H2020-MG-2014-2015

MOBILITY FOR GROWTH 2014-2015

H2020-MG-2014_TwoStages

Simulation results

Version 1.0

Sustainable **U**rban **C**onsolidation **C**entr**ES** for con**S**truction

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 633338.

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EXECUTIVE SUMMARY

One of the main objectives of the SUCCESS project is to evaluate the impact of the distribution of materials for construction sites and to provide solutions by a quantitative analysis of the impact of a Construction Consolidation Centre on the distribution process.

In this deliverable, we report on the quantitative simulations performed in WP4 to identify optimal solutions between the scenarios that each city defined in WP3.

The simulations considered all the scenarios and solutions defined in D4.2 and evaluated all of them, with a fine tuning made with a side-by-side work with WP5, using the AGILE methodology to improve the solutions.

In particular, we focused on the following quantitative KPIs out of the ones defined in WP2:

- Travel time (outside and inside the city centre);
- CO_2 equivalent;
- PM_x;
- Number of deliveries.

In addition, we computed the number of kilometres travelled outside and in the city centre, the CO and NOx emissions and the percentage load factor. The remaining KPIs have been evaluated with qualitative methods in WP5.

The findings are extremely clear. The use of a CCC (a) **improves upon congestion** and **safety,** (b) **decreases the pollutants emissions,** (c) **improves the on-time deliveries,** (d) **if properly managed is economically sustainable without external interventions.** The barriers against a real implementation are in the business habits and current supply chain management rules. Some interventions from the municipalities may encourage the companies to reorganize the supply chain based on the CCC usage.

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1 Introduction

The SUCCESS Project main objective is to study, evaluate, and improve the organization of the supply chain and the logistics of Constructions Sites in urban areas considering the point of view of different stakeholders, such as construction companies, transportation and logistics companies, local administrations and public authorities. The project also investigates their possible collaboration and cooperation that has an outcome in the study of possible introduction of one or more CCCs.

In other stages of the project, and hence in other deliverables, some methods have been developed and some possible solutions have been defined, tested and simulated. The results are presented in this deliverable. In particular, we defined **methods** in:

- Deliverable D3.3, where we delineated a set of business models for construction logistic optimization and for the introduction of CCCs; these will support in the decisions of policies and cooperation structures.
- Deliverable D3.4, where we delineated a set of mathematical programming tools for construction logistics optimization problems. For instance, we consider the use of mathematical models for the location and sizing of CCCs, their allocation to suppliers and construction sites. Moreover, we use heuristic algorithms to determine the best material flows and day to day operation costs.

Moreover, we defined possible **solutions** in Deliverables D3.3 and D4.2, where several possible scenarios to be tested have been built considering a collection of additional data needed for the simulation and solution testing that can be found in this deliverable.

The **aim of this deliverable** is to present the complete set of quantitative results obtained using the above methods, and to present some evaluation drawing conclusions for the project's quantitative KPIs. More results on the qualitative KPIs will be presented in the WP5's deliverables. The KPIs considered in this deliverable are well assessed indicators for the improving of logistic and transport activities, namely: (i) pollutant's emissions; (ii) number of trips (deliveries); (iii) number of kilometres travelled, (iv) time spent on the road and (v) loading factor.

As done for the entire project, also in the present deliverable we rely on the 4 pilot sites of Luxembourg City, Paris, Valencia, and Verona. The use of data and information coming from these sites is very important because they represent construction sites of different size and type (public and private building, parks, hospitals, administrative, commercial and residential buildings) in very different urban situations (see, e.g., the complexity of the urban texture of Paris, or the different altitude level of the City of Luxembourg, the narrow streets of the medieval Verona, and the logistic relevance on the urban area of the port of Valencia). These pilot sites represented different possibilities also regarding

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construction and disposal materials, in terms of delivery vehicles, city policies, management of the logistics processes (see, e.g., deliverable D3.2 to that extent).

