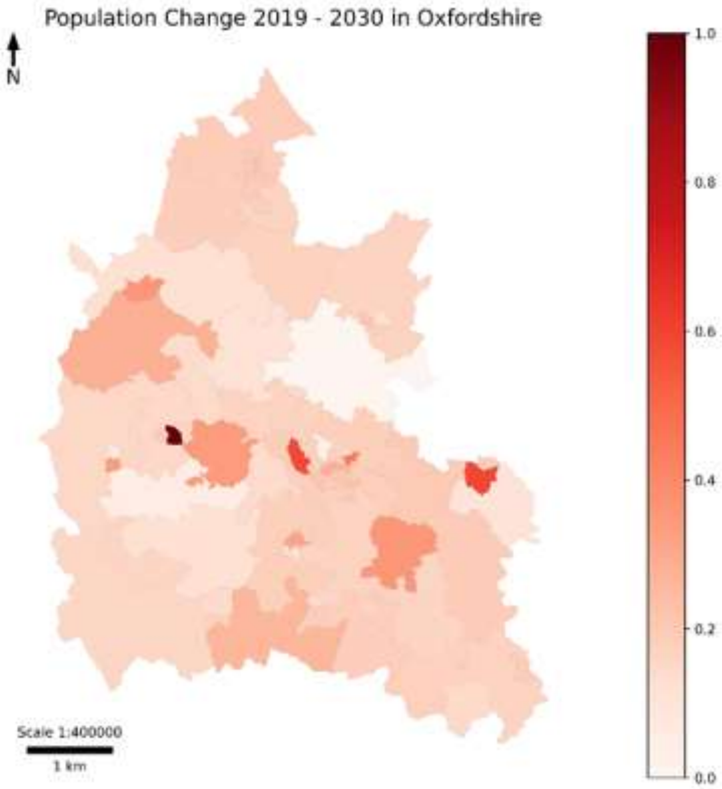

Figure 20: Population change between 2019 and 2030 in Oxfordshire

However, housing accessibility presents some difference from 2019 until 2030. The highest rates for people using car are in the cities of Oxford, Abingdon, Banbury, Bicester and Carterton in 2019. The only increase in 2030 happens in Chipping Norton and Witney. For people using bus and rail in 2019, the highest scores are found in the city of Bicester and its surrounding areas, the city of Banbury and its surrounding areas, Chipping Norton, Witney and Didcot. In 2030, the areas of Chipping Norton, Didcot, Oxford and Witney have the bigger rise. Regarding the change from 2019 to 2030, the city of Witney and the region west to it presents a difference of 60% for car, while for bus and rail the cities of Woodstock, Kidlington, Witney, Thame and Chipping Norton present the highest differences. The highest negative change for car is found in some parts of the city centre, in the town of Wantage and its surrounding villages, in Didcot and Bicester, while for bus and rail in Bicester and in the Headington neighborhood of Oxford city.

LDM

Outputs for the 1st Scenario (Figure 21) represent projected desirability for both 2019 and 2030 and suitability of land for residential development in Oxfordshire. The land suitability output shows all white pixels as non-developable corresponding to each of the constraint layers used in the model. Since slope, population density and distance from green spaces were the negative attractors included the model, darker blue pixels correlate to land that is flatter, less populated and closer to green spaces relative to the rest of the land in the region and is therefore, theoretically, more conducive to development. To predict land desirability, job and housing accessibility are added as positive attractors for 2019 and 2030. Therefore, the shade of blue corresponds to the normalized slope, population density, 2,5 km distance from the green spaces and the job and housing accessibility of the land supply within the region as determined by the LUTI model. The map that shows the difference of land desirability between 2019 and 2030 reveals that only the areas of Bourton, Shrivenham and Watchfield and some pixels of Bandbury show a small increase (up to 0.14) in 2030.

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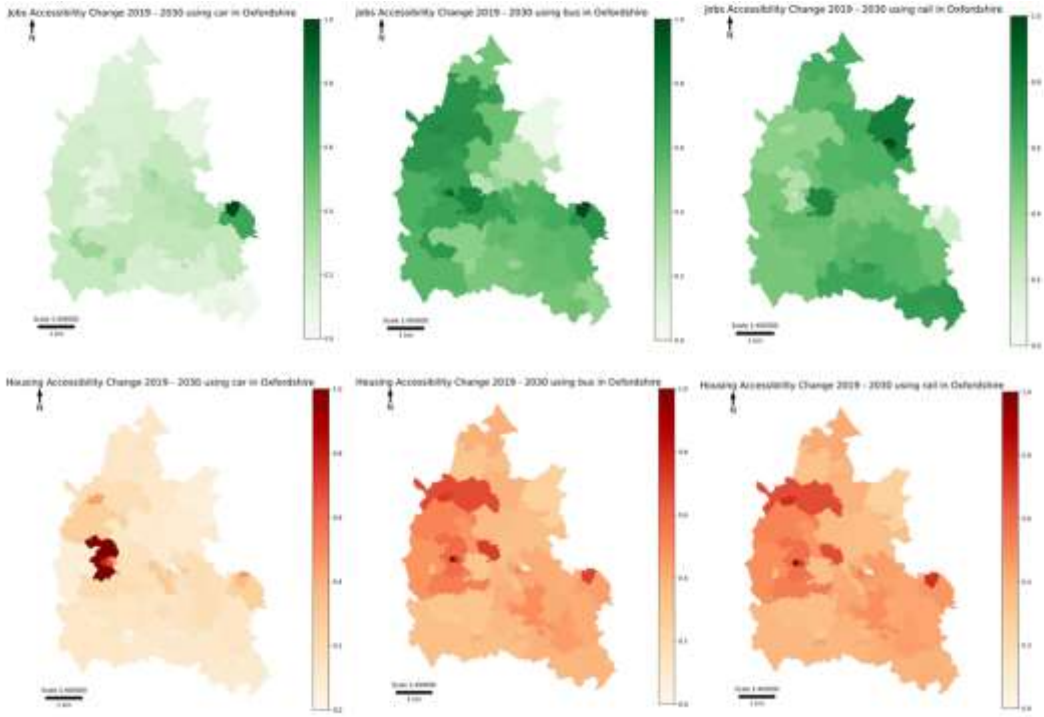

Figure 21: Job (up) and Housing (down) accessibility change in % between 2019 and 2030 for car, bus and rail

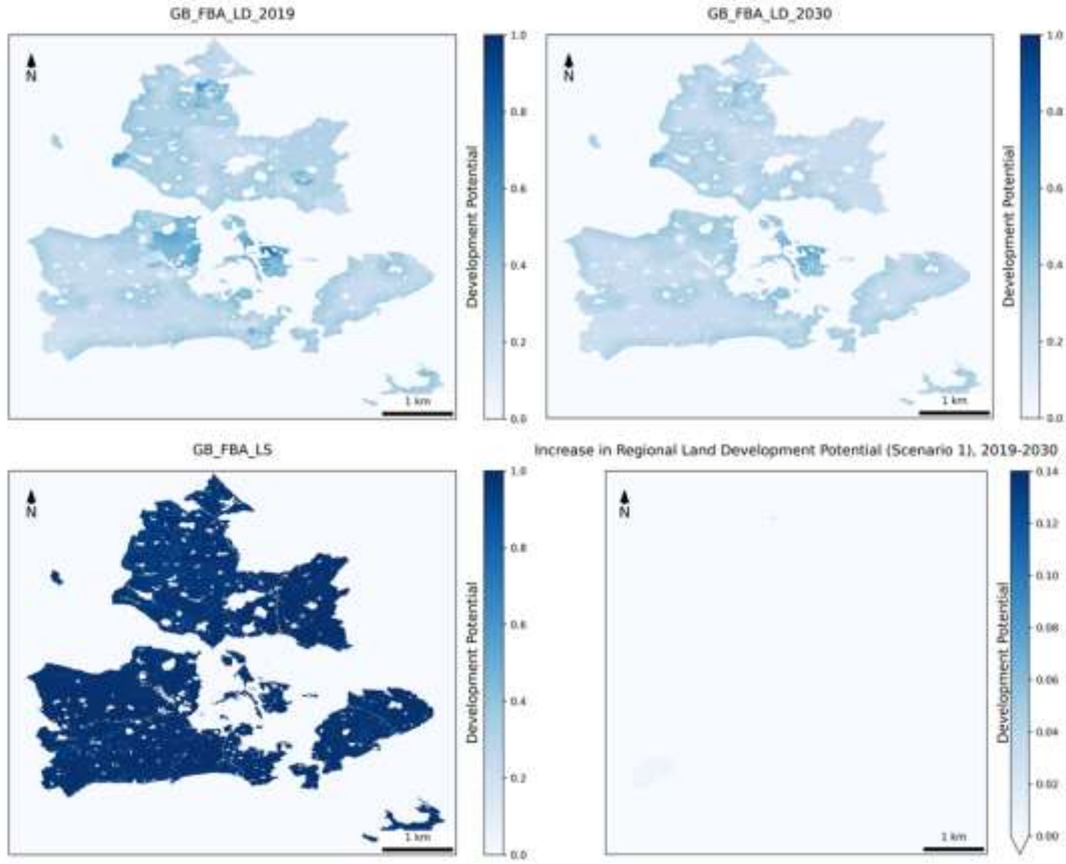

Figure 22: Scenario 1 - Land desirability for 2019 (up left) and 2030 (up right), land suitability (down left) and difference between 2019-2030 (down right)

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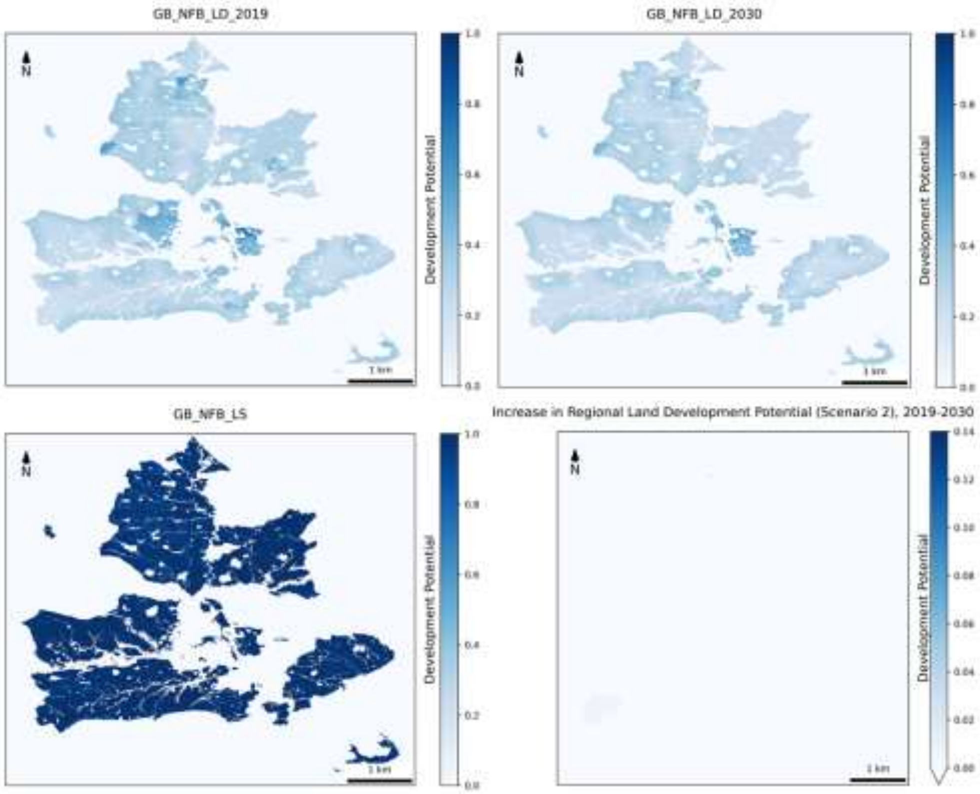

Figure 23: Scenario 2 - Land desirability for 2019 (up left) and 2030 (up right), land suitability (down left) and difference between 2019-2030 (down right)

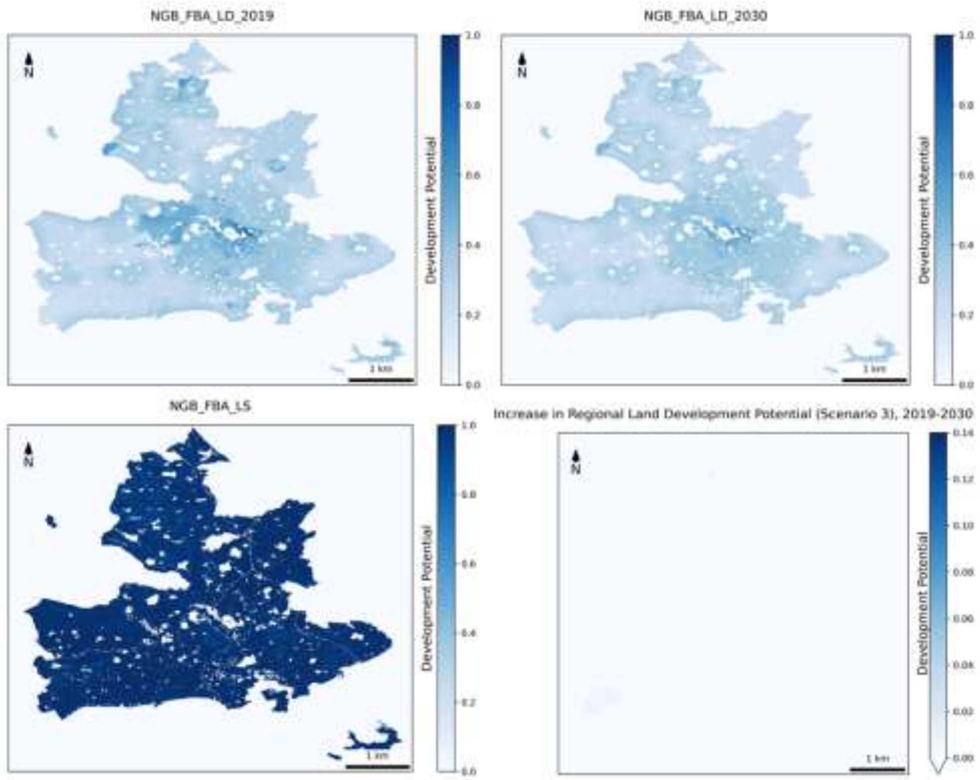

Figure 24: Scenario 3 - Land desirability for 2019 (up left) and 2030 (up right), land suitability (down left) and difference between 2019-2030 (down right)

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Figure 22 presents the same results as Figure 3 with the only difference that building in flood risk areas is not allowed and thus there are more white pixels representing non-developable land.

Figure 23 displays again the same results as Figure 3 and Figure 4, but the blue pixels cover a greater area in the maps than those in the 2 previous figures. That' s reasonable as building in both green belts and flood risk areas is allowed.

Figure 24 displays the same results as in the figures above with building being allowed in green belt areas but not in flood risk areas.

Generally, the outputs of land desirability in every scenario indicate that the regions that have the higher residential potential are the cities of Oxford, Banbury, Bicester, Chipping Norton, Abingdon and Didcot.

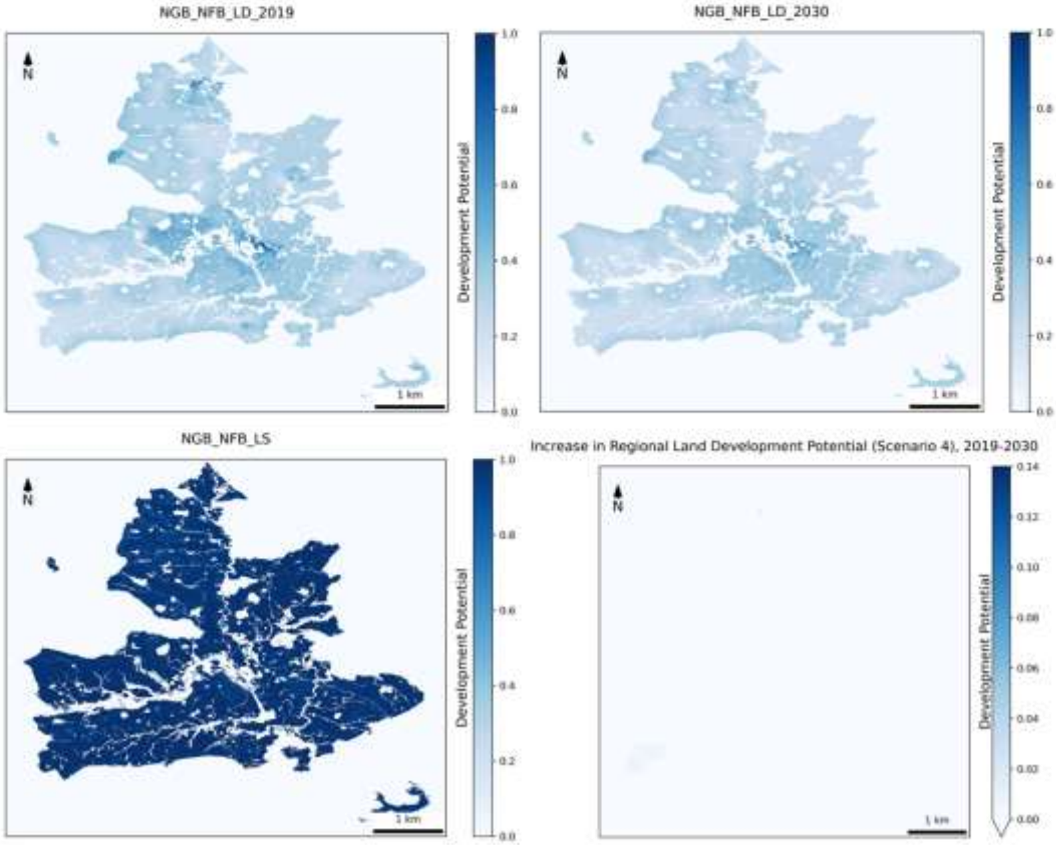

Figure 25: Scenario 4 - Land desirability for 2019 (up left) and 2030 (up right), land suitability (down left) and difference between 2019-2030 (down right)

[1] See documentation at https://github.com/nismod/household_microsynth

[2] See documentation at https://github.com/nismod/household_microsynth

[3] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

3.4 Operational models template: simulation results and evaluation

For the **DRT use-case** several scenarios were evaluated, including a base case and variations with differing penetration rates and fleet sizes. The simulation time occurred over the period from 8am to 9am, with a warmup period of 30 minutes. The complete set of KPIs from Aimsun for the base case is found in Table 16. The same set of statistics are available for all scenarios, and included here to show the full breadth of statistics that are available via the simulator.