With this diversity of data and pieces of information it has been possible to consider a set of **scenarios** in the different sites: such as the optimization of logistic flows in the current situation; the introduction of one or more CCCs with different locations and sizes; the optimization of the so-called first-echelon (the network from supplier to CCCs/from CCCs to dumpsites) and/or the optimization of the so-called second echelon (the network between the CCCs and the construction sites); the evaluation of one or more different types of construction site in the same simulation; the amount of inventory of materials to be stored in different parts of the network; the use of vehicles with different sizes and fuel types; different types of regulations of a given urban area, etc.

The several scenarios, as said, can be considered in a tactical, strategical point of view (introduction of CCCs) or from more operational point of view (the day-by-day operations).

All these scenarios are used in our methods (described above) to produce the **simulation** that is the core activity of this WP and that leads to the results. In particular, we firstly defined the data to be used for the simulations and built the ones that are suitable for our methods. We determined the periods to simulate; we consider construction sites of the pilot city and other novel realistic construction sites based on construction information gathered from municipality data and data from the construction companies; we generate the demand of these construction sites based on their type and size; we contemplate stochastic scenarios to evaluate decision to be made here and now but that will affect the future; we scrutinize different suppliers, CCCs and vehicles; we acknowledge direct and reverse logistic flows; we provide solutions for the day-by-day operations in both the supply chain and the reverse logistics.

The **outputs** are represented in terms of number of deliveries, number of km travelled, costs, etc., and in terms of externalities - pollutants emissions, etc. -, but also in the indication in using one or another business models for one or more scenarios; indication of different possible policies as well (such as the use of small electrical vehicles or the introduction of a congestion charge). These outputs are produced for the scenarios defined and for pilot sites cities.

The simulation process and its outputs are performed in an iterative process with the **validation** tasks of WP5 that is required to validate the proposed solutions.

1.1 Relations with Work Package 5

According to the proposal plan, the development of the simulation solutions of task 4.3 have been conducted with a strict relation with work package 5 (see

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Figure 1, for the relations of the work packages as designed in the proposal and in the grant agreement).

The optimized solutions designed in this task have been continuously evaluated and validated by WP5 following an AGILE methodology which foresees an adaptive, iterative and evolutionary development. After each evaluation by WP5, the modification required has been implemented by WP4 to design, test and simulate a new optimized solution.

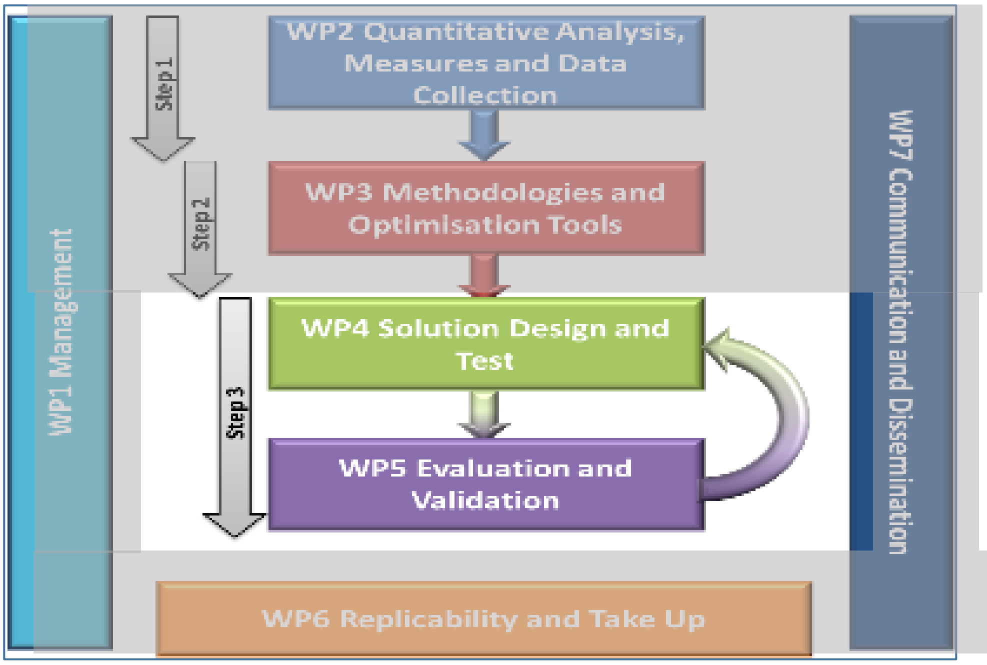

Figure 1: WP relations from the proposal.