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Table 16: Simulation outputs produced by Aimsun Next

Time Series	Value	Standard Deviation	Units
CO2 - All	85209863.25	N/A	g
CO2 - Bus	0	N/A	g
CO2 - Car	78632940.52	N/A	g
CO2 - Truck	6576922.73	N/A	g
Delay Time - All	46.84	64.52	sec/km
Delay Time - Bus	33.9	23.64	sec/km
Delay Time - Car	47.01	64.8	sec/km
Delay Time - Truck	38.41	49.9	sec/km
Density - All	19.66	N/A	veh/km
Density - Bus	0.07	N/A	veh/km
Density - Car	19.19	N/A	veh/km
Density - Truck	0.41	N/A	veh/km
Flow - All	18679.33	N/A	veh/h
Flow - Bus	78.67	N/A	veh/h
Flow - Car	18357	N/A	veh/h
Flow - Truck	243.67	N/A	veh/h
Harmonic Speed - All	31.06	15.14	km/h
Harmonic Speed - Bus	17.52	4.1	km/h
Harmonic Speed - Car	31.1	15.1	km/h
Harmonic Speed - Truck	36.93	18.21	km/h
Input Count - All	75409	N/A	veh
Input Count - Bus	251	N/A	veh
Input Count - Car	74033	N/A	veh
Input Count - Truck	1125	N/A	veh
Input Flow - All	25136.33	N/A	veh/h
Input Flow - Bus	83.67	N/A	veh/h
Input Flow - Car	24677.67	N/A	veh/h
Input Flow - Truck	375	N/A	veh/h
Mean Queue - All	10858.99	N/A	veh
Mean Queue - Bus	30.11	N/A	veh
Mean Queue - Car	10588.98	N/A	veh
Mean Queue - Truck	239.9	N/A	veh
Mean Virtual Queue - All	4673.48	N/A	veh
Mean Virtual Queue - Bus	0	N/A	veh
Mean Virtual Queue - Car	4552.93	N/A	veh
Mean Virtual Queue - Truck	120.55	N/A	veh
Missed Turns - All	0	N/A	
Missed Turns - Bus	0	N/A	
Missed Turns - Car	0	N/A	

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Missed Turns - Truck	0	N/A	
NOx - All	146833.67	N/A	g
NOx - Bus	0	N/A	g
NOx - Car	113974.39	N/A	g
NOx - Truck	32859.28	N/A	g
Number of Lane Changes - All	87.19	N/A	#/km
Number of Lane Changes - Bus	0.48	N/A	#/km
Number of Lane Changes - Car	85.5	N/A	#/km
Number of Lane Changes - Truck	1.21	N/A	#/km
Speed - All	38.44	17.36	km/h
Speed - Bus	18.48	5.98	km/h
Speed - Car	38.43	17.3	km/h
Speed - Truck	45.91	19.53	km/h
Total Distance Travelled - All	360883.55	N/A	km
Total Distance Travelled - Bus	1732.6	N/A	km
Total Distance Travelled - Car	352427.09	N/A	km
Total Distance Travelled - Truck	6723.86	N/A	km
Total Distance Travelled (Vehicles Inside) - All	2955.18	N/A	km
Total Distance Travelled (Vehicles Inside) - Bus	0	N/A	km
Total Distance Travelled (Vehicles Inside) - Car	2909.84	N/A	km
Total Distance Travelled (Vehicles Inside) - Truck	45.34	N/A	km
Total Number of Lane Changes - All	62533	N/A	
Total Number of Lane Changes - Bus	345	N/A	
Total Number of Lane Changes - Car	61319	N/A	
Total Number of Lane Changes - Truck	869	N/A	
Total Travel Time - All	10617.79	N/A	h

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Total Travel Time - Bus	97.22	N/A	h
Total Travel Time - Car	10356.21	N/A	h
Total Travel Time - Truck	164.36	N/A	h
Total Travel Time (Vehicles Inside) - All	32343.49	N/A	h
Total Travel Time (Vehicles Inside) - Bus	46.17	N/A	h
Total Travel Time (Vehicles Inside) - Car	31568.71	N/A	h
Total Travel Time (Vehicles Inside) - Truck	728.61	N/A	h
Total Travel Time (Waiting Out) - All	13599.23	N/A	h
Total Travel Time (Waiting Out) - Bus	0	N/A	h
Total Travel Time (Waiting Out) - Car	13249.74	N/A	h
Total Travel Time (Waiting Out) - Truck	349.48	N/A	h
Travel Time - All	115.91	68.51	sec/km
Travel Time - Bus	205.46	49.26	sec/km
Travel Time - Car	115.77	68.47	sec/km
Travel Time - Truck	97.47	54.27	sec/km
Vehicles Inside - All	25460	N/A	veh
Vehicles Inside - Bus	21	N/A	veh
Vehicles Inside - Car	24952	N/A	veh
Vehicles Inside - Truck	487	N/A	veh
Vehicles Lost Inside - All	0	N/A	veh
Vehicles Lost Inside - Bus	0	N/A	veh
Vehicles Lost Inside - Car	0	N/A	veh
Vehicles Lost Inside - Truck	0	N/A	veh
Vehicles Lost Outside - All	0	N/A	veh
Vehicles Lost Outside - Bus	0	N/A	veh
Vehicles Lost Outside - Car	0	N/A	veh

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Vehicles Lost Outside - Truck	0	N/A	veh
Vehicles Outside - All	56038	N/A	veh
Vehicles Outside - Bus	236	N/A	veh
Vehicles Outside - Car	55071	N/A	veh
Vehicles Outside - Truck	731	N/A	veh
Vehicles Waiting to Enter - All	19013	N/A	veh
Vehicles Waiting to Enter - Bus	0	N/A	veh
Vehicles Waiting to Enter - Car	18519	N/A	veh
Vehicles Waiting to Enter - Truck	494	N/A	veh
Waiting Time in Virtual Queue - All	534.55	1288.44	sec
Waiting Time in Virtual Queue - Bus	0.1	0.42	sec
Waiting Time in Virtual Queue - Car	531.29	1285.42	sec
Waiting Time in Virtual Queue - Truck	804.19	1498.15	sec

Two alternative scenarios were tested for two DRT penetration rates, meaning four scenarios were tested with five different random seeds each. The random seeds enabled confidence intervals to be calculated for the metrics obtained. For each scenario, the start time was at 8am and DRT trips were allocated between 8am and 9am. However, the scenarios ran until 11am, allowing all DRT trips to complete. Metrics were obtained over the entire three hour period. The two alternative scenarios were for DRT and grouped DRT. Grouped DRT emulates a ride-sharing scenario by grouping together similar trips, that is, trips with the same origin and destination zone, departing within the same 15 minute period. Since trips with the same properties are grouped together, there are a fewer number of trips needing to be fulfilled by the DRT trips.

Table 17 compares various measures for ungrouped and grouped trip scenarios for 1% and 10% DRT. There was a greater reduction in trip counts (26% compared to 7%) for the 10% DRT case, compared to the 1% DRT case. In both cases, the average trip time (including the time required for the vehicle to reach the passenger's origin) was about 20 mins. The average delivery time (from passenger origin to destination) was about 10 mins. Therefore the fleet size required to accommodate all trips is approximately $T \div 6020$, where T is the number of trips. This equates to about 100 vehicles in the case of 1% DRT and 1000 vehicles for 10% DRT. For the purpose of testing these scenarios, a fleet large enough to accommodate all trip requests was created. In both cases, a large fleet is required to make a substantial difference to network performance metrics. It may be unrealistic to assume that a large enough fleet exists to service enough demand to make a substantial difference to network performance. However, by grouping trips together, the number of trips and therefore emissions is reduced, even if network congestion is not substantially improved.

Generally, the number of trips grouped together (and therefore the number of occupants) is low – between 1 and 2 people in both cases. However, the maximum number of occupants is 34 in the case of 10% DRT, indicating that a larger vehicle would be required to accommodate such a large number

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of occupants. Figure 26 shows the number of trips that were conducted for different ranges of occupants. As can be seen, the majority of trips require a capacity of less than 5 seats.

Table 17: Comparing metrics for ungrouped and grouped trip cases

Percentage DRT (%)	1	10
Trip count	**348**	**3482**
Trip count (grouped)	**324**	**2580**
% reduction	**7**	**26**
Max. occupants	**7**	**34**
Average occupants	**1.07**	**1.35**
Std. dev. Occupants	**0.47**	**1.80**
Avg. trip total time (min) including traveling to passenger	**18**	**19**
Max trip total time (min) (including travelling to passenger)	**51**	**92**
Avg delivery time (min)	**12**	**11**
Max delivery time (min)	**39**	**89**

Figure 27 and Figure 28 illustrate how these metrics changed as the percentage of DRT trips increased. With increasing penetration rate, the demand created as background traffic decreased by the same amount. For example, when DRT demand was 4% of the total demand, background traffic was 96% of total demand. The figures show that network performance may degrade a little when the penetration rate for DRT is only 1%. However, both total network travel distance and CO2 emissions may decrease as the penetration rate increases to 10%. It should be noted, though, that the error bars are quite high and when they overlap, a definitive statement about the trend of the metric cannot be made. A reduction in emissions and travel distance is observed when trips are grouped together for the 10% DRT penetration rate scenarios.

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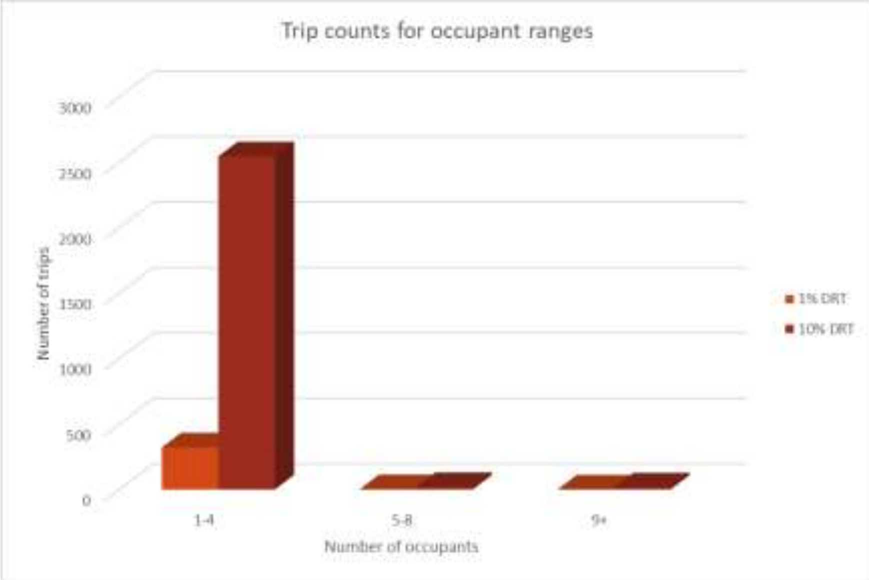

Figure 26: Number of trips for 1% and 10% DRT scenarios when trips are grouped.

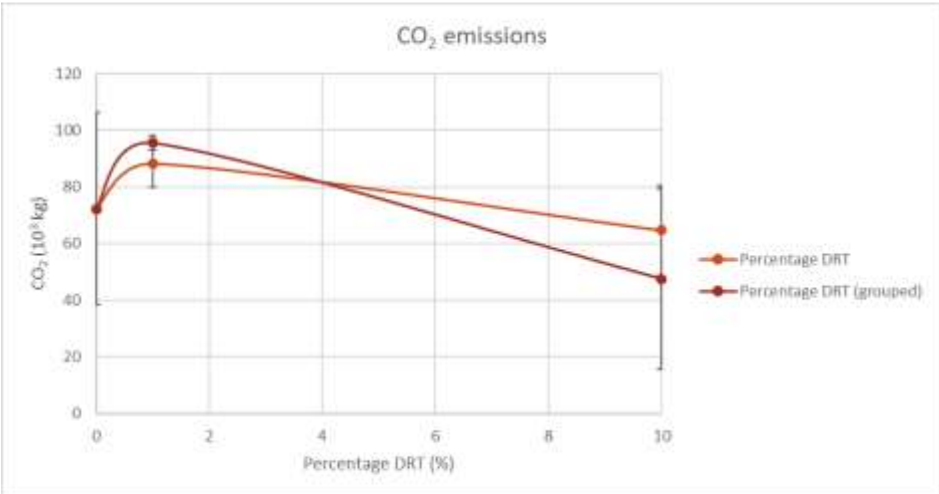

Figure 27: CO2 emissions as percentage of DRT trips varies

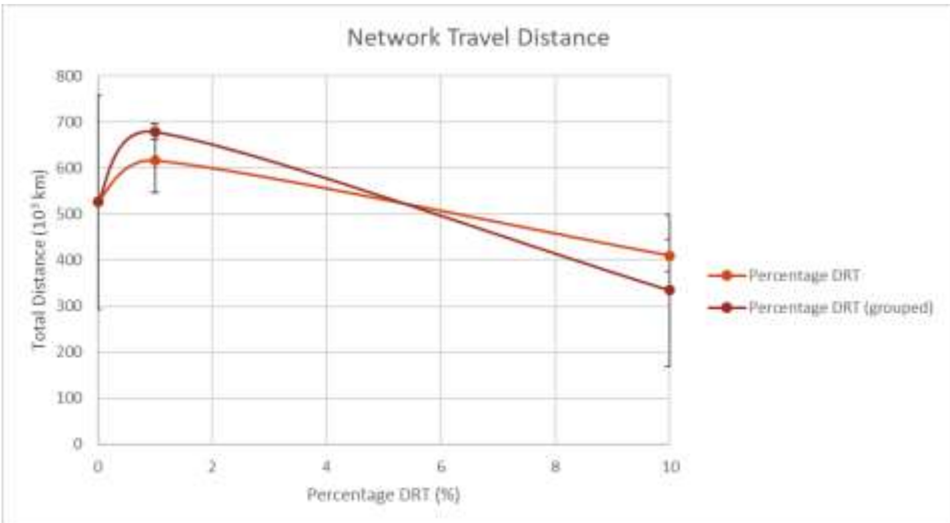

Figure 28: Total network (car) distance as percentage of DRT trips varies

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3.5 Summary

To evaluate the impact of a new housing development in Oxfordshire, four Strategic models (DFM, REM, LUTI and LDM) have been applied. The results described above present that Oxfordshire's population is expected to rise to 832,300 (+21%) and the number of jobs to 432,000 (+11%) in 2030. Thus, new dwellings and transport infrastructure will be built in order to support new population and job positions. LUTI results reflect new mobility patterns by 2030 and show how the housing and jobs accessibility will be formed around the new housing locations. They also indicate which of these locations are more suitable to build on and which of them are more preferable, i.e. where higher demand and prices are expected.

In general, the results confirm that the HARMONY model suite constitutes a powerful tool that can support policy – making, spatial and transport planning and can be used to explore the impact of different scenarios. New housing development is one of them, but the methodology of this tool can be utilized in the future to test and access multiple scenarios in Oxfordshire, like the new high-speed railway from London to Birmingham, post-pandemic, post-Brexit and climate crisis periods. This methodology can be combined with methodologies and guidelines on SUMP appraisal suggested by the EU in order to design SUMPs for Oxfordshire County

The simulation results of the DRT use-case within the Operational Simulator show that a large fleet size is required to accommodate all trip requests to make a substantial difference to network performance metrics. Grouping trips together can reduce the number of trips and emissions, even if network congestion is not substantially improved. The network performance may degrade slightly when the penetration rate for DRT is only 1%, but total network travel distance and CO_2 emissions may decrease as the penetration rate increases to 10%. Overall, the results provide important insights into the potential impact of DRT services on traffic congestion and emissions in Oxfordshire and can inform evidence-based decision-making towards a more sustainable and low-carbon transport system.

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3. Use Cases Simulations: Turin

4.1 The use cases for Turin

Turin is one of the main Italian cities, located at the western edge of the Po valley. With a strong industrial tradition especially in the automotive sector (FIAT), in recent years the de-industrialisation trend has significantly affected the economy and the development of the city and of its metropolitan area.

The Turin municipality pursues the goal of rebalancing the demand for transport between collective and individual, in order to reduce congestion and improve the accessibility to the various urban functions. Pursuing this strategy implies an incisive mobility policy, pushing the collective transport use through large infrastructure implementation (such as the underground and the metropolitan railway service) and through new ITS technologies development, while, on one hand, improving the economy in the use of these services and, on the other hand, developing new sharing services.

Considering the overall vision described above, the Turin pilot goals within the HARMONY project is focused on a modelling study on the territorial impact generated by the new public transport infrastructure and the new MaaS mobility paradigm on the Turin Urban Functional Area, with reference to its integration with the Metropolitan Railway System (SFM). Furthermore, the topics of remote working and urban vehicle access regulation are addressed with the modelling application.

The modelling components of the HARMONY MS have been developed and applied to Turin Urban Functional area, which includes the municipality of Turin and 87 municipalities within the province of Turin, segmented in a zoning system of about 270 zones. The base year considered is 2019, while the projection year is 2030 for all use cases.

Use case 1: Land use development & new public transport infrastructure

The first use case has been designed to simulate selected land use developments and new public transport infrastructures planned to be in place at the projection year 2030, as reported in the following table. The projects have been selected considering the reference scenario designed for the SUMP of the Turin Metropolitan area, published in July 2021[1]. On one hand, there are transport infrastructure projects aiming to improve public transport services at urban and inter-urban level (metro and tram lines as well as metropolitan railway network); on the other hand, some land use development projects related to university, health and public administration office are considered for their relevance also at metropolitan scale.

Table 18 Planned land use developments and new public transport infrastructures in Use case 1 at 2030 in Turin

Area		**Interventions**
PT infrastructure	Urban and suburban public transport network	Extension of the Metro Line n. 1 towards Rivoli-Cascine Vica
		New Metro Line n. 2, from Rebaudengo Fossata / Pescarito to Orbassano
		Extension of Tram line 3 to piazzale Toselli
		Extension of Tram line 4 to Stupinigi
		Extension of Tram line 15 to Grugliasco
		New SFM3 line, which will connect the Porta Susa railway station with the Caselle International Airport Sandro Pertini.

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	Metropolitan Railway System (SFM)	The SFM5 line, connecting the Torino Stura railway station to the City of Orbassano. Three new railway stations: Orbassano Ospedale S.Luigi, Grugliasco – Le GRU and Torino-San Paolo
Land use development	Torino	Lingotto area: – offices (Regional administration headquarter), – hospital (Città della Salute) – health research area, university (Città della Salute) – closing hospitals (Azienda Ospendaliera O.I.R.M.S. Sant' Anna and Ospedale Molinette)
	Grugliasco	University extension
	Moncalieri e Chieri	Closing existing hospitals (Ospedale Maggiore and Ospedale Santa Croce)
	Trofarello	New hospital

Use case 2: MaaS demand

This use case is implemented on top of Use case 1. The topic of new MaaS mobility paradigm on the Turin Urban Functional Area is among those of main interest for the City and Metropolitan area, already exploring these aspects in several projects such as BIPforMaaS[1], Buoni Mobilità[2] and IMOVE[3]. The aim is to promote the integration of public transport (urban and inter-urban) with shared mobility services, applied to the whole FUA. The modes involved would include: urban public transport, metropolitan rail, car sharing, bike sharing, shared e-scooters, shared moped scooters.

[1] https://www.bipformaas.it/en/home-en/

[2] https://www.muoversiatorino.it/it/maastorino/

[3] https://www.uitp.org/projects/imove/

Use case 3: Remote working / activity schedule

This use case is implemented on top of Use case 1. The aim is to test the impacts of changes in mobility patterns of individuals, as a result of the diffusion of remote working and revised activity schedule. In fact, remote work and virtual meetings are likely to continue, albeit less intensely than at the pandemic's peak. The pandemic accelerated existing trends, and this use case aims to explore the potential impacts of long-term new habits on passenger mobility in the metropolitan area.

Use case 4: Urban Vehicles Access Regulation measures

This use case is implemented on top of Use case 1.

Concerning Urban Vehicles Access Regulation, the following measures are considered in the Use Case at the projection year 2030:

- **Extension of application of Limited Traffic Zone** in the central area of Turin municipality. The area is currently defined as Limited Traffic Zone (ZTL) and applied only in the morning 7:30 to 10:30 during working days (Figure 29). The assumption of the use case is to implement in the model an extension of the ZTL application, during working days from 7.30 to 19.30.

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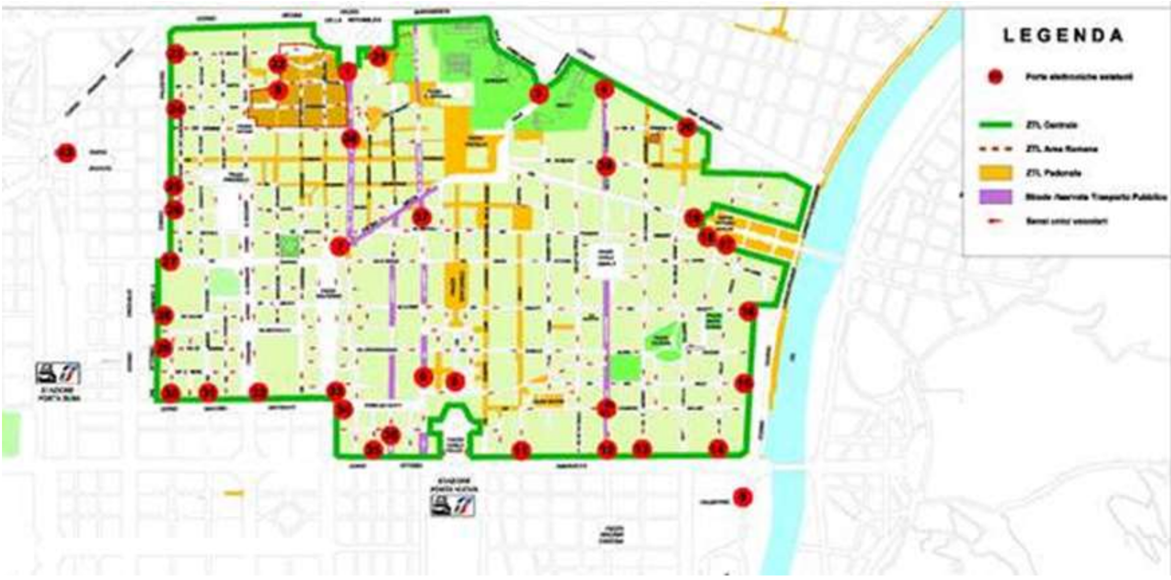

Figure 29 Limited Traffic Zone in the central area of Turin municipality (www.comune.torino.it)

- **Traffic calming areas** (zone 30) implemented extensively in Turin municipality, as well as in the neighbouring municipalities of Settimo Torinese, Venaria Reale, Collegno, Rivoli, Grugliasco, Orbassano, Moncalieri, Nichelino. The extension of the area is defined according to the SUMP scenario of the Metropolitan City of Turin[1] (adopted in August 2021) and reported in Figure 30.

Figure 30 Traffic calming zones in Turin and other municipalities of the Turin Urban Functional area according to the SUMP scenario [August 2021]

- **Low Emission Zone** in the area including several municipalities of the Turin Urban Functional Area, assuming that only vehicles complying with Low emission standard can travel within the area shown in Figure 31. The municipalities involved are the same considered in the Air pollutant emission winter Emergency Plan[2] already in place in the North Italian regions, namely those reported in the following Table 19. The measure should allow the circulation of petrol and diesel vehicles with a minimum standard of EURO6, as well as hybrid and electric vehicles.

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Table 19 List of municipalities of the Turin Urban Functional Area included in the LEZ at 2030

Municipalities of the LEZ				
Alpignano	Caselle Torinese	Leini	Pino Torinese	Settimo Torinese
Baldissero Torinese	Chieri	Moncalieri	Piobesi Torinese	Torino
Beinasco	Collegno	Nichelino	Piossasco	Trofarello
Borgaro Torinese	Druento	Orbassano	Rivalta di Torino	Venaria Reale
Cambiano	Grugliasco	Pecetto Torinese	Rivoli	Vinovo
Candiolo	La Loggia	Pianezza	San Mauro Torinese	Volpiano
Carignano				

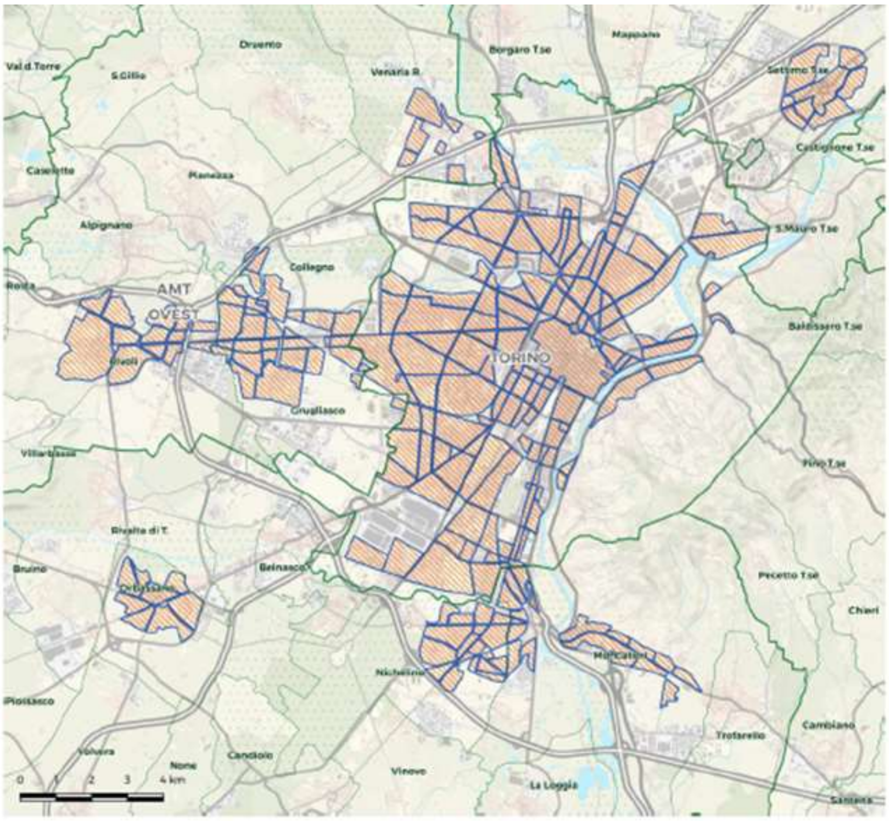

Figure 31 Extension of the LEZ in the Turin Urban Functional area under analysis

[1]http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/RapportoFIN_v10.pdf

[2] http://www.arpa.piemonte.it/approfondimenti/temi-ambientali/aria/aria/semaforo-qualita-dellaria-pm1

[3] http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/RapportoFIN_v10.pdf

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4.2 Application of the HARMONY MS simulators

The four use cases designed for Turin have been simulated with the modelling components of the HARMONY MS. More in details, use case 1 has been simulated at first as an application of the strategic models, as well as with the combination of the tactical and operational models.

Use cases from 2 to 4 have been simulated with tactical and operational models, using inputs from some of the strategic models.

In the end, two templates (related to the combination of modelling components) have been use for the simulation of the use cases in Turin.

The first template is related to the **strategic level models** i.e., aggregate and disaggregate regional economic, demographic forecasting, land-use transport-interaction and land development models for spatial planning. These models consist of: i) a population model, that generates the total population disaggregated into age-sex cohorts that define the overall size of the city systems in question. ii) A regional economy model (REM) associated with the entire suite of models in HARMONY, that generates future employment and structures the demand for physical travel. iii) A Land Use Transport Interaction (LUTI) model, that takes inputs from the aggregate economic and demographic forecasting models, allocating these activities to small zones using spatial interaction approaches consistent with the transport activity models at the tactical scale. iv) A land development model for predicting land availability / suitability.

These four models can work as stand-alone models, but they can also interact with each other, exchange data and act as a single cluster of models, as shown in Figure 32. The Demographic Forecasting Model takes census population data as an input and supplies the Regional Economy Model with numbers of total population and Land-Use Transport-Interaction model with population per zone data, while it also produces people and household's data for the reference year and the future ones. Apart from the population data, REM takes public investments, National GDP, tourism and Income data as main input and produces employment projections by economic sector per year, supplying the LUTI model with total employment data per zone. The LUTI model also takes attractivity factors and travel cost matrices by mode of transport from exogenous sources and purveys the Land Development Model with jobs and housing accessibility data, while it produces flow matrices, modal split and impact heatmaps. The LDM also needs physical constraints, socio-demographic data, GIS layers and town planning constraints in order to predict the land availability.

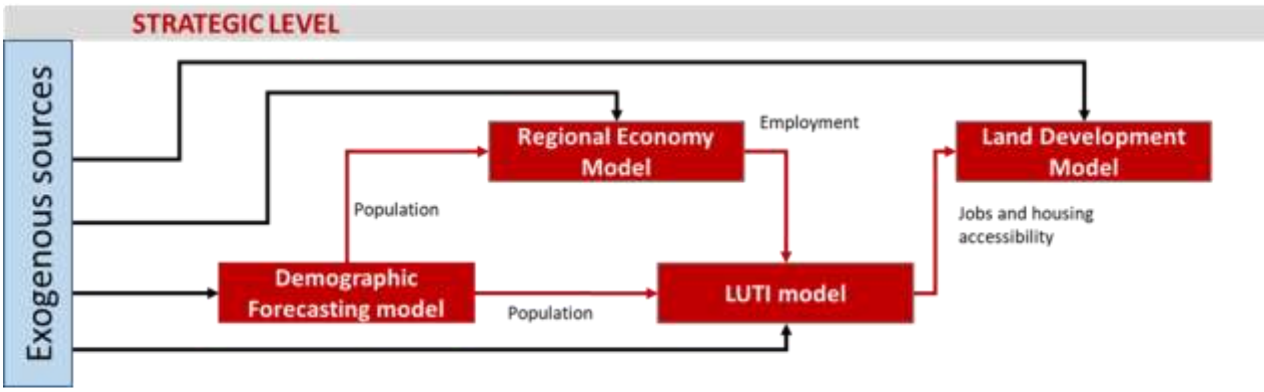

Figure 32 Template of Strategic Model Suite for Turin

The second template is mainly related to the **tactical and operational levels,** linked with some models of the **strategic level**. These models consist of: i) a population model, that generates the total population disaggregated into age-sex cohorts that define the overall size of the city systems in question. ii) A synthetic population model to translate into more disaggregated population the data from population model. iii) A long-term household and individual vehicle choice model, to estimate vehicle ownership and mobility services subscriptions. iv) A tactical agent-based passenger model, that takes

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inputs from the aggregate economic and demographic forecasting models and estimates passenger' choices on a day-to-day level. v) A passenger network traffic assignment model, to load passenger demand into different types of networks. vi) An energy and emission model, to estimate energy consumption and air pollutant emissions related to passenger mobility patterns in the metropolitan area.

These models interact with each other, exchanging data as shown in Figure 33.

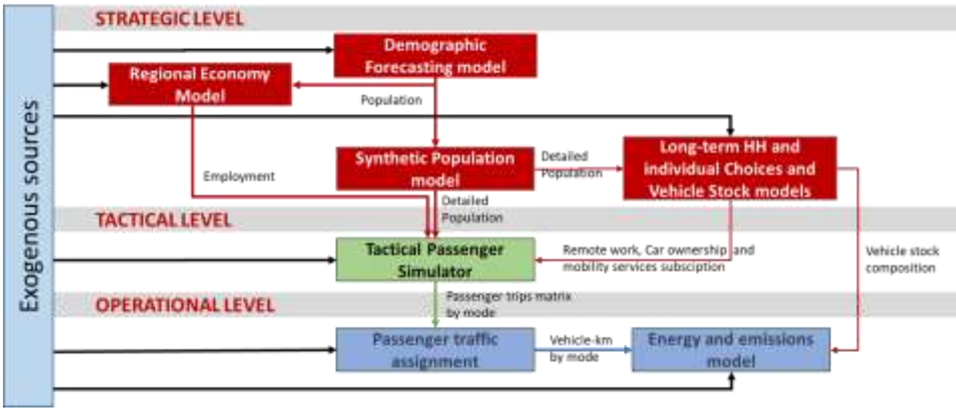

Figure 33 Template of Strategic-tactical and operational Model Suite for Turin

4.3 Strategic models template: simulation results & evaluation

Results of use case 1: Land use development and transport infrastructures

The DFM Lite model has been applied to simulate population projections at the year 2030, based on input from the Italian National Institute of Statistics (ISTAT) and the Demographic Territorial Observatory of the Piemonte Region. The total population of the Turin Urban Functional Area (FUA) accounts for about 1.7 million inhabitants in 2019, with approximately 870,000 residents in the Turin municipality and 500,000 in the first belt municipalities. As reported in the following figure, the population above 65 years old represents about a quarter of total population in 2019. The ageing of population is a trend already observed in the last decade and projected also in the future: in the year 2030, the share of population above 65 is expected to represent about 29% of inhabitants in the Turin metropolitan area. With this respect, the Ageing index[1] is estimated to increase from 199 in 2019 to 264 in 2030, while the Age dependency ratio[2] is increasing from 61 to 65 in the same time period. Total population is slightly decreasing from 2019 to 2030 (-4% i.e., by about 70,000 inhabitants).

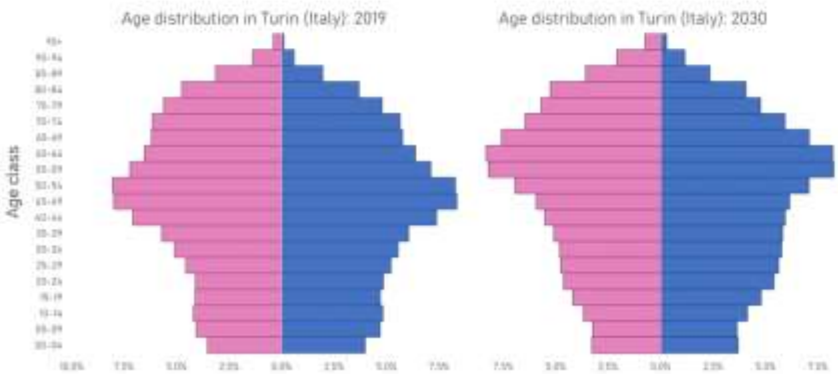

Figure 34 Age distribution in the Turin Functional Urban Area in 2019 and 2030

In terms of distribution on the territory of the Turin metropolitan area no major changes are simulated between 2019 and 2030, with higher population density remaining in the Turin municipality and its surroundings. The application of the REM model has been implemented considering exogenous trends deriving from selected scenarios, extrapolation of recent trends and dedicated assumptions. In terms of GDP, the trend is aligned with the EU Reference scenario 2020[3] projection for Italy for the period

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2020-2030. After a decrease of nearly 8% in 2020, a recovery is assumed, with a growth rate of 1.4% until 2025 and 0.3% to reach 2030. Population trend has been taken directly from the DFM Lite model. Concerning the index representing tourism, after the COVID impact resulting in a reduction of about 60%, it has been assumed a recovery to pre-pandemic levels by 2024 with a slight increase in the following years (based on past trend). The index related to public investments has been estimated on the basis of planned infrastructures included in the scenario simulation. Other input trends such as e-commerce index, residential and transport cost, etc. have been estimated on the basis of past trends. The following figure presents the trend of total jobs in the Turin Functional Urban Area; an increase of 2.6% is forecasted from about 705,000 jobs in 2019 to 724,000 in 2030. Actually, a higher average growth rate is expected for the next year considering the loss of 29,000 jobs in 2020. This variation seems reasonable with respect to the input data and the Italian context of application.

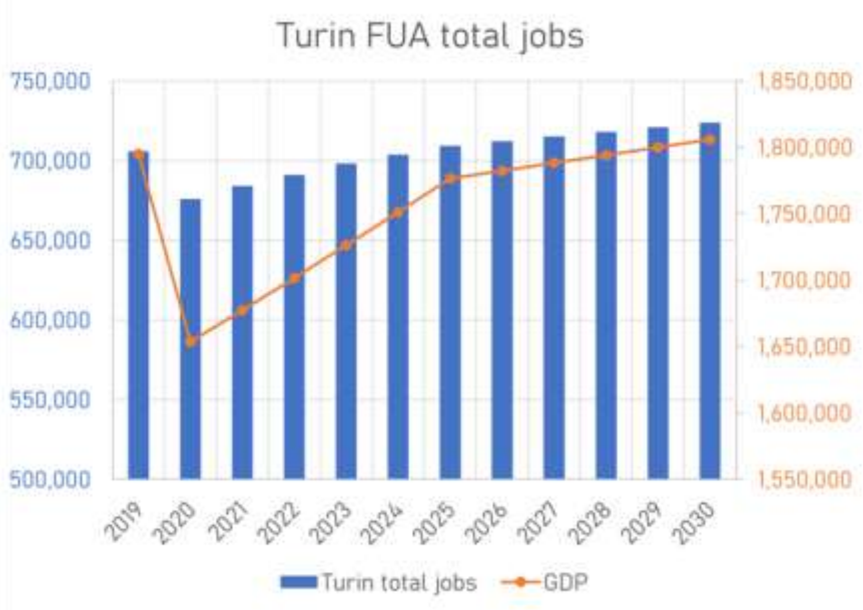

Figure 35 Total jobs in Turin and GDP projections in the Turin Functional Urban Area

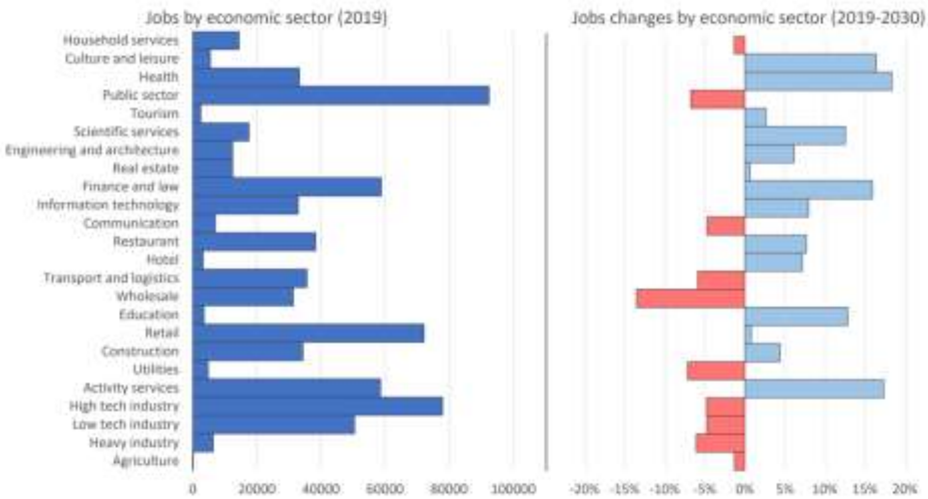

Figure 36 Jobs by economic sector in 2019 and changes between 2019 and 2030 in the Turin FUA

Looking at the variation by economic sector, jobs are expected to increase more than the average in tertiary sectors like culture and leisure, health, scientific services, finance and law, education and activity services. On the other hand, wholesale is the economic sector showing the most negative

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variation in the period considered. In general, the changes do not affect the overall contribution of each sector to the economic structure of jobs in Turin Functional Urban Area.

In Turin as in Oxfordshire, the flows of people travelling with car are much higher than the ones with bus. It is obvious that the flows of cars are expanded also in populated areas around the city centre that cannot be served by buses. In both cases, the flows are mainly concentrated in the roads of the city centre and the number of them increases a little bit in 2030 (up to 5%). The highest augmentation (more than 5%) is observed around the area of university "Politecnico Lingotto" and the new hospital and the highest decline mainly in the south – western part and in some northern parts. A shapefile that contains commuter's flows can be easily downloaded from the HARMONY MS Dashboard and visualized on a map using any GIS software.

In Figure 37, it is observed that the norther part of the City of Turin and the FUA of San Mauro Torinese, as well as the southern part of the city centre and the FUAs of Orbassano and Beinasco show the highest population change. This is reasonable as these regions will become hub stations of the new metro line that will be constructed in 2030.

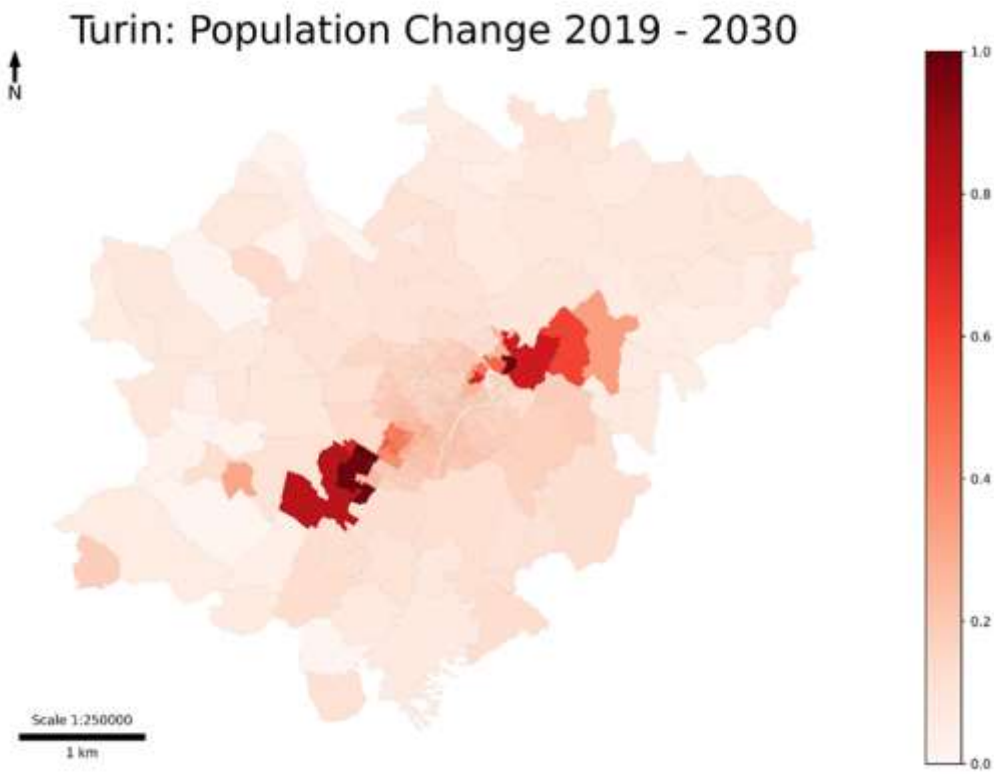

Figure 37 Population Change between 2019 and 2030 in Turin

Regarding the accessibility around job locations in Turin between 2019 and 2030, the most notable change happens in the area of the new hospital "Citta della Salute" for all the modes of transportation. Only for people using rail, the norther part of the City of Turin and the FUA of San Mauro Torinese, as well as the southern part of the city centre and the FUAs of Orbassano and Beinasco show also notable changes. The highest negative difference happens in the western part for car and bus, while for rail most of the areas will become less accessible in 2030. Concerning the accessibility around housing locations in Turin between 2019 and 2030, the biggest positive change (up to 10%) for people using car is observed in the zones of the city centre, while the biggest negative (-2% to -1.3%) is in the areas of Rivalta di Torino, Bruino and Sagano and Trana. The majority of the areas present a slight negative change, with the biggest one (-1.3%) in the area of Bruino and the biggest positive in the neighbourhoods of the city centre for bus network. For people using rail, the greatest positive and

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negative changes are observed in the same areas (except for the area of the new hospital) described for job accessibility. In general, for all years and modes of transport the areas of the city centre have the highest accessibility scores. It is worth mentioning that the areas with highest accessibility change in the train network appear to have the lowest change in bus and car network. This is a reasonable result since these areas are expected to be connected by a new metro line in 2030, so that implies a modal shift of commuters in these areas.

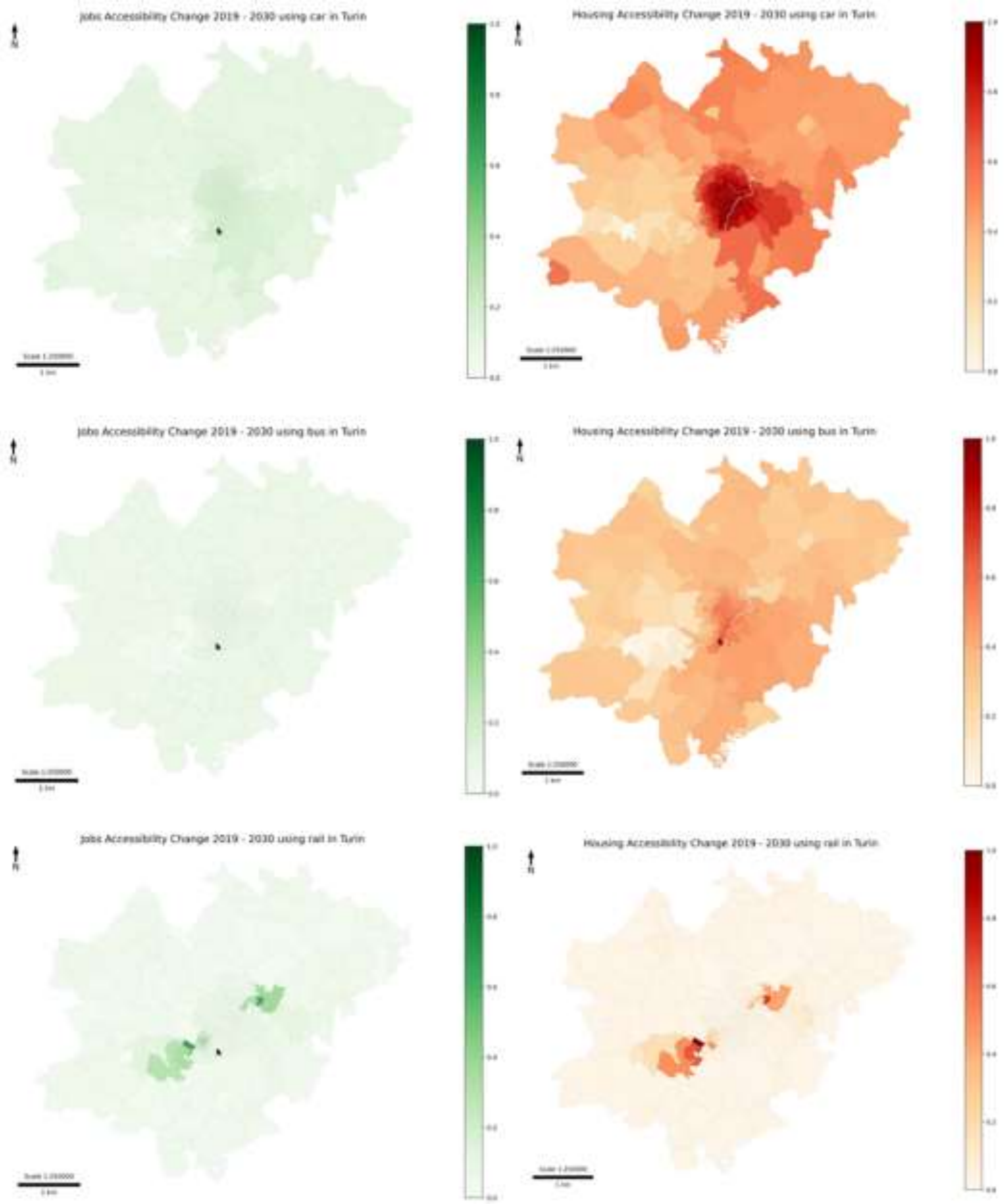

Figure 38 Jobs (left) and Housing (right) Accessibility change of people using car, bus and rail in Turin between 2019 and 2030

Combining the constraint layers with slope as a negative attractor and the job and housing accessibility from the LUTI model as positive attractors, Scenarios 1.1 to 3.3 were tested in succession as listed in Table 20.