The AGILE process consists in a series of iterations where a fast development/implementation phase is followed by an evaluation, a definition of new requirements and a successive development phase until the best solution is identified.

Figure 2: AGILE loops.

To implement the AGILE methodology a specific "simulation" working group including people in charge of the development of WP4 and of WP5, has been set up. Weekly meetings have been organised to discuss step by step the requirements, the design decisions, the implementations, and to evaluate the results of the intermediate simulations. The simulation environment presented in this deliverable, the assumptions, the tools and the numerical results are the final findings of several interactive loops performed during the execution of Task 4.3.

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2 Simulation environment

2.1 Simulation models for distance and pollution computation

In this section, we describe the data and processes implemented to compute the optimal location of possible CCCs and to simulate the distribution of the materials with and without the introduction of the CCCs to serve a construction site or an entire set of construction sites in a given city.

2.1.1 Simulation model: Input data

In this section, we describe the input data needed to compute the optimal location of possible CCCs and material flows.

The input data are divided in groups accordingly to the different data classes.

2.1.1.1 Simulation period

The duration of the simulation period is the first data to be defined. For the current simulations, we assumed that the simulation period spans three years. This seems to be a reasonable period in order to have a complete vision of the foregoing construction activities, since almost all licenses for these constructions have already been issued. In our opinion, a longer period seems to be not reasonable due to the high variability that can occur.

The data regarding the exact duration of each single construction site (see next section) are given within the other information of the construction sites, in particular in terms of total budget for each of the three years.

2.1.1.2 Construction sites

Each city has its pilot construction site and additional **construction sites** identified as the most relevant construction works for the next three years in the city.

Each construction site has a time period of 1, 2 or 3 years.

The activities of each site are identified by the **budget** allocated to the site for each year. A zero budget for a certain year indicates that the site is not active in that year. The distribution of the budget has been taken from the specific information we have collected for the sites. In absence of a specific information, i.e. when only the total budget and the number of years of activities are known, we used the following rules to allocate the activities to the three years:

- for three years site: 1/5 of the budget for the first year, 2/5 of the budget for the second and third year;
- for two years site: 2/5 of the budget for the first year, 3/5 of the budget for the second year.

Each construction site is associated with one of the following four project **typologies**:

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1. public buildings;
2. apartments;
3. urban works (roundabout, parks, etc.);
4. offices.

These typologies are associated, respectively, with the pilot site as follows:

Type of site	Associated pilot
public buildings	Verona
apartments	Luxembourg
urban works	Valencia
offices	Paris

Table 1: Association construction site – Pilot.

The pilot site is always included in the sites to be used for the simulation and is associated by default to id zero.

The data of the construction sites are given in input as a CSV (Comma Separated Values) file as shown in the following Figure 3.