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Table 20 Land Development Model Scenarios

Scenario	Acronym	Description
1.1	csLS	City Structure
1.2	csLSD19	City Structure & LUTI 2019
1.3	csLSD30	City Structure & LUTI 2030
2.1	csLS_wPA	City Structure with Protected Areas
2.2	csLSD19_wPA	City Structure & LUTI 2019 with Protected Areas
2.3	csLSD30_wPA	City Structure & LUTI 2030 with Protected Areas
3.1	csLS_wPALU	City Structure with Protected Areas and Land Use
3.2	csLSD19_wPALU	City Structure & LUTI 2019 with Protected Areas and Land Use
3.3	csLSD30_wPALU	City Structure & LUTI 2030 with Protected Areas and Land Use

Outputs for Scenarios 3.1 – 3.3 (Figure 39) represent projected suitability and desirability of land for residential development in Turin in 2019 and 2030. The land suitability output shows all white pixels as non-developable corresponding to each of the constraint layers used in the model. Since slope was the only negative attractor included the model, the shade of blue corresponds to the region's topography. Darker blue pixels correlate to land that is flatter relative to the rest of the land in the region and is therefore, theoretically, more conducive to development. Job and housing accessibility are added as positive attractors representing land desirability in 2019 and 2030. Therefore, while the white pixels in Figure 39 remain non-developable in accordance with conservation and land use policies, the shade of blue corresponds to the normalized slope and the accessibility of the land supply within the region as determined by the LUT model. It should be noted that only the results of the 3rd scenario are shown ae they are the most meaningful.

By subtracting the output from the 2030 scenario by the 2019 scenario it is observed that the normalized positive increase in development potential across the region from 2019 to 2030. The largest increase in development potential, the darkest blue, corresponds to the location of the new hospital and the increase in capacity of Politecnico Lingotto.

In 2030, Turin's population is expected to decrease by 4% with respect to 2019 and simultaneously the percentage of elderly and dependent people to increase, as shown by the results from DFM lite. In addition, Turin's employment will increase by only 2.6% and mostly in Lingotto area, where the new land developments will happen. These results indicate small changes in population and employment distribution from 2019 to 2030.

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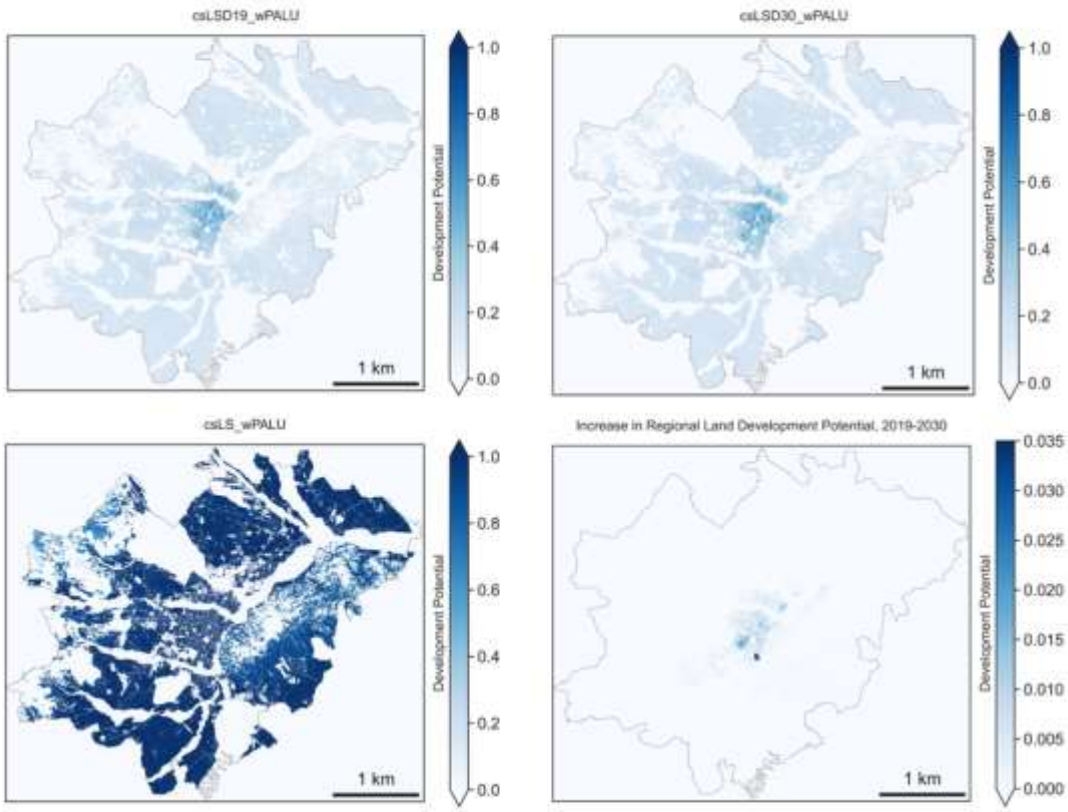

Figure 39 Scenario 3 - Land desirability for 2019 (up left) and 2030 (up right), land suitability (down left) and difference between 2019-2030 (down right)

On the other hand, LUTI's results show bigger changes in the distribution of flows and modal split, thanks to the new public transport infrastructure and services. Turin is known as Italy's motor city. For this reason, the city decided to implement an ambitious SUMP of the Turin municipality in 2010 (as an evolution of the Urban Traffic Plan) to change the way people move in the city and to incentivize the use of sustainable transport modes. In the last decades, the highly implemented offer of public transport enabled the decrease in the use of car by 5% between 2010 and 2013 (CIVITAS, 2016). The new SUMP of 2021, which covers the whole metropolitan area, takes into account for the projection year the construction of a new metro line, new train infrastructure, extension of tram lines as in the HARMONY use case, complemented by new bike lanes, the addition of bike sharing services, the diffusion of electric mobility, shared mobility and autonomous driving in the city. The implementation of the SUMP aims at the reduction in congestion, increase in the use of public transport and bicycle, improvement of safety and use of digital mobility services. Admittedly, LUTI's results reveal 1.2% rise in the use of rail (42.7%), with 1% and 0.2% decrease in the use of car (41.9%) and bus (15.4%) accordingly, between 2019 and 2030. Slow modes (cycling and walking) are not considered in the LUTI model. In this sense, the results of the use case support the objectives aimed by the policy measures, reducing the use of car in favour of public transport.

Regarding LDM's results, they highlight an augmented land desirability in the neighborhoods of the city centre, especially in Lingotto area and in the areas that the new metro line will serve by 2030, which is confirmed by job and housing accessibility results produced by LUTI model.

[1] Number of elderly population (aged 65 years and over) per 100 individuals younger than 14 years old

[2] Ratio of dependents--people younger than 15 or older than 64--to the working-age population--those ages 15-64

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4.4 Strategic-tactical and operational template: simulation results & evaluation

To explore the tactical-operational use-cases in TUR the TPS (Tactical Passenger Simulator) was applied to the area, to generate travel demand. The TPS utilizes a series of econometric models to estimate activity participation, duration, activity start and end times, destination and mode choice based on the digital travel and activity survey collected through MOBY app. Additionally, it utilizes a series of rule-based data transformation in the pipeline called the adaptive scheduler in order to schedule travel and activities and apply the model results to the synthetic population. The final output of the simulator is OD matrices for the zone system in TUR (as presented in D5.2) for the different years and use-cases. More details on the particularities and overall pipeline of the TPS can be found in D5.3. The use-case investigation begins with an application of the model for the base year, which is then calibrated using the existing transport simulation model of TUR.

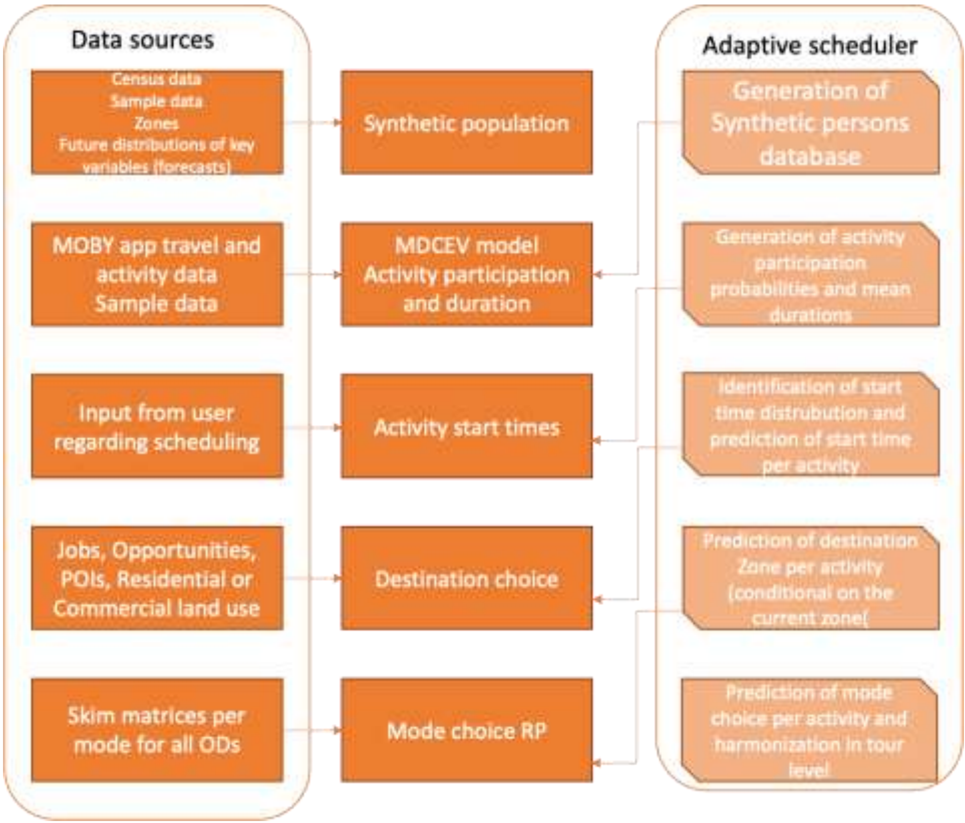

Figure 40 Tactical Passenger Simulator structure

All future use-cases are temporally located in the year 2030, where infrastructure development is predicted to be as follows: a) new land use development and relocation in Turin and in the FUA (work, health, university) and b) extension / new metro lines and metropolitan rail in the FUA

The TPS takes into account these developments by:

1. Accounting for population changes and overall demographic evolution, getting data from the DFM model and regenerating the future population synthesis [Population Synthesis module]
2. Accounting for land-use changes where data is available [Destination choice model]
   a. Changes in jobs, schools and other variables available through the DFM-Lite
   b. Changes in land-use by considering the new developments in the area, for example the new developments in student housing
3. More importantly, estimating the mode choice models by taking into account the new skim matrices (cost and time) which will produce different modal splits for the future years [Mode choice]

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As described above, use case 1 includes changes in land use and new public transport infrastructures planned to be in place at the projection year 2030. Demand matrices have been estimated by the Activity Based Model and assigned to the network.

Modal Split

The figure below shows the modal split for the Use case 1 2030 in the whole Turin functional area (estimated on passenger trips) calculated by the Activity Based Model and compare it with modal split in the base year (2019) It must be highlighted that the ABM model considers only mode car and public transport. For this reason, bike, motorbike and sharing modes trips are calculated applying in each scenario constant their observed shares of the base year.

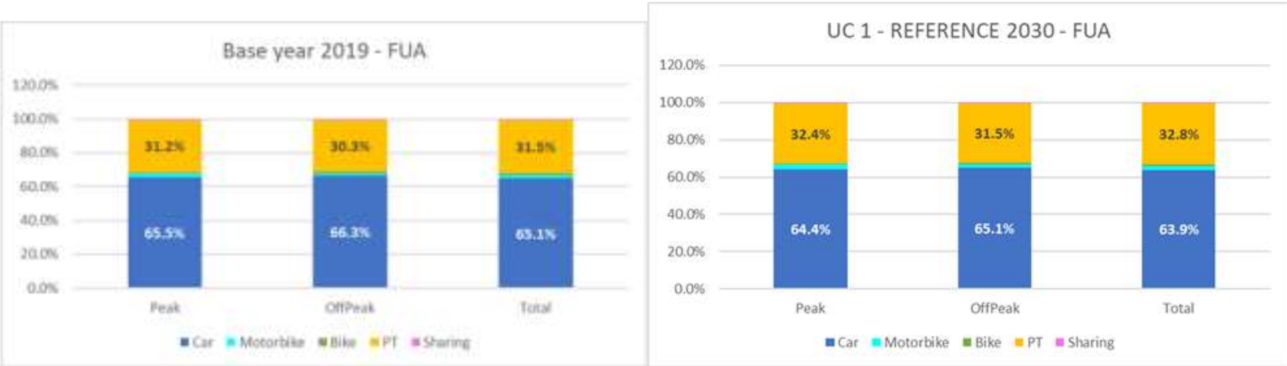

Figure 41 Modal split – Base year and Use Case 1

Compared to the base year 2019 modal split in UC 1 shows an increase of PT share of 1% on the whole Functional Area.

Transport Activity

Tables below show the transport activity in terms of passengers-km segmented by Macrozone, Day time and mode. As it can be noticed a general decrease in transport activity is foreseen for projection year 2030 due to a population decrease. Nevertheless, due to the new public transport infrastructure, the transport activity of collective modes decreases less than transport activity by car. The transport activity by car results in -3% in the morning peak and -4% in off-peak hour while PT transport activity decreases -1% in the peak hour and -2% in during off-peak.

Table 21 Passengers-km for the Base year 2019

	MACROZONE	Car	PT
Morning peak	Turin	1 174 930	404 608
	Rest of FUA	1 561 604	196 104
	Total	2 736 534	600 712
Off-peak	Turin	941 656	230 769
	Rest of FUA	1 265 638	108 381

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	Total	2 207 294	339 150

Table 4-6: Passengers-km for the UC 1

	MACROZONE	Car	PT
Morning peak	Turin	1 137 813	401 537
	Rest of FUA	1 503 730	192 742
	Total	*2 641 544*	*594 279*
Off-peak	Turin	908 322	227 102
	Rest of FUA	1 220 751	103 861
	Total	*2 129 073*	*330 964*

Emissions

The following tables summarise the impacts in terms of CO_2 emissions (considering both combustion and lubricant oil) by mode.

In line with the energy consumption impacts, the reference scenario shows a reduction with respect to the base year of about -20%, mainly due to the car vehicle fleet composition projections where conventional vehicles decrease their relevance in the stock. The emissions related to buses are also decreased (about -11%), thanks to the fleet renewal.

Table 22 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour

CO_2 (tons)		**2019**	**Reference (2030)**
Car	**Peak**	323.60	258.95
	Off-peak	252.06	201.70
Bus	**Peak**	10.42	9.21
	Off-peak	5.31	4.75
TOT	**Peak**	334.02	268.16
	Off-peak	257.37	206.46

Table 23 below shows the CO_2 emissions in case the whole fuel life cycle in considered (so called well-to-wheel emissions). The reduction with respect to the base year is slightly lower (-19%)

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Table 23 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, well-to-wheel emissions

CO_2 (tons)		2019	Reference (2030)
Car	Peak	377.80	306.65
	Off-peak	294.29	238.92
Bus	Peak	12.10	10.74
	Off-peak	6.17	5.54
TOT	Peak	389.91	317.39
	Off-peak	300.45	244.46

Results of Use case 2: MaaS demand

The MaaS demand use-case was the most challenging to model. On the demand side, since there are no significant results from the vehicle tool ownership model to support the investigation of the ownership/usership of MaaS for the future scenario, we adjusted our approach to demonstrate the capability of the TPS to model MaaS trips in coordination with the developments and adjustments on the supply side (VISUM network). The adjustments include: a) the adaption of the code of the TPS to allow for insertion of parameters from outside models, to predict the future ownership/usership or willingness-to-purchase MaaS plans among a sample/synthetic population; b) the indication of which trips in the synthetic schedules are predicted to be conducted by a MaaS operator, or to be more precise, by the user utilizing their MaaS plan to conduct the trip; c) the conception of a parallel calibration and data exchange loop between the tactical and the operational simulator to identify how the indicated trips are being communicated and how we can make the interaction more dynamic to allow for the exchange of information for rejected or delayed trips.

Suggestions to improve the MaaS module of the TPS include: a) the engagement of the mobility tool onwership of the HARMONY MS to be more precise in predicting the agents which are more likely to purchase a MaaS package in the future; b) the design and implementation of a SP or other experiment to determine the behavior of respondents in the context of already having an active MaaS plan, with specific constraints/budget and the "spending" of budget in their daily travel; c) the full integration with the MaaS controller of the operational passenger simulator.

Results of Use case 3: Remote work/Activity schedule

The remote work use-case, built on the use-case 1 as well, investigates the impacts of changes in mobility patterns of individuals, as a result of the diffusion of remote working and revised activity schedule.

After the model estimation, the results are applied to the synthetic population database to generate the percentage of people working remotely. The percentage of people predicted to work fully remote are excluded from further scheduling of work trips, the percentage of people working partially remote, balanced or mostly office are predicted to have work tours in a probabilistic way, given that for the current applications of the TPS the model simulates a single day.

Figure 42 shows the workflow for the remote work use-case. Initially the SP experiment database is utilized to estimate the remote work model (1). Subsequently, the results of the model are inserted in the sequencer and the synthetic population database is transformed, indicating which agents are more

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likely to work remotely (2). Then, the ABM model is engaged, and the agent schedules (for work purpose) are produced (3,4). The OD matrices are produced (5) and can be transferred to the dashboard generating new KPIs (6) and new dashboard visualizations (7).

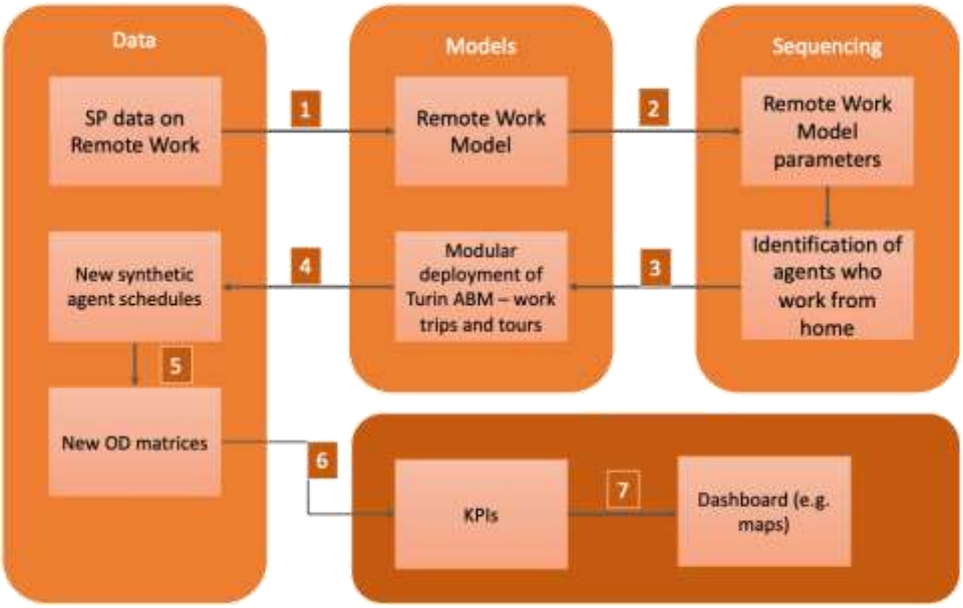

Figure 42 Remote work use case workflow

After the successful application of the sequence of models and modules described above, we can output the newly calculated OD matrices and engage the traffic assignment module of the architecture, i.e., the operational simulator. In the case of Turin, the network model is an existing VISUM model and the exchange protocol involves the exchange of OD matrices. In the workflow of the remote work use-case the exchange, after the demand cycle is completed is as follows:

1. Updated OD matrices, incorporating the effect of remote work are transferred to the VISUM model
2. The model runs based on the new OD matrices and produces a variety of KPIs, comparing the BAU scenario with the remote work use-case
3. The newly calculated skim matrices are fed back to the ABM
4. Auxiliary operations, validation/calibration and application of dynamic behavior models may initiate if needed, using the updated skim matrices

To demonstrate the capabilities of the integrated, modular architecture of the HARMONY MS, in Figure 143 we present the outcome of the application of the demand cycle for the remote work use-case. We observe reduction of trips in specific zones, affected by the socio-demographic characteristics which in turn affect the choice among remote work settings. By applying the demand cycle of the HARMONY MS ABM, we are able to pinpoint the models which are engaged in order to derive specific results, based on the objectives of the study and deploy a modular version of the MS to save on computational time and resources.

The modal matrices produced by the ABM model were assigned to the network model. Results are shown in the following tables and graphs

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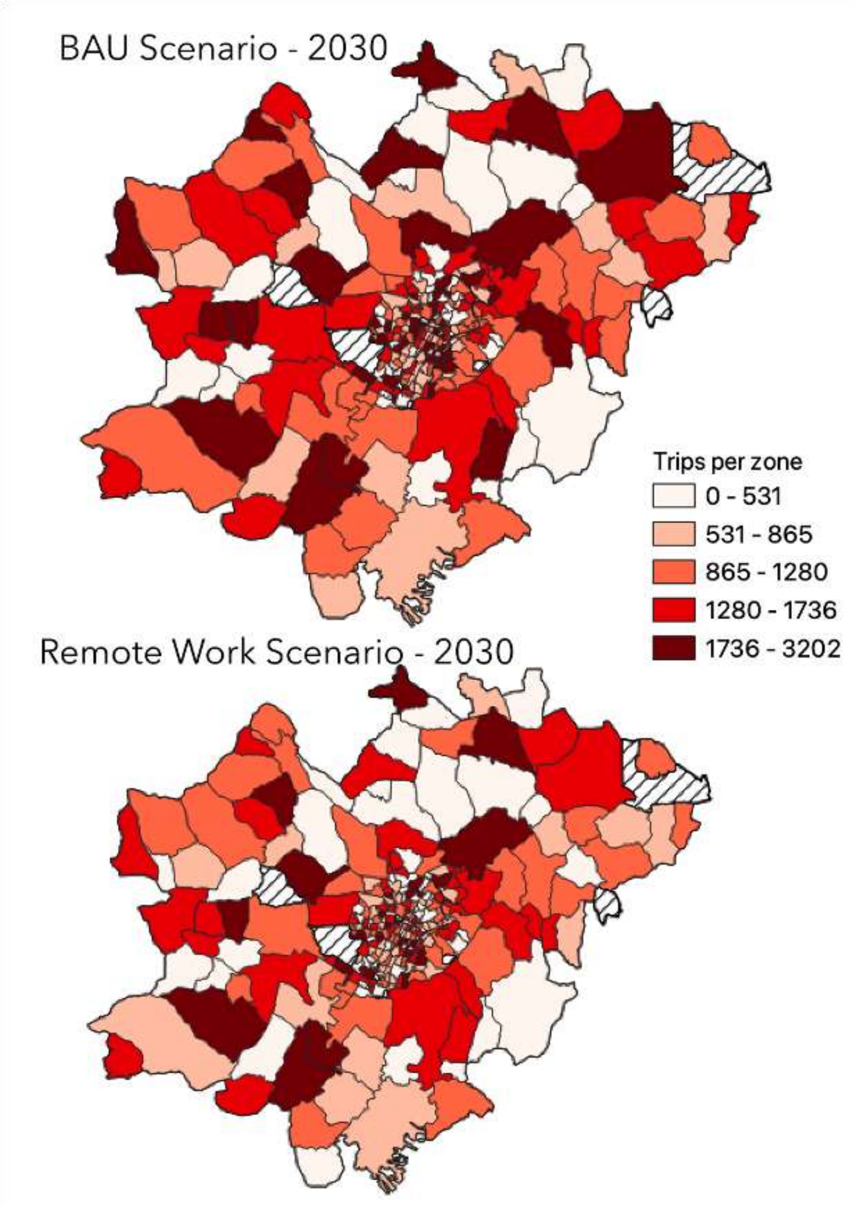

Figure 43 Generated trips per zone / BAU and RW use-case

Modal Split

The graph below shows the modal split in the Remote Working scenario. At first glance it seems that PT modes gain passengers, but the increased modal share of public transport is an effect of the decreased numbers of commuters travelling by car. In remote working scenario a share of commuters, travelling mainly by, car does not travel anymore while trips for mode study, done mainly by PT, does not decrease. This effect is visible in the peak hour where most of the trips for purpose study is performed.

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Figure 44 Modal split –Use Case 1 and Use Case 2 - FUA

Transport activity

Tables below show the passengers activity in the Remote Working scenario.

Table 24 Passengers-km for the UC 2

	MACROZONE	Car	PT
Morning peak	Turin	978 872	374 322
	Rest of FUA	1 294 958	186 482
	Total	2 273 830	560 805
Off-peak	Turin	802 283	196 002
	Rest of FUA	1 071 367	89 274
	Total	1 873 650	285 275

In the morning peak hour there is a decrease of -14% in pkm by car while in off-peak hour the decrease is about -12%.

Emissions

The following tables summarise the impacts in terms of CO_2 emissions (considering both combustion and lubricant oil) by mode.

The remote working scenario shows a reduction of cars emissions with respect to UC1 of about -16% in the peak hour and -13% in the off-peak hour, due to the reduction in number of trips. A reduction of -5% and -7% respectively in peak and off-peak hour is expected for bus due to a supposed service reduction because of decreased demand.

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Table 25 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, tank-to-wheel emissions

CO_2 (tons)		Reference (2030)	UC 3
Car	Peak	258.95	217.98
	Off-peak	201.70	174.44
Bus	Peak	9.21	8.73
	Off-peak	4.75	4.40
TOT	Peak	268.16	226.71
	Off-peak	206.46	178.84

Table below shows the CO_2 emissions in case the whole fuel life cycle in considered.

Table 26 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, well-to-wheel emissions

CO_2 (tons)		Reference (2030)	UC 3
Car	Peak	306.65	258.27
	Off-peak	238.92	206.73
Bus	Peak	10.74	10.19
	Off-peak	5.54	5.14
TOT	Peak	317.39	268.45
	Off-peak	244.46	211.87

Results of Use case 4: Urban Vehicles Access Regulation measures

The final use-case for TUR is an exploration of the effect that urban vehicle access regulation measures, mainly the enforcement of a LEZ in specific zones in the FUA of TUR would affect the transport network. On the demand side, the main model involved in the exploration of this use-case is the mode choice model. Based on the results of the vehicle stock model, we derive a predicted range of future LEV ownership in the area and we attempt to diffuse this range among the different geographic regions of TUR. Then, we create an additional mode option for the mode choice model which is the choice of a privately owned, LEV. The new model estimation is done for the existing situation but the application of the model to the synthetic population database is done by utilizing the updated skim matrices which include different values for regular private vehicles and LEV.

The model results present a significant reduction in regular private car trips, a significant rise in the usage of LEVs, especially in the zones affected by the LEZ and also a significant rise in the PT split.

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The Activity based model has calculated the demand matrices resulting from the application of urban access regulation measures.

Modal Split

Figure below compares modal shares of UC 4 and UC1for the whole Functional Urban Area of Turin.

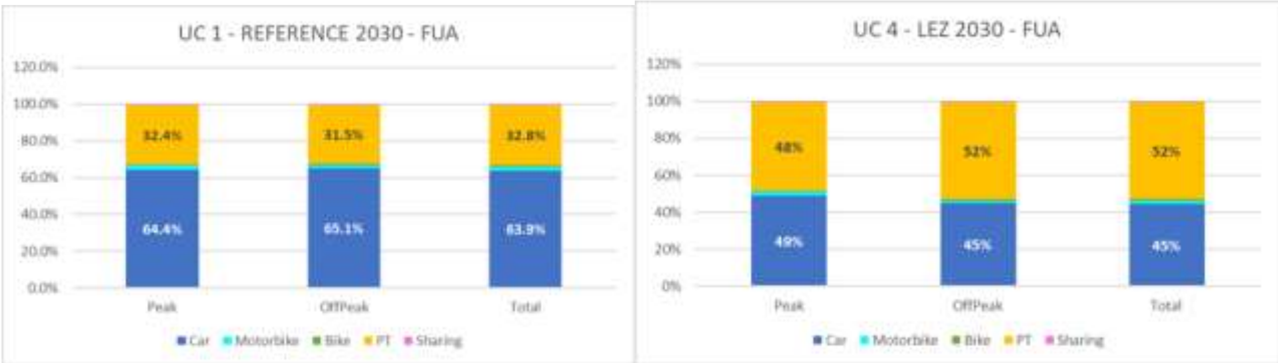

Figure 45 Modal split –Use Case 1 and Use Case 4 - FUA

The application of Vehicles Access Regulation measures leads to strong increases in PT modal share both in peak and off-peak hours. Since the LEZ includes all the city of Turin the effects on modal shift for trips within the city are even stronger as shown in figure below.

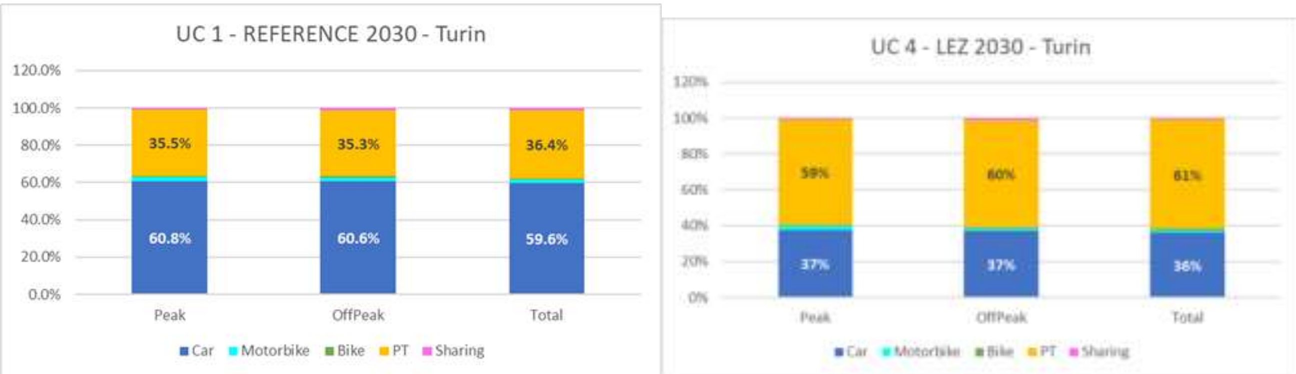

Figure 46 Modal split –Use Case 1 and Use Case 4 – Turin Municipality

Transport Activity

Table below shows the transport activity in terms of passengers-km segmented by Macrozone, Day time and mode.

Table 27 Passengers-km for the UC 4

	MACROZONE	Car	PT
Morning peak	Turin	892 930	584 658
	Rest of FUA	1 418 172	189 527
	Total	*2 311 101*	*774 185*
Off-peak	Turin	719 916	465 387

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Rest of FUA	1 201 423	178 187
Total	*1 921 338*	*643 574*

The PT increase during the morning peak is about +30% in the whole FUA, while during off-peak the PT increase reaches almost +95% pkm. It is interesting to notice that compared to UC1 the pkm in Turin decrease both for peak and off-peak area of about 20% while in the rest of the FUA (where not all trips are involved in LEZ restrictions) pkm by car decrease less than 5%. During the peak hour, in the rest of the FUA, PT pkm decrease of about -1.7%. This might appear counterintuitive, but the reason is that in the rest of the FUA the car congestion decreases because of all those trips by car directed to the LEZ suppressed. The lower congestion causes a shift of part of the PT passengers toward the mode car that become more convenient in the rest of the FUA for those trips not affected by the restrictions

Emissions

When comparing the use case 4 results with the reference scenario at 2030, a decrease of about -10% is observed over the whole FUA and explained by the mode shift from car to the other modes. Accordingly, the emissions from bus mode are increased as an increase of the service is required to face the increase of demand in terms of passenger-km.

Table 28 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour

CO_2 (tons)		**UC1 (2030)**	**UC4 (2030)**
Car	Peak	258.95	240.54
	Off-peak	201.70	179.88
Bus	Peak	9.21	10.48
	Off-peak	4.75	5.84
TOT	Peak	268.16	251.02
	Off-peak	206.46	185.72

Table 29 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, well-to-wheel emissions

CO_2 (tons)		**Reference (2030)**	**UC 4**
Car	**Peak**	306.65	283.52
	Off-peak	238.92	212.21
Bus	**Peak**	10.74	12.22
	Off-peak	5.54	6.81
TOT	**Peak**	317.39	295.75
	Off-peak	244.46	219.03

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If only the LEZ area is considered CO_2 emissions of mode car decrease of about -25% as shown in the tables below-

Table 30 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, tank-to-wheel emissions

CO_2 (tons)		Reference (2030)	UC 4
Car	Peak	119.95	89.86
	Off-peak	91.70	69.16
Bus	Peak	6.02	7.30
	Off-peak	2.98	3.57
TOT	Peak	125.96	97.16
	Off-peak	94.68	72.73

Table 31 CO2 emissions by mode at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour, well-to-wheel emissions

CO_2 (tons)		Reference (2030)	UC 4
Car	Peak	141.65	106.14
	Off-peak	108.32	81.75
Bus	Peak	7.02	8.51
	Off-peak	3.47	4.17
TOT	Peak	148.67	114.65
	Off-peak	111.79	85.92

4.5 Summary

Generally, the results prove that HARMONY MS could be used to simulate efficiently some of the strategies and scenarios of the new SUMP of the Metropolitan City of Turin. It also gives the opportunity to support the 2021 SUMP and to update the long-term spatial and transport planning for Turin city and its surrounding areas.

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4. Use Cases Simulations: Athens

5.1 The use cases for Athens

Athens, the capital city of Greece, is a densely populated area with the number of inhabitants across its metropolitan extensions estimated at 3,792,469 (2021 Census Data). Athens is also the centre of political, social and business activities in Greece as well as a world-wide known tourist destination. In addition, the port of Piraeus, located in the south-west end of the broader city area, is the largest passenger port in Europe and the second largest in the world. As a result, the Athens metropolitan area is in need of an extensive transportation network that can provide efficient and effective transportation services to all of its citizens and visitors in order to sufficiently support and satisfy the needs of the city.

In this context, transportation planning in Athens arises as a key element of its everyday functionality. As such, the Athens Public Transport Organization (OASA), the sole public transport operator in the Attica region, has developed a spatially extensive transport network model that covers the entire Athens metropolitan area. The model is used for testing different transportation policies and measures and evaluating their expected performance before proceeding with their actual implementation on the network. The model is also used for the verification of the performance of existing measures and modelling assumptions and the suggestion of possible improvements and / or changes where needed.

The Athens network model is a spatially extensive transportation analysis tool that has been created in the traffic planning software PTV VISUM. The software belongs to the category of macroscopic simulation tools. The transport model covers the entire Athens metropolitan area and consists of a large number of links (over 22,000), nodes (over 7,000) and zones (1284 in total). It considers different types of transportation modes, with a distinction made between public and private transport. The public transport system in particular includes six different types of modes, that is bus, intercity bus, tram, subway, trolley and rail.

In the framework of the HARMONY project, Athens participates as one of the pilot cities, mostly involved in strategic- and operational-level simulations. This is realized through the development of city-specific models of both levels, which take into account the city's characteristics, its needs, worldwide transportation and environmental trends as well as the already formulated transportation and land use related plans that are currently under implementation or are expected to start over a short- or mid-term horizon. On the other hand, contribution of Athens on the tactical simulation level is mainly realized through the assessment of the conclusions derived from other cities for possible future application in the city.

As such, with respect to strategic-level simulations, OASA had four models developed for the Athens case, namely the Athens demographic forecasting model, the Athens regional economy model, the Athens LUTI model as well as land development models. These models were developed by HARMONY partners, while OASA provided the necessary data to the modelling teams and assisted in any queries that arose. More specifically, the *Athens LUTI model* is an origin-constrained model, containing a journey to work sub-model. This model considers workplaces as origins and homes as destinations. The model is built for the whole Attica region, but the changes refer to only four zones. The model considers the Elliniko investment, one of the greatest land use changes that have ever been undertaken in the city of Athens. Two scenarios were developed to assess the impact of the investment, along with an additional base case scenario:

a) The Elliniko scenario 2030: This scenario considers a 50% completion rate of the project and a change in the employment with an addition of 25,000 temporary jobs.

b) The Elliniko scenario 2045: This scenario regards the Elliniko project as fully completed. This results in the addition of 90,000 permanent jobs in the current employment rate and in the increase of residential floorspace of about 291.5 ha.

The Athens LUTI model is complemented by:

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- The *Athens demographic forecasting model*, which produces population and household projections until 2045 by using 2011 census data.
- The *Athens regional economy model*, which provides estimations of future employment with the use of 24 economic sectors over a 2050 horizon. In this case too, the Elliniko investment served as the case study for Athens.
- The *Athens land development model*, which predicts land suitability and land desirability under two scenarios.

On the operational level, OASA decided to investigate different scenarios that would be of interest to the Authority and that, if applied, could have implications to the city's day-to-day operation of transportation means. Three case studies have been examined in this regard.

a) *The electrification of public transport:* This case study investigates the transition from conventional fuel buses to battery electric ones. It is based on the actual initiative currently undertaken in the city of Athens, which is expected to be fully realized over the next years. The main goals of the initiative are to: (a) renew the existing bus fleet and increase the passengers' Level of Service (LoS), (b) promote the use of public transport through the improved level of service provided and attract more passengers from the private means of transport, (c) promote the contemporary image of Athens, (d) conform to the European transport and environmental guidelines, and (e) improve the air quality in the capital, and thus provide health benefits to the residents over the short and long run.

b) *The electrification of public transport with additional consideration of micro-mobility interventions:* In this case study, the previous scenario is enriched with the consideration of micro-mobility schemes on the network. The micro-mobility interventions simulated in this regard are based on the actual plans devised for the construction of two major bicycle paths in the city. Smaller scale (on the municipality level) micro-mobility interventions have also been proposed as part of the Sustainable Urban Mobility Plans (SUMPs) that are currently undertaken in the greater Athens metropolitan area. The scope of incorporating micro-mobility interventions is to gradually shift passengers from more traditional modes of transport to more environmentally friendly ones, thus, once again, providing air quality and health benefits to the residents as well as decreasing congestion.

c) *The operation of autonomous vehicles (AVs):* This case study examines the effect of different AV penetration rates on the network through the adjustment of the model’s Volume - Delay Functions (VDFs). Although not a scenario that is expected to be realized in the near future in Athens (at least when considering significant penetration rates), the study of this hypothesis is interesting as an indication of the future operation of the transport system.

All three case studies were simulated in the Athens PTV Visum model, which was, each time, appropriately adjusted to fit the modelling requirements.

5.2 Application of the HARMONY MS simulators

Strategic Simulator

Four strategic-level models have been applied in the Athens case study, namely: (a) the Demographic Forecasting Model (DFM) Lite, (b) the Regional Economy Model (REM), (c) the Land Use Transport Interaction (LUTI) model and (d) the Land Development Model (LDM).

In particular, the DFM lite produces population and household projections until 2045 by using 2011 census data from the Hellenic Statistical Authority and supplies first, the regional economy model with numbers of total population and second, the LUTI model with population per zone data. In the Athens case, however, due to reasons of data availability, population data produced by the DFM were not used as input and only a journey to work LUTI model was applied. The DFM’s population per zone data was used to check the validity of the LUTI results.

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In addition, the REM model takes as input population data from the DFM model and couples them with data regarding public investments, national GDP, tourism and income, eventually producing employment projections by economic sector per year. The model also supplies the LUTI model with total employment data per zone.

As far as the LUTI model is concerned, in the Athens case, this assesses the impact of one of greatest land use changes in Greece over the last decade: the renovation of the former airport in Elliniko. The Elliniko investment is of utmost importance for Athens, as it will include substantial residential development projects, entertainment and leisure activities and it is estimated that, after its completion, it will attract more than one million extra tourists each year (Lamda Development S.A., 2019).

In more detail, the Elliniko area is administratively part of the Regional Unit of the Southern Sector of Athens and specifically of three municipalities: Alimos (north), Elliniko - Argyroupoli (northeast) and Glyfada (south). The largest part belongs to the Municipality of Elliniko – Argyroupoli (Figure 47). This area extends approximately over 6,200 acres (6,205,677 m^2).

The project started in 2020 and will be implemented in three phases:

- Phase 1, with sub-phases:
  - Phase 1A (years: 1 - 5): 2021 – 2025
  - Phase 1B (years: 6 - 10): 2026 – 2030
- Phase 2 (years: 11 - 15): 2031 – 2035
- Phase 3 (years: 16 - 25): 2036 - 2045

Employment in the area is expected to increase by 25,000 people by 2030. In the following years, with the gradual completion of the construction activity and with more business activities in full operation, about 90,000 jobs in total are expected to be permanently added in the Attica region (year 2045).