Id cant	Public/Private	Name/type	Address	Pilot	Lat	Long	2017	2018	2019	start	end	Months	Total Value	Size m^2
0	Pub	Hospital (Pilot)	Via Goffredo Mameli	Verona	45.45396	10.98478	70000000	56000000	0	01/01/17	31/12/18	24	126000000	7339
1	Pr	House	Lungadige Sangiorgio 3	Luxembourg	45.44862	10.99987	660000	880000	0	01/01/17	31/12/19	36	1540000	380
2	Pr	Apartment	Piazza Arditi, 1	Luxembourg	45.4378	10.98868	460000	920000	920000	01/01/17	31/12/19	36	2300000	240
3	Pr	Penthouse	Piazza Arditi 3	Luxembourg	45.4376	10.98878	430000	860000	860000	01/01/17	31/12/19	36	2150000	380
4	Pr	Penthouse	Piazza delle Erbe 15	Luxembourg	45.44273	10.99731	400286	533714	0	01/01/17	31/12/19	36	934000	231
5	Pr	Apartment block	Piazza delle Erbe 25	Luxembourg	45.44295	10.99704	0	591429	788571	01/01/17	31/12/19	36	1380000	340
6	Pr	Apartment	Piazza Renato Simoni 1	Luxembourg	45.43401	10.9851	0	762857	1017143	01/01/17	31/12/19	36	1780000	440
7	Pr	Apartment	Piazzetta Santi Apostoli 7	Luxembourg	45.44085	10.99227	270000	360000	0	01/01/17	31/12/19	36	630000	120
8	Pr	Apartment	Piazzetta Serego 34	Luxembourg	45.44058	10.99919	432857	577143	0	01/01/17	31/12/19	36	1010000	250
9	Pr	Apartment block	Via Adigetto 11	Luxembourg	45.43598	10.99599	420000	840000	840000	01/01/17	31/12/19	36	2100000	515
10	Pr	Apartment block	Via Agostino Mainardi 2	Luxembourg	45.43311	11.02133	522857	697143	0	01/01/17	31/12/19	36	1220000	300
11	Pr	Apartment	Via Anfiteatro 11	Luxembourg	45.44027	10.99599	257143	342857	0	01/01/17	31/12/19	36	600000	145
12	Pr	Apartment block	Via Campofiore 57 37129 Verona	Luxembourg	45.43766	11.00805	960000	1920000	1920000	01/01/17	31/12/19	36	4800000	1872
13	Pr	Penthouse	Via Cappello 14	Luxembourg	45.44151	10.99866	505714	674286	0	01/01/17	31/12/19	36	1180000	290
14	Pr	Apartment	Via Cefalonia 2	Luxembourg	45.4522	10.987	257143	342857	0	01/01/17	31/12/19	36	600000	145
15	Pr	Apartment	Via Cefalonia 6	Luxembourg	45.45174	10.98735	257143	342857	0	01/01/17	31/12/19	36	600000	145
16	Pr	Building	Via Duomo 182	Luxembourg	40.85128	14.2596	1200000	2400000	2400000	01/01/17	31/12/19	36	6000000	625
17	Pr	Apartment	Via Macello 5	Luxembourg	45.43591	10.99942	428571	571429	0	01/01/17	31/12/19	36	1000000	240
18	Pr	Loft	Vicolo Vento	Luxembourg	45.43785	10.99968	0	295714	394286	01/01/17	31/12/19	36	690000	150
19	Pr	Apartment block	Via Filippini 8	Luxembourg	45.43736	10.99998	0	771429	1028571	01/01/17	31/12/19	36	1800000	1000
20	Pr	Penthouse	via Frattini 3	Luxembourg	45.43915	10.9966	0	381429	508571	01/01/17	31/12/19	36	890000	164
21	Pr	Apartment	Via Gaetano Trezza 16	Luxembourg	45.44066	11.00519	0	600000	800000	01/01/17	31/12/19	36	1400000	340
22	Pr	Penthouse	Via Gaetano Trezza 26	Luxembourg	45.44054	11.00625	660000	880000	0	01/01/17	31/12/19	36	1540000	348

Figure 3: Example of construction site data.

The meaning of the fields:

Field	Description	Format
Id site	A number that identifies the site. Value 0 is associated to the pilot site	integer
Public/Private	Label Private/Public is used to identify the type of site	char
Name/type	Name of the construction site	char
Address	Street of the construction site	char
Pilot	Pilot associated to the construction site (see above)	char
Lat	Latitude coordinate of the site	string
Long	Longitude coordinate of the site	string
2017	Budget allocated to the site in the first year	string
2018	Budget allocated to the site in the second year	string
2019	Budget allocated to the site in the third year	string
start	Start day of the activities	date
end	End of the activities	date

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Months	Duration of the activities in months	string
Total Value	Total budget (sum of fields 2017-2019)	string
Size m2	Size of the site in square meters	string

2.1.1.3 Demand generation

In WP2 we collected for each pilot site information on the kind of materials, quantities and times of use in the pilot. These data define **flows of materials** from the suppliers to the construction site. We have completed the data by adding the material flows for the periods not covered by the WP2, using the activity and material plan (PERT charts and related documents) developed by the companies before starting the construction work, and updated during the execution. These flows of materials have been used to define the request of materials (quantities and times) for each construction site, by associating each new site with one of the four pilots, accordingly to the type of the site.

The **quantities** of the materials to be used in a specific site are defined proportionally to the ratio of the budget of the construction site, over the budget of the corresponding pilot.
The **timing** for the use of the materials is enlarged or reduced proportionally to the duration of the simulated construction site (1, 2 or 3 years) over the duration of the corresponding pilot. For example, if a material is used in the first 2 months of the pilot site of Verona, which has a duration of 22 months, and we have to produce the materials flows for a site having the same typology as Verona and during 12 months, we define a flow of this material in the first 2 x (12 / 22) months, that is 1 month and 2 days.

2.1.1.4 Stochastic scenarios

In order to define the correct location for the CCCs we need to evaluate the future demand of transport using a robust approach which considers the possible variation from the forecasting we have today. To do this, we adopt a stochastic optimization approach which consists in defining a few stochastic scenarios, for the input data, and to optimize over the weighted average of these scenarios.

For each city three **stochastic scenarios** have been considered. The first scenario, namely the **base scenario** is the one we generate directly from the material flows we have from the pilot (see previous section).

In the **expanded scenario,** we consider one-by-one the construction sites of the base scenario. With probability 50% we increase the size of the construction site, with probability 5% we reduce the size of the site. The increase is randomly

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generated with up to 150% the base site, the reduction is randomly between 90% and 100% of the base scenario.

For the **reduced scenario**, we consider each base site and we delete it with probability 10%. We reduce the remaining sites with probability 50% and we increase them with probability 5%. The maximum (random) reduction is by 50%, the maximum increase is 20%.
An example of the stochastic scenarios is given in the next Figure 4 where we report the global material flows, in cubic meters, of the three stochastic scenarios (base, expanded and reduced) for the pilot site of Verona.

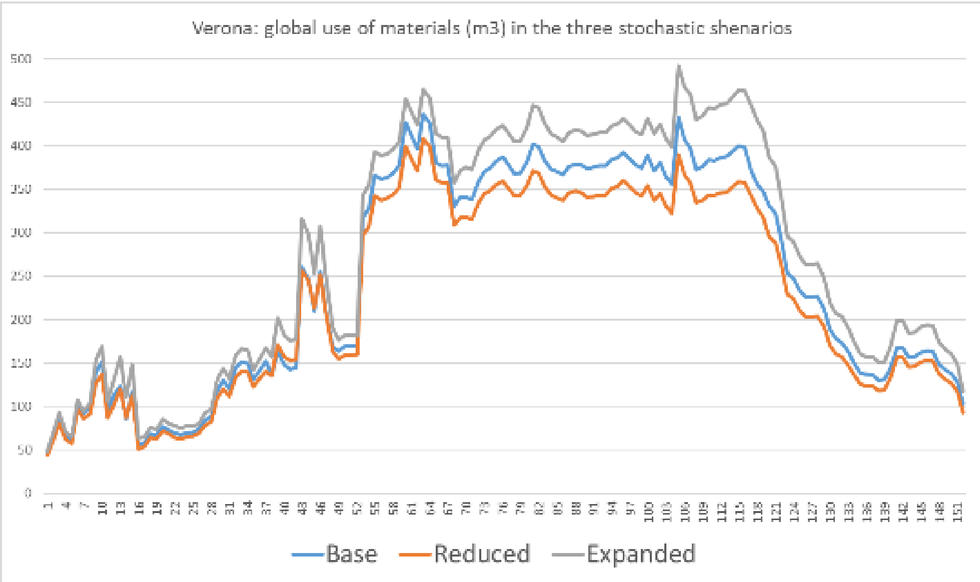

Figure 4: Three stochastic scenarios – Verona.