In this light, three scenarios were identified on the basis of the project's three construction phases. The first scenario describes flow distributions of journeys to work in year 2019. The second scenario refers to year 2030 and the associated, project-related predictions (creation of 25,000 new jobs, many of which being temporary). The third scenario considers year 2045, with the project being fully completed and 90,000 permanent jobs having been established. Implementation of the scenarios is as follows:

- *Scenario 1 - Attica Region 2019 (base case scenario):* The Attica region is divided in 1265 zones and the model is applied with the use of employment and household floorspace data from year 2011 and travel time data from year 2016 (i.e., the most recently available data).
- *Scenario 2 - Elliniko Scenario 2030:* A total of 25,000 jobs are added in the four zones where the project extends. The model is then applied by using the calibrated βk of the base case scenario (scenario 1).
- *Scenario 3 - Elliniko Scenario 2045:* In the four zones of the Elliniko project, the number of jobs is increased by 90,000. In addition, 291,533 hectares of new household floor space are added to the respective zones as Attractor Aj. The rest of the process is the same as in Elliniko Scenario 2030.

Finally, the land development model uses as constraint layers the administrative boundaries of Athens, the surface water, flood zones, protected areas, parks and gardens, areas protected under Natura 2000 as well as highways. Slope, population density and a distance of 2500m from green spaces are considered as negative attractors, while job and housing accessibility by public and private transport (in years 2019 and 2045) are deemed as positive ones. On that basis and in accordance with the LUTI model, two distinct scenarios were built for Athens:

- *Scenario 1:* Land suitability and land desirability (for 2019 and 2045) are predicted considering allowance to build in flood risk areas.
- *Scenario 2:* Land suitability and land desirability (for 2019 and 2045) are predicted considering prohibition of construction in flood risk areas.

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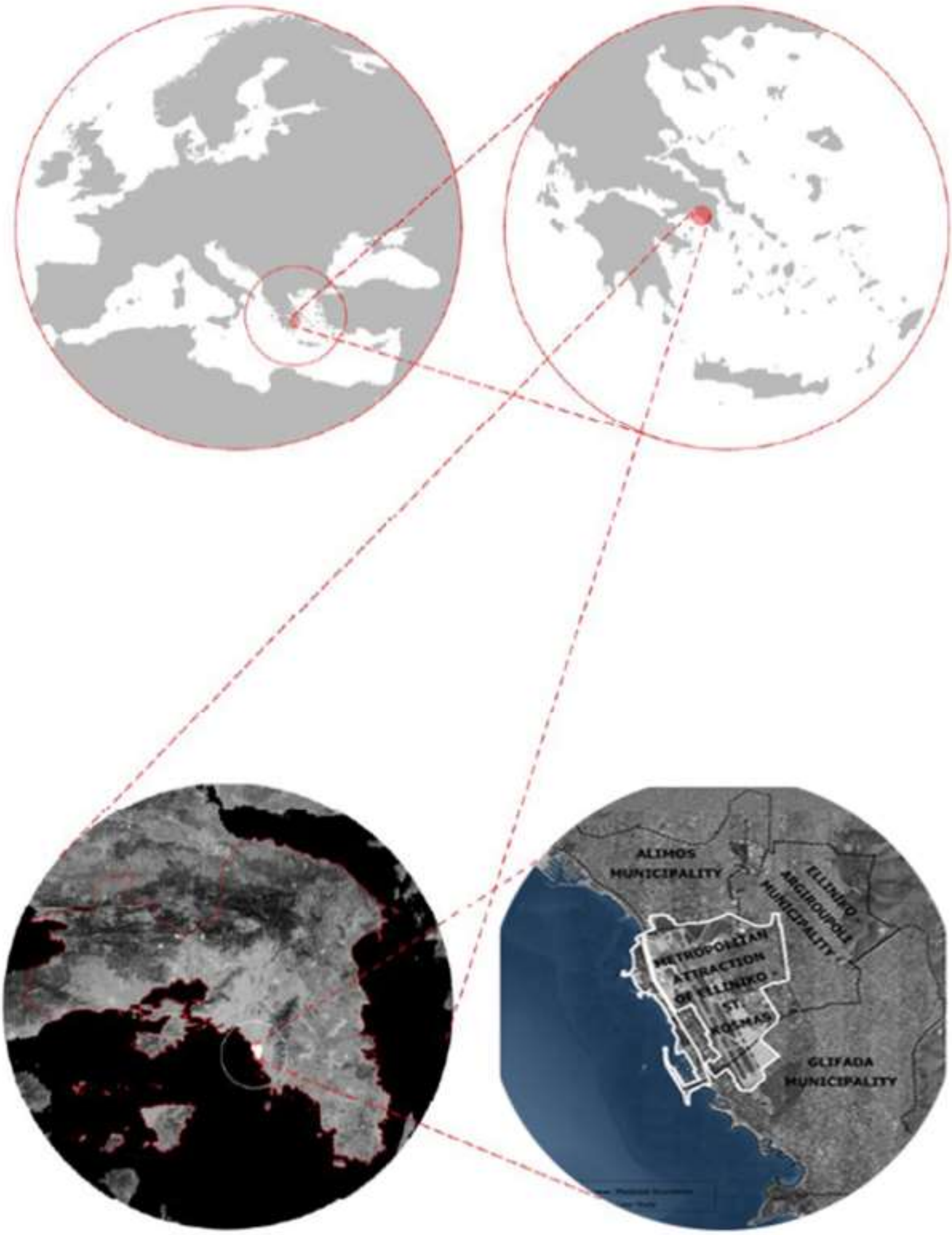

Figure 47 Geographical location of the area of the Metropolitan Pole of Elliniko - Agios Kosmas, Source: Foster and Partners Ltd et al. (2016)

<u>Operational Simulator</u>

Application of the operational-level use cases of the Athens pilot is described below, with a separate section dedicated to each use case.

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Public Transport Electrification

The electrification of public transport is viewed as the first step towards the transition of the capital to a new, more sustainable and environmentally friendly, mobility era. Along with the gradual shift of the public to private electric cars and other initiatives that are to be undertaken in the future, it is believed that it is going to contribute towards improved air quality in the city and better health for the residents.

As it is known, battery electric buses (BEBs) produce no tailpipe emissions. However, in a wider perspective, emissions associated with electricity production and transfer should also be taken into account when estimating the actual environmental footprint of the electric buses. Nevertheless, till now, the tender for the BEBs is not completed yet and, thus, there is no data on the energy consumption and the charging efficiency of the buses that will operate on the system. Therefore, the present analysis can only be based on tailpipe emissions of the conventional buses with consideration of their gradual substitution by BEBs. For this reason, the analysis takes into account the gradual electrification of some of the bus lines operating on the system with the simultaneous replacement of the most polluting buses and the redistribution of the rest of the conventional fleet to the other bus lines. As a result of this process, the number of veh-km run by conventional buses gradually drops, in addition to the conventional fleet being progressively composed by less polluting buses, thus leading to a decrease of air pollutants.

Public Transport Electrification with Consideration of Micro-Mobility Interventions

It is true that Athens currently lacks any significant infrastructure dedicated to micro-mobility means of transport. Indeed, Athens has, for many years, allowed an excessive increase in the use of private vehicles, a trend that was only partially limited by the operation of the three Athens subway lines in 2000, followed by the economic recession of years 2009 - 2019 and the 2020 - 2022 covid-19 pandemic. Despite all these, Athens is currently shifting to more sustainable forms of transport, with the electrification of public transport being the first measure in this direction, followed by the application of other soft mobility measures. In this context, in June 2020, the Minister of Environment and Energy announced the construction of two major bicycle paths in Athens. These are the following (**Figure 5.2**):

- *Bicycle path 1: Faliro - Gazi – Kifisia (completed section: Faliro – Gazi)*

The total length of the path is about 27 km. The bicycle path crosses the entire Athens metropolitan area and densely populated neighbourhoods, in order to help alleviate some of the congestion occurring. The southern part of the path (Faliro – Gazi, about 10km) has already been constructed, while the northern part (Gazi – Kifisia, about 17km), when initiated, is expected to be completed in 18 - 20 months. The total project budget is 7,000,000€ and it is funded by the Green Fund.

- *Bicycle path 2: Katehaki – Polytechnioupoli – Panepistimioupoli – Evangelismos*

The total length of the path is about 10km and, when constructed, it will be connected with the current bicycle path in Polytechnioupoli (about 4km). When initiated, the project is estimated to be completed in about 15 - 18 months. The total project budget is 3,000,000€ and it is funded by the Green Fund.

Both bicycle paths are designed to be connected to subway stations in order for them to allow for intermodal transport. As already explained, these are part of a greater plan to gradually transform the transportation patterns in Athens to more environmentally friendly forms. Indeed, many of the SUMPs currently undertaken in the municipalities across the Attica region also propose the operation of micro-mobility schemes.

In this light, the present use case integrates the public transport electrification scenario with the modelling of these two major bicycle paths that are going to be realized in Athens in order to assess their combined environmental impact on the network.

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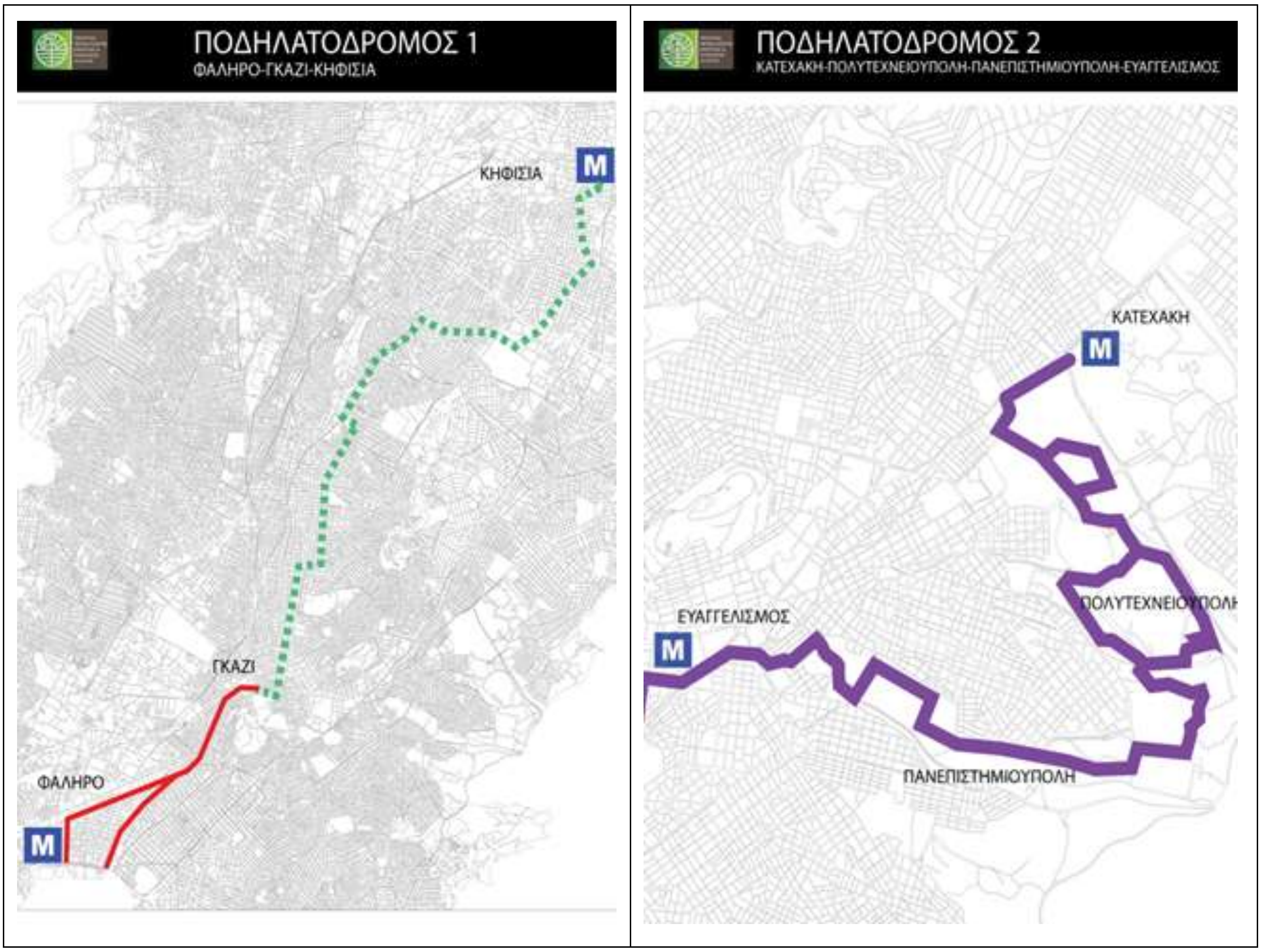

Figure 48 Bicycle path 1: Faliro - Gazi - Kifisia,

Operation of Autonomous Vehicles (AVs)

Although not a scenario to be implemented on the streets of Athens in the near future, mixed traffic, composed of both conventional and autonomous vehicles, is expected to be the norm over the years to come, with increasing AV penetration rates. Among their other characteristics and according to the literature, higher AV penetration rates can have a beneficial effect on the network by increasing the traffic flows due to the shorter headway needed by the autonomous vehicles and the decreased reaction times that they exhibit.

In this case study, with the help and guidance of Aimsun, the methodology developed by the Levitate project (https://levitate-project.eu/tag/traffic-microsimulation/), which intends to upscale the effects of different AV penetration rates from the microscopic simulation level to the macroscopic one, is applied on the city of Athens. The scope of this use case is to investigate how the penetration of different AV rates is going to affect the traffic flows and the travel times on the network. In this regard, the Levitate methodology can be summarized as follows:

1. First, microscopic simulation-based experiments are run in order to derive network capacities for scenarios with mixed traffic flow consisting of both conventional and autonomous vehicles.
2. Then, a statistical analysis is carried out in order to identify the effect of the relative change of the capacities when considering different types of mixed flow (different AV penetration rates) on the estimation of the Passenger Car Unit (PCU) factors. This results in the estimation of a functional relationship between the PCU factors and the AV penetration rates.

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3. Finally, the derived PCU relationship is provided as input to the Volume Delay Functions (VDFs) of the macroscopic demand model in order to forecast the potential macroscopic implications induced by different AV penetration rates on the network performance.

5.3 Strategic models template: simulation results and evaluation

The results of the analyses conducted on the strategic-level models are provided herein, with a separate section dedicated to each one of the use cases.

Demographic Forecasting Model

The DFM Lite model was applied to estimate population projections for years 2030 and 2045, based on input from the Hellenic Statistical Authority (ELSTAT) and growth rates from the EUROSTAT Baseline Population projections at regional level[1]. The model was applied under the hypothesis of the Elliniko investment being completed in 2045, as shown in Figure 49

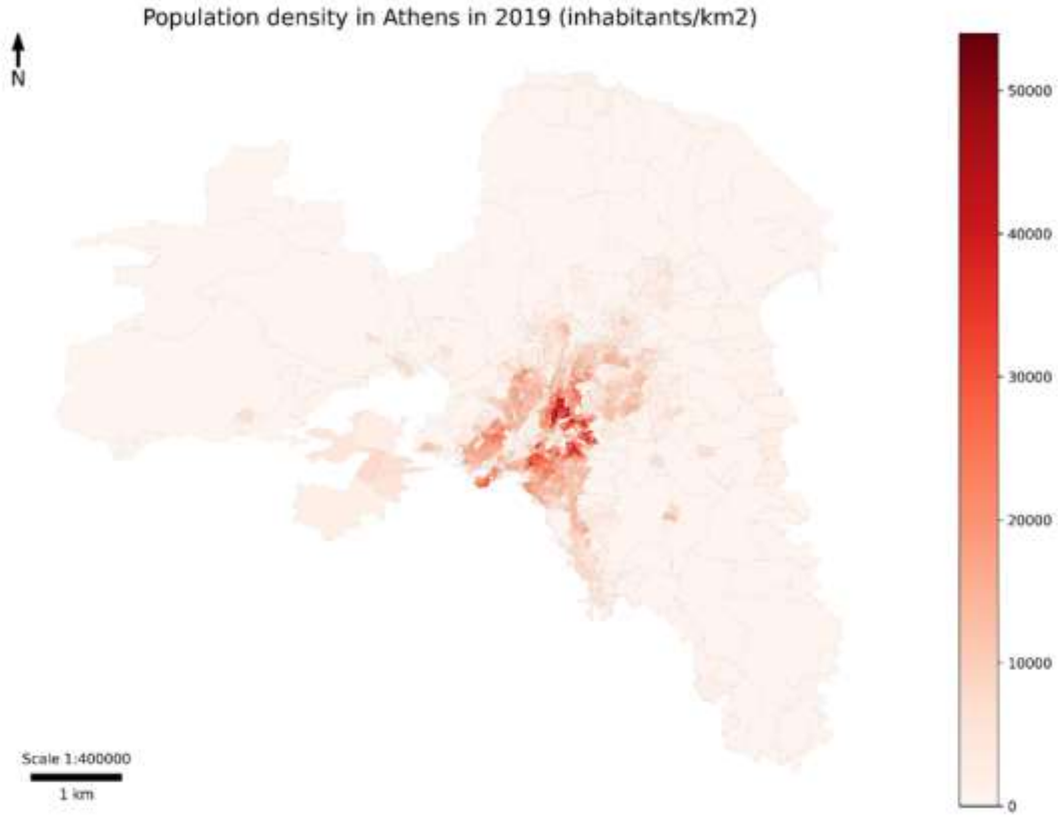

Figure 49 Population density in Athens (2019)

In 2019 (base year of the projections), the total population of Attica is estimated to be around 3.7 million inhabitants. However, moving towards years 2030 and 2045 it is expected to decrease to 3.5 million and 3.2 million respectively. Moreover, as illustrated in Figure 50 an ageing trend of the population can be observed: whereas in 2019 the population share of people aged 65 years or more corresponds to 21% of the total population, this share is expected to increase to 26% in 2030 and to 34% in 2045. Using the ageing index[2] for this aspect, the index is estimated to rise from 144 in 2019 to 201 in 2030 and to 296 in 2045. In the same period, the dependency ratio[3] is increasing from 54 in 2019 to respectively 62 in 2030 and 84 in 2045. The demographic pyramid in **Figure 5.4** also shows a female population that is slightly older than the male one.

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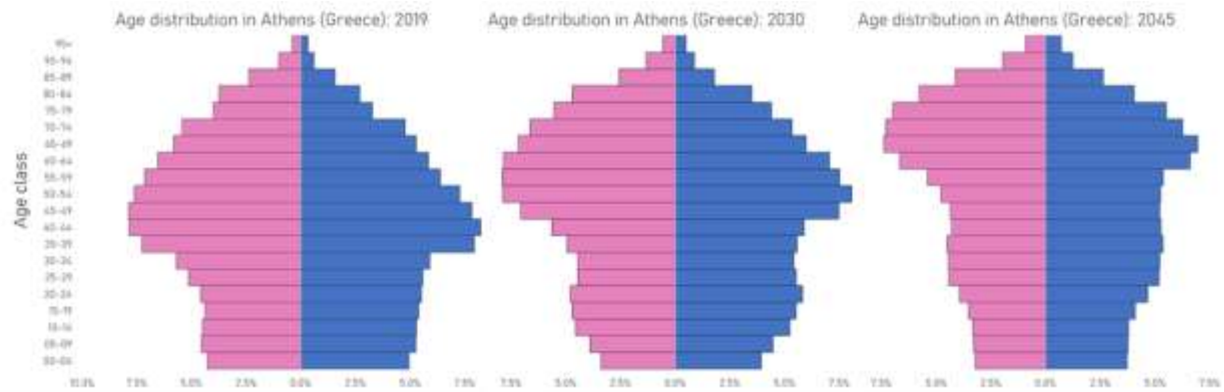

Figure 50 Age distribution in Athens in years 2019, 2030 and 2045

Regional Economy Model

Exogenous trends serve as input into the REM model. The scope of the model is to represent the impacts of socio-demographic aspects related to national trends and regional components on the evolution of jobs in the Athens metropolitan area. In this respect, the GDP of the Athens metropolitan area is aligned with the EU Reference scenario 2020[3] projection for Greece for the period from 2020 to 2030. Since this time frame includes the COVID-19 pandemic period, an initial decrease of 9.0% is considered in 2020. In the following years, a steady recovery is assumed, with a growth rate of 2.2% until 2025 and of 0.6% until 2030. Tourism is also deemed to be affected from the COVID-19 pandemic, with a drop of 68% in 2020, followed by the assumption of a rapid increase until 2023, in order for it to reach the pre-COVID values in 2024. Other input trends such as the e-commerce index, public investments, residential and transport costs etc. have been estimated on the basis of past trends. In addition, population data has been taken directly from the DFM lite model. In Figure 51, job density is represented with the use of a logarithmic scale in order for it to be able to better illustrate smaller-scale results. In the city centre, six zones exhibit a job density of over 200,000 jobs per km^2.