2.1.1.5 *Material classes*

The material flows from the four pilot sites have been merged and analysed in order to define a complete list of the materials needed in the four types of construction site. We aggregated similar materials by defining a list of 34 **classes** of materials given in the next table.

Class	Class (following)
Accessories	Metal
Bitumen	Paint
Bricks	Parquet
Cement	Pipes
Coating	Plants
Electrical	Plaster
Epoxi	Polystyrene
External Doors	Precasted Concrete
Fences	Roof
Fire Doors	Scaffolding

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Gabions	Signals
Garden Equipment	Steel
Geotexil	Stone
Glass wool	Tar
Hydraulic	Tiles
Internal Doors	Windows
Lift	Wood

Table 2: Material classes.

In the Figure 5, for example, we report in detail the material flows, in cubic meters, for each class of material, for the pilot of Verona, in the base scenarios.

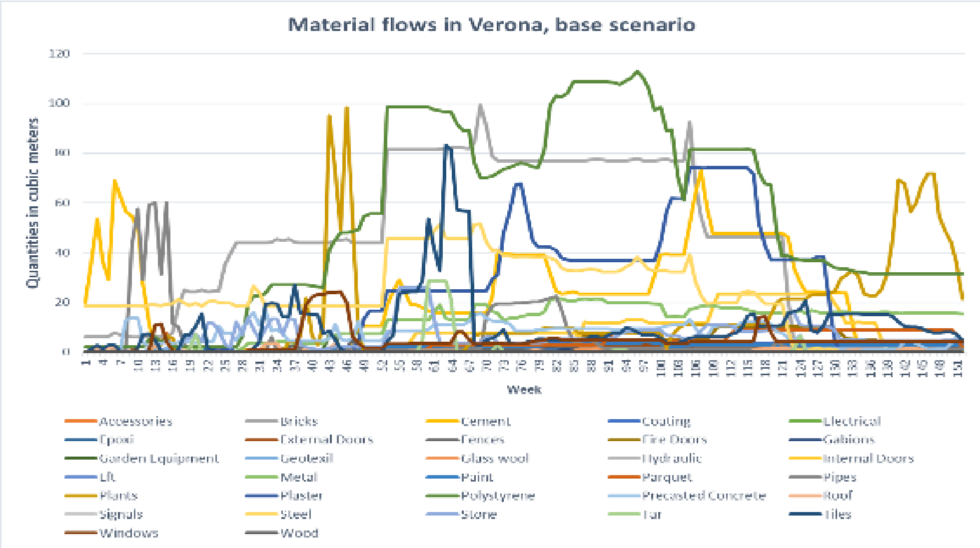

Figure 5: Material flows by material type – Verona.

2.1.1.6 *Suppliers*

The **suppliers** we used for the simulation of a given city are those the construction pilot site of the city deals with. This list has been completed by adding other suppliers for the materials not used in the pilot site of the city, but needed because used in some construction sites associated with a pilot of another city.

These suppliers have been selected using information from the construction companies.

Each supplier is associated with one or more materials, accordingly to the real information.

For the simulations in Luxembourg, Valencia and Verona it is reasonable to have a fixed list of suppliers for all the construction sites. For the simulation in Paris, due to the bigger dimension of the city and because of the major importance of the distances, we have selected different suppliers for different construction sites. Also, this choice has been made using information from the local construction company.

The input data is given as a CSV file as that of the example in Figure