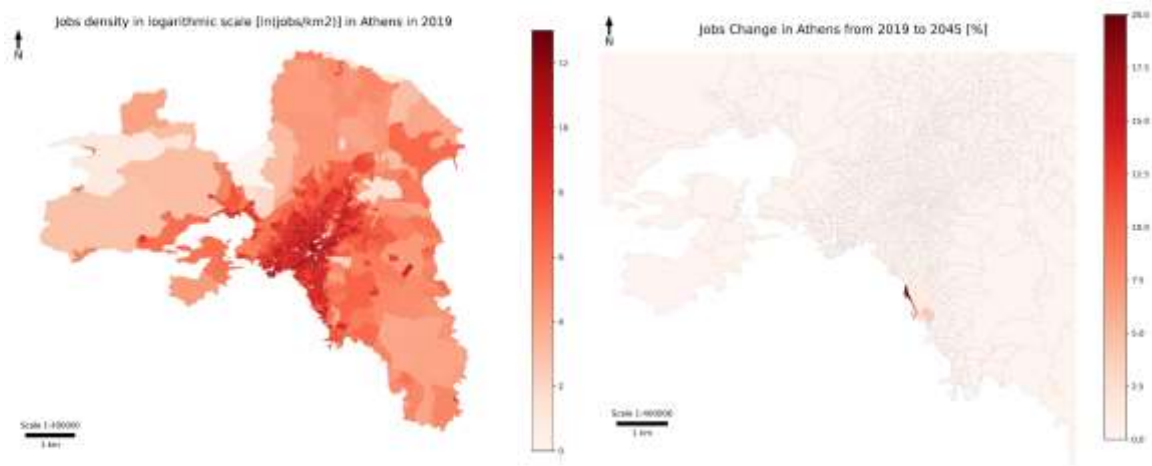

Figure 51 Job density (jobs/km2) in Athens at base year (2019), expressed in logarithmic scale (left). Change in jobs from 2019 to 2045 [%] on the right, with the significant change in jobs of the Elliniko development area depicted in red.

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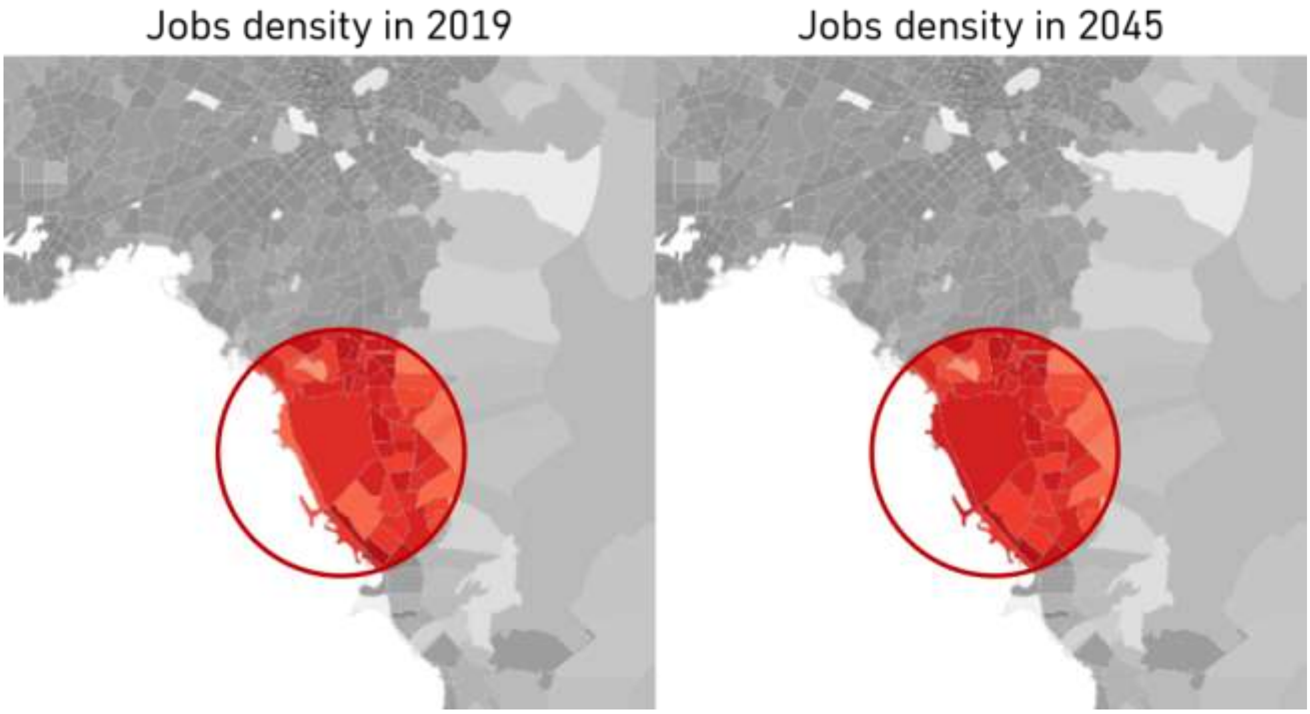

Figure 52 Job density in 2019 and 2045 in the Elliniko area

The estimated total number of jobs in the future years is shown in Figure 53. In 2020, a 4.8% reduction (from 1.75 to 1.67 million jobs) with respect to the base year (2019) is estimated as a result of the economic downturn caused by the COVID-19 pandemic. After that, a slow rise of 2.2% per year until 2025, 0.6% per year until 2030 and 1.5% until 2045 is estimated. As a result of this trend, the number of jobs estimated in year 2019 is recovered in 2025.

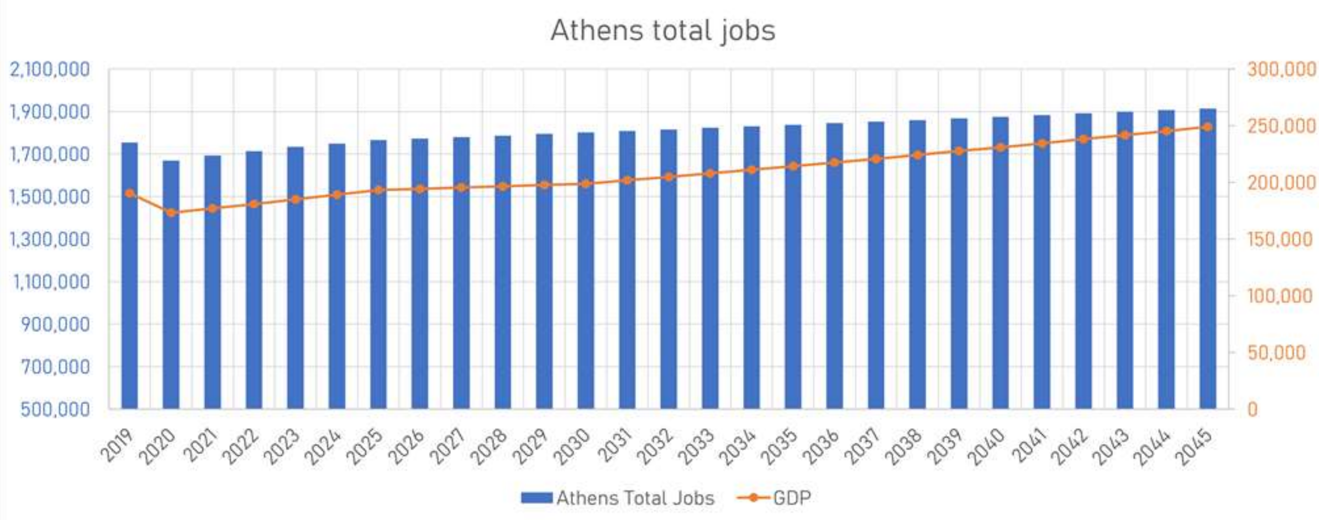

Figure 53 Total jobs trend in Athens between 2019 and 2045

With respect to the projections by economic sector (Figure 54), agriculture shows the biggest reduction in jobs between 2019 and 2045. A negative trend is also estimated for the industry, utilities, and retail sectors, while job growth is appraised for all other sectors, with the transport and logistics sector showing the greatest signs of increase.

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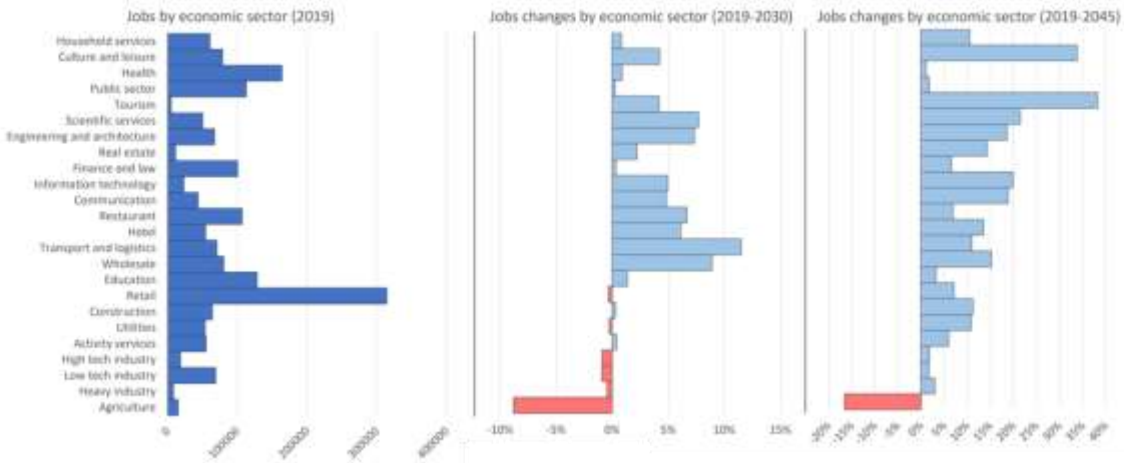

Figure 54 Jobs by economic sector (2019), job changes by economic sector in Athens between 2019 and 2030 and between 2019 and 2045

Land-Use Transport-Interaction Model

Private and public transport flows in Athens are relatively equal, with the exception of some city suburbs where private transport flows are higher. Between years 2019 and 2030, the most significant flow changes appear to occur in Elliniko and its surrounding areas. These changes are more considerable in the case of public transport (more than 150%) than in the case of private transport (50 – 150%). The rest of Athens displays a small change of around 0 – 5%, with the absence of negative percentages like in previous case studies. Between 2030 and 2045, the most notable shifts are once again concentrated near the Elliniko area and in the southern parts of the city centre. However, the other areas of the Attica region also exhibit a change in flows, which, this time, is greater (5 – 10%) than the one observed between 2019 and 2030. A shapefile that contains commuter's flows can be easily downloaded from the HARMONY MS Dashboard and visualized on a map using any GIS software.

Regarding the population change that can be directly produced as a map from the HARMONY MS Dashboard, it is clear that between 2019 and 2030 the highest change happens in the southern part of Attica region and especially in Elliniko area and its surroundings (Figure 56). However, between 2030 and 2045 only the intervention area of Elliniko shows a notable change.

Employment accessibility of private transport in the city centre is higher (in absolute values) in all years (2019, 2030 and 2045). In particular, the highest positive change between 2019 and 2030 is around the area of Elliniko, with smaller changes (up to 20%) also occurring in northern and southern suburbs. On the contrary, the greatest negative changes are concentrated in some areas of the city centre and in the municipality of Marathonas. The same distribution seems to also be valid between years 2030 and 2045, with areas around the Elliniko investment exhibiting even further amelioration and areas around the city centre yet deteriorating. With respect to public transport accessibility, the absolute values of all years (2019, 2030 and 2045) seem to be higher in the city centre and in the areas of Piraeus and Skaramagas (west), Krioneri and Marathonas (north) and Koropi, Vari and the airport (south-east). The most notable improvement appears to once again be in the area of Elliniko, with the upgrade continuing until 2045. At the same time, most of the suburbs are expected to became less accessible in 2030 due to lack of a public transport network, with the deterioration continuing towards 2045.

As far as housing accessibility is concerned, this is mainly higher in the city centre, with little differences between 2019 and 2030. In addition, southern areas of Athens will become more accessible over the course of time, while northern areas and the northern part of the central neighbourhoods will become less accessible for private transport. With respect to public transport, only the coastal areas from Piraeus to Anavyssos, some southern parts of the city centre and some areas near Elliniko and Koropi will be more accessible in 2030. Between 2030 and 2045, Elliniko and its surrounding areas will continue to improve their accessibility, but for the northern suburbs, accessibility for private transport

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will decrease. Finally, in 2045, housing accessibility for public transport will rise significantly in Elliniko, in the southern suburbs and in some northern regions like Erythres, Avlonas, Parnitha, Kapandriti, Nea Makri and Dionysus. On the contrary, it will be reduced in the western municipal units of Mandra, Elefsina, Megara, Kineta and in the north-eastern areas like Kifisia, Drosia, Penteli, St. Stefanos and St. Panteleimon.

Land Development Model

The results of the first scenario, in Figure 57**,** illustrate the projected desirability (for years 2019 and 2045) and suitability of land for residential development in Athens. In the land suitability output, all the non-developable areas (corresponding to each of the constraint layers used in the model) are depicted as white pixels. Since slope, population density and distance from green spaces were the negative attractors included the model, the darker blue pixels correlate to land that is flatter, depopulated and closer to green spaces compared with the rest of the region and is therefore, at least theoretically, more conducive to development. In order to predict land desirability, job and housing accessibility were also added as positive attractors for 2019 and 2045. Therefore, the blue-shaded pixels depict the parameters of normalized slope, population density, 2,5 km distance from the green spaces and job and housing accessibility of the land, as this is determined by the LUTI model. The map comparing land desirability between years 2019 and 2045 reveals that only the area of Elliniko and some surrounding areas exhibit a slight increase (up to 0.04) in 2045.

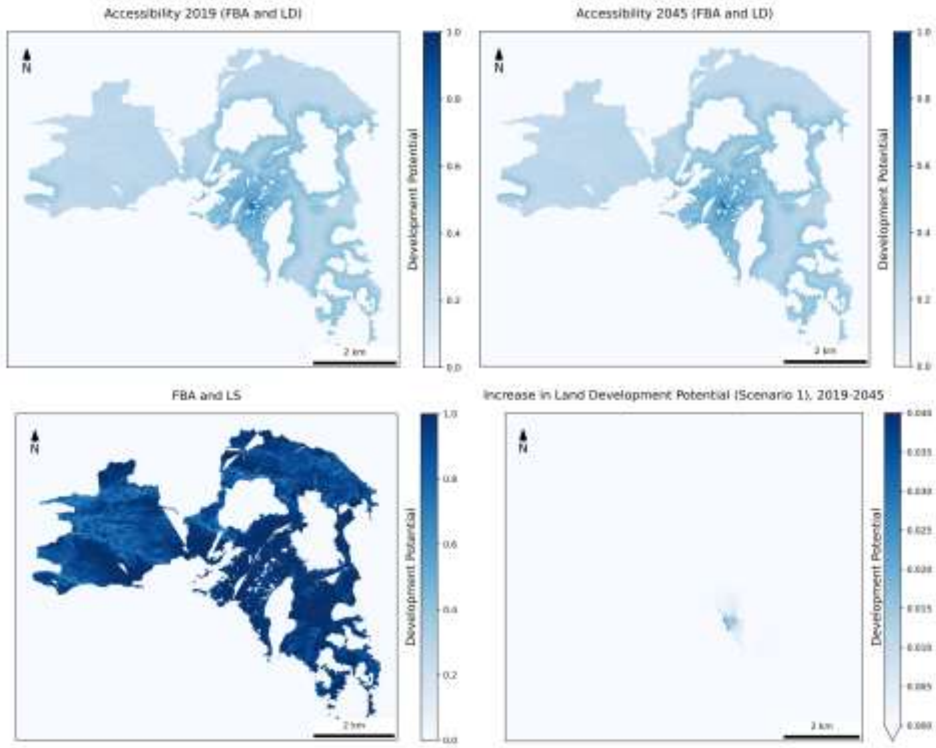

Figure 55 Scenario 1 - Land desirability for 2019 (up left) and 2045 (up right), land suitability (down left) and difference between 2019-2045 (down right)

Figure 58 displays the results of the second scenario. In this figure, the blue pixels (more desirable areas according to the criteria set) cover less extent of the map due to the prohibition of construction in flood risk areas. In addition, the difference in land desirability between years 2019 and 2045 regards a smaller area (compared with the first scenario), focusing mainly around the Elliniko intervention area. In both scenarios, areas lying closer to green spaces as well as the neighbourhoods of the city centre seem to be more desirable.

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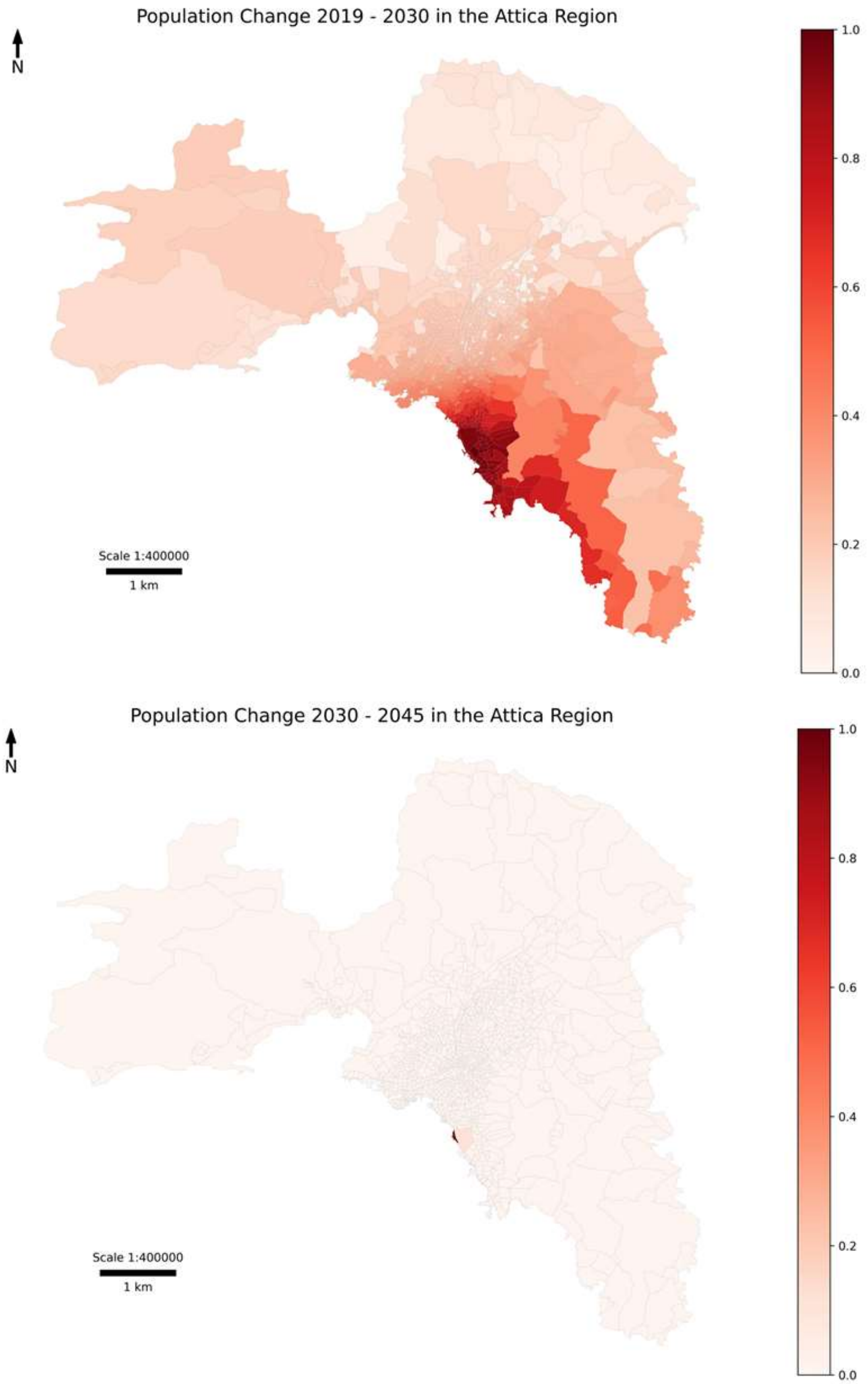

Figure 56 Population Change between 2019, 2030 and 2045 in Athens

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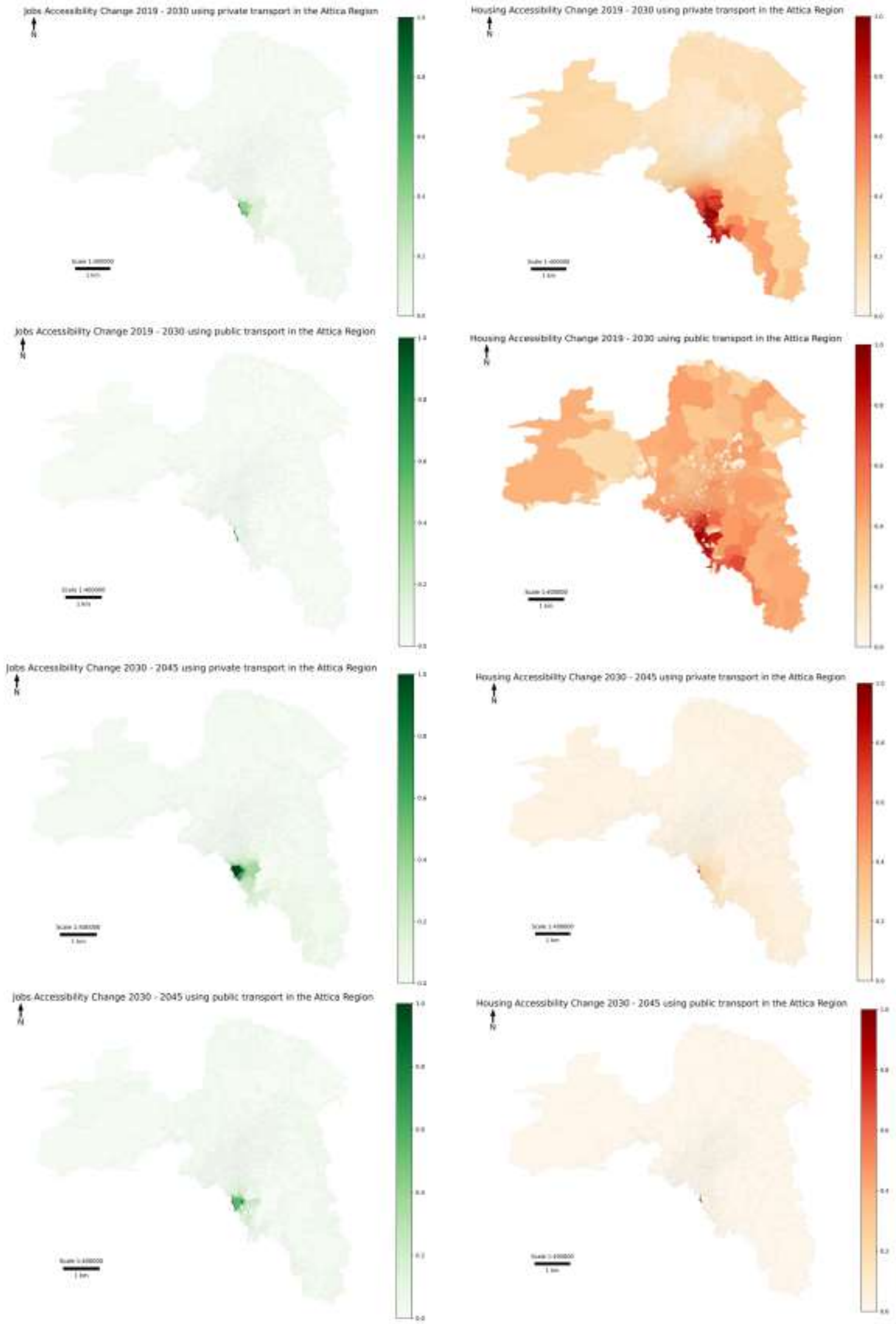

Figure 57 Change in job (left) and housing (right) accessibility in Athens for people using private and public transport between 2019 and 2030 and between 2030 and 2045

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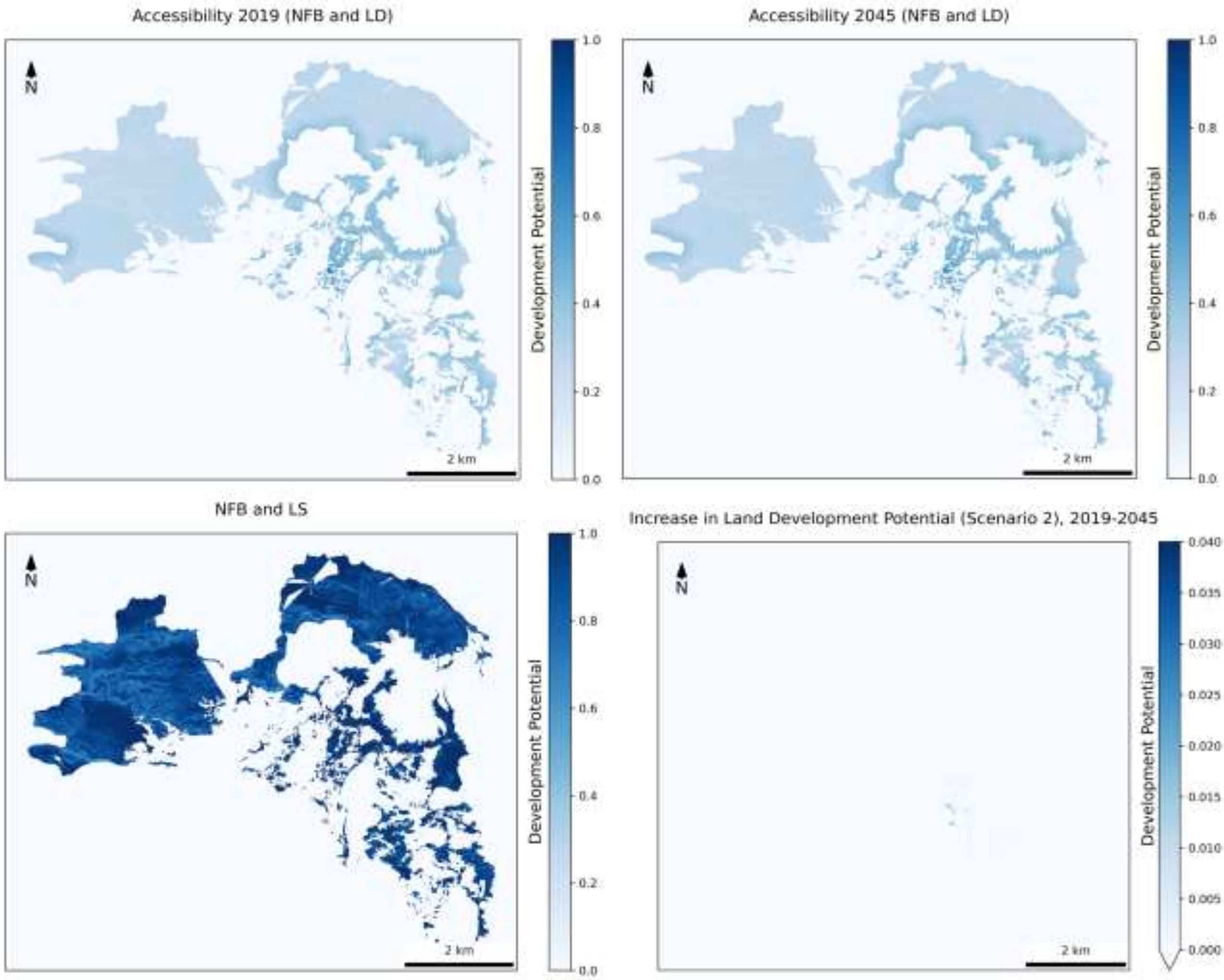

Figure 58 Scenario 2 - Land desirability for 2019 (up left) and 2045 (up right), land suitability (down left) and difference between 2019-2045 (down right)

5.4 Operational models template: simulation results and evaluation

The results of the analyses conducted on the operational-level models are provided herein, with a separate section dedicated to each one of the use cases.

Public Transport Electrification

Since the ultimate goal of the Ministry of Transport is the gradual electrification of all bus lines in Athens, this case study is broken down into five scenarios, each one considering a different number of bus lines operated by battery electric buses. These are illustrated in Table 32.

Table 32 Scenarios examined for the operation of Battery Electric Buses (BEBs) use case

Scenario	Number of BEB lines	Scenario	Number of BEB lines
1	0	4	150
2	50	5	200
3	100		

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The aim is the investigation of the effects of electrification in terms of the exhaust emissions (CO, NOx, PM2.5 pollutants) of the conventional buses remaining in operation. With a total of 284 bus lines, gradual electrification of some of the lines with simultaneous replacement of the most polluting buses and redistribution of the rest of them to the other bus lines can result in substantial decrease of air pollutants.

In this analysis, the first 50 electrified lines have the potential to halve the CO emissions of the remaining in operation conventional buses and decrease the respective NOx emissions by 46% (Figure 59). Naturally, results may vary on the basis of the number of BEBs available at the various stages of the procurement and the combination of the lines electrified.

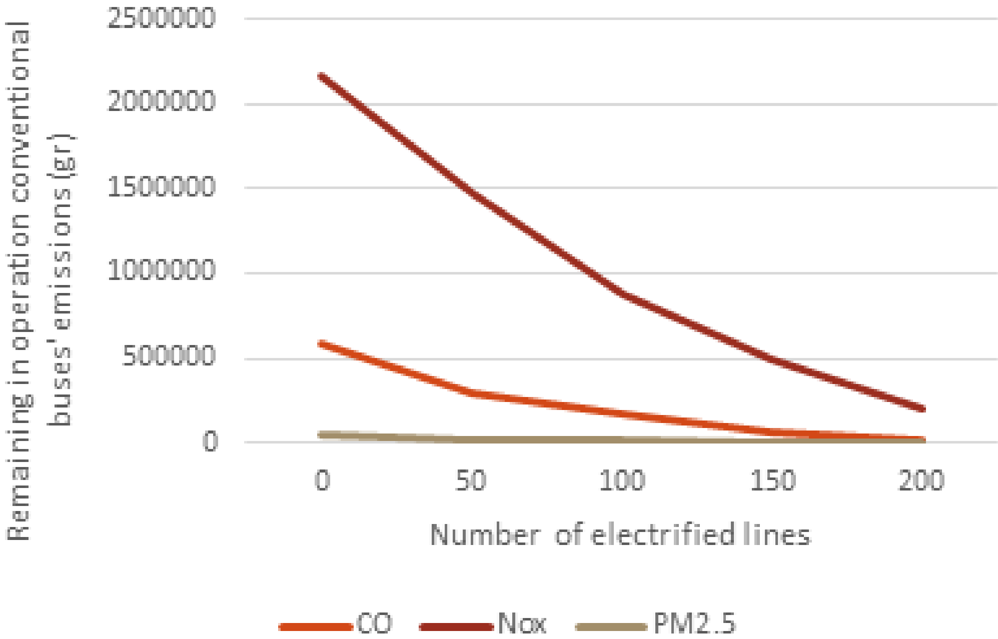

Figure 59 CO, NOx, and PM2.5 emissions of the remaining in operation conventional buses per number of electrified lines

Public Transport Electrification with Consideration of Micro-mobility Interventions

When considering the combined operation of Battery Electric Buses (BEBs) and micro-mobility schemes on the Athens network, the results from the analyses show that the additional impact of the two bicycle paths on the overall environmental footprint of the traffic is negligible. As expected, the decrease of the emissions is driven by the electrification of public transport. Construction of additional micro-mobility infrastructure in downtown Athens can potentially show some further amelioration in air quality. However, the structure of the capital in terms of topological characteristics and land use arrangements along with the established travel patterns call for the implementation of substantial measures in terms of intervention and spatial extent for them to hold the possibility for significant environmental impact.

Operation of Autonomous Vehicles (AVs)

Ten scenarios were developed and examined on the Athens network based on different AV penetration rates. These are illustrated in Table 33.

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Table 33 Scenarios examined for the operation of autonomous vehicles (AVs) use case

Scenario	AV penetration rate (%)	Scenario	AV penetration rate (%)
1	0	6	60
2	10	7	70
3	20	8	80
4	40	9	90
5	50	10	100

For each of the scenarios, the new PCU factors (dependent on the AV penetration rates and calculated through the Levitate methodology) were used as input in order to update the respective VDF functions. For the base case scenario (operation of only conventional vehicles, AV penetration rate = 0%), the PCU factor is equal to one. For all other scenarios, the PCU factors range from 0.98 to 0.82, with lower PCU factors corresponding to higher AV penetration rates.

It can be concluded that since higher AV penetration rates are related to lower PCU factors, a greater number of autonomous vehicles theoretically increases the available roadway capacity. As a result, travel times also drop as the AV penetration rates increase. Indeed, the difference of total network travel time between the base case scenario and the 100% AV penetration rate scenario is -8.97% (Figure 60). The results are in accordance with the ones derived for the Barcelona network in the Levitate program.

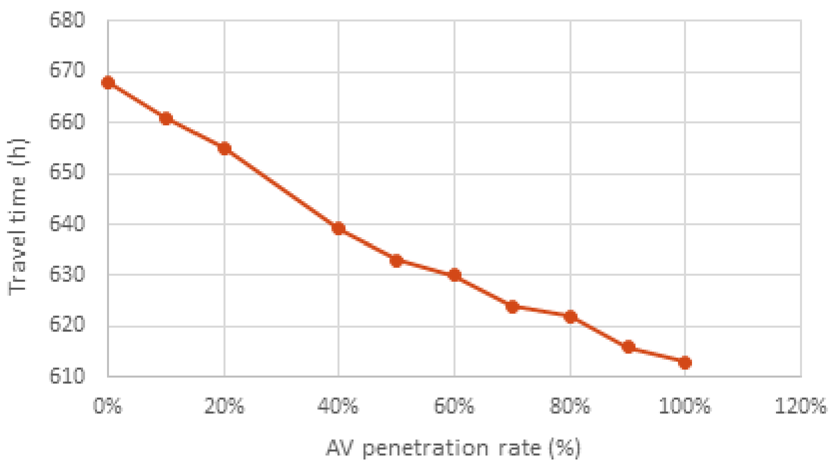

Figure 60 Total network travel time per different AV penetration rates

5.5 Summary

With respect to the strategic-level models, the results of the DFM lite clearly show that, although the population in the Elliniko area is expected to increase, the total population in the Attica region will significantly decrease by 2045 (-14%). Moreover, the percentage of the elderly is expected to increase, possibly indicating a low birth rate along with emigration of younger people; both factors lead to shrinkage of labour force. However, the results of the REM show a 9% increase in the number of jobs by 2045, with most of these jobs located in the Elliniko area. This fact implies that not only Athenians,

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but possibly people from neighbouring cities will commute to Elliniko every day, highlighting, thus, the need for better interregional public transport.

Furthermore, one of the main results of the LUTI model regards the prediction of the working population distribution in 2045. According to the study of Foster and Partners Ltd *et al.* (2016), Table 34 shows the number of residents that are expected to live in each urbanisation zone of the Elliniko intervention area by 2045. The results show that the total working population that will live in the five urbanisation zones of Elliniko and in the coastal urbanisation zone will be 2,169 and 1,852 residents respectively. Comparing these results with Table 34, it can be observed that the working population in the urbanisation zones 1 - 5 corresponds to only 9,7% of the total predicted population, while this rate raises to 90,5% when considering the coastal zone. Both percentages lie far from the 30% rate of working population to total population that is valid for Attica. However, it should be noted that this latter percentage (30%) is based on aggregated, regional-level estimations, while the actual distribution of working population in Attica remains unknown. As such, although it would be reasonable to expect that the model produces results closer to 30% for all zones, the limitations of the model may justify the extremely high or low values of some zones and their average can be calculated as an aggregated value. It is deemed that a more refined model would produce results of higher quality; consideration of the type and cost of dwellings as well as of the type of employment and the salaries of the working population would produce more accurate and disaggregated predictions at the zone level.

Table 34 Area, population and density per new urbanisation zone, Data source: Foster and Partners Ltd et al. (2016)

Urbanisation Zones (following Figure 55 division)	***Area (ha)***	***Population***	***Population Density (residents / km²)***
Zone No.1	32,147	3486	108
Zone No.2	55,591	5751	103
Zone No.3	31,801	3448	108
Zone No.4	77,528	3987	51
Zone No.5	37,974	2840	75
Zone No.6	26,474	2923	110
Coastal Zone	30,038	2048	68
Total	**291,553**	**24.483**	**84**

Moreover, a goal of the LUTI and the land development models is to contribute to policy making. In this case, the above results showed the emergence of the Elliniko area as another pole of interest apart from the city centre. The considerable growth, the new population, the jobs and the infrastructure that will be created after the construction of this project will pose the need for the appropriate policy framework for both the transport network and the land uses.

Athens' land use policies are determined by the Athens Regulatory Plan (ARP) (Hellenic Parliament, 2014). The Regulatory Plan of 1983 was in force for about thirty years, until, in 2014, the new Athens - Attica Regulatory Plan was instituted (valid until December 2021), with it currently being under revision. As a specialisation of the "ARP 1983", the General Urban Plan (GUP) of the Municipality of Athens of 1988 was instituted (Hellenic Parliament, 2014). The GUP delimited the development of the city centre in the following areas: Academy / University / Stadium, Syntagma, Omonia and Commercial Triangle. As land uses in the centre of Athens, it mainly envisaged areas of "urban centre", "neighbourhood

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centre" and "general residence", which were characterised by a mixture of land uses and a multifunctional character (Gerardi, 1998). Simultaneously, it emphasised the decongestion of central areas and the stimulation of local centres within the Municipality of Athens, with parallel control / restriction of the development of new central functions along the major arteries. Moreover, it promoted the highlighting of the historic character of the city centre, the control of land uses, the reduction of building restrictions, the stimulation of housing and restrictions on the location of offices and trade. From the 1980s to the 2000s, a series of Presidential Decrees designating specific land uses for neighbourhoods of each municipality were instituted as further specialisations of the GUP (Tournikiotis, 2012).

Unlike the ARP of 1983, the new regulatory plan of 2014 envisaged the model of the "compact city" instead of the logic of "decongestion" of the city centre and aimed at the renewal of the existing building stock. It presented as a direction the "complete reconstruction" of the centre, and as axes the strengthening of activities, jobs and housing, the activation of the empty building stock, the promotion of public transport, etc. Additionally, it fostered the development of other poles outside the centre, such as the major "development axes" and major road projects, the promotion of large shopping centres, and the construction of a new development pole at the old airport of Elliniko (Hellenic Parliament, 2014).

Although the new regulatory plan of 2014 focuses on the development of other poles besides the city centre (such as the old airport of Elliniko), it does not present targeted and specialised policies for this area and its surroundings. Partially, this seems reasonable as the Regulatory plan was prepared in 2014 when the construction of the new development of Elliniko had not yet begun. However, taking into account the results of the above model concerning the predictions of new jobs, population and flows, the renewed Regulatory plan that will be issued at the beginning of 2022, should include detailed instructions regarding the permitted land uses, building conditions, urban planning, productive activities, infrastructure, protection of the cultural and environmental resources, coastal front management, tourism management, etc. for the area of Elliniko and its surrounding municipalities.

With respect to the transport policies that exist in the Attica region, policies like “Park and Ride Athens” and “PARK in ATHENS”, which aim at reducing illegal parking in the city centre (it is estimated that 8,000 cars are illegally parked every day (Efthymiou and Antoniou, 2013)), can also be implemented in the municipality of Elliniko. “Park and Ride Athens” refers to the operation of parking lots near seven metro stations with high daily demand (Spiliopoulou and Antoniou, 2012; STASY, 2012). On the other hand, “PARK in ATHENS”, introduced in 2006 by the municipality of Athens, includes parking pricing systems for visitors with a maximum stay of 3 hours and it is considered to have a positive impact (Municipality of Athens, 2006). Implementation of another pilot project called “Megalos Peripatos (Great Walk)” aimed at creating routes that would connect the historic neighbourhoods of the Athens city centre by bicycle and on foot (Enikos, 2020). The pilot project lasted from May 2020 to June 2021 with limited positive impact (Serafeim, 2021). In this light, the construction of a new parking lot next to Elliniko metro station could be implemented in the “Park and Ride Athens” policy, under the condition that entrance is allowed only to people travelling from Elliniko to the city centre in order to promote the use of public transport. Furthermore, a network of bicycle paths (as in the project "Megalos Peripatos") which connect the city centre with the area of Elliniko could be built in order to boost soft mobility options. Finally, the same “PARK in ATHENS” system should be applied in the area of Elliniko in order to lessen traffic congestion.

As far as sustainable mobility is concerned, many municipalities of the Attica region, including the municipality of Elliniko – Agryroupoli, have carried out SUMPS. More specifically, the Elliniko – Argyroupoli SUMP was designed in 2019 and approved in 2020 and provides “interventions related to the traffic regulation of the municipality, the regulation of parking, the design of green routes, the upgrading of public transport, the strengthening of the sidewalk network, the smooth operation of sidewalks, the management of public areas and the reduction of carbon dioxide emissions” (Elliniko - Agryroupoli Municipality, 2019). The design of SUMPs is one of the nine key objectives of the HARMONY project, and the strategic-level models developed in this framework (DFM, REM LUTI and LDM) constitute key tools for their generation. Thus, the results produced from the HARMONY Strategic

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Model Suite for the Elliniko investment can be used to improve and enrich the existing area SUMPs. In particular, the higher private car use in the suburbs due to inadequate public transport derived from the LUTI model and the higher land desirability near the Elliniko area predicted by the LDM should be appropriately addressed through suitable intervention proposals in the SUMPs.

Finally, the operational-level use cases examined in the city of Athens proved to be of high value to the Athens Urban Transport Authority. They indeed indicated the shift that can occur in the environmental footprint of the capital through the electrification of public transport, while they also pointed to a decrease in travel times, should AVs penetrate the Greek vehicle market. In addition, the inability of micro-mobility interventions to provide notable improvements in air quality is merely due to the hypotheses considered and not due to lack of the simulation framework. As such, examination of the present case studies should only be viewed as a starting point towards further testing of transport policies and interventions. OASA, dedicated to the service of the public, will continue to use simulation tools to promote the implementation of measures that can improve its LoS as well as the transport system and its holistic impact.

5. Conclusion

In summary, Deliverable 2.5 presents the results of the co-created scenarios for four metropolitan areas, demonstrating the potential of the HARMONY Model Suite (MS) to support evidence-based transport and policy decision-making. The Deliverable confirms the successful delivery of the HARMONY MS at Technology Readiness Level 7 and provides a comprehensive report of the results obtained from the respective use-cases. The scenarios highlight the integration and interaction between the three temporal horizon levels, showcasing the functionalities of the MS, required input data, and key performance indices.

The outcomes of the HARMONY project underscore the crucial role of comprehensive modelling and integrated simulation tools in supporting the transition to a low-carbon new mobility era in a sustainable manner. Future research may expand the application of the HARMONY MS to a wider range of regions worldwide to assess their unique mobility challenges and develop tailored solutions, while also exploring the model transferability. Furthermore, the MS can be enhanced through the incorporation of new data sources, extensions in simulator functionalities, and the integration of additional modelling components to expand its scope and coverage of emerging challenges in transportation. The proposed research directions can also contribute to advancing the state-of-the-art in transport modelling and simulation tools, enabling more informed and evidence-based decision-making in the field of urban mobility.

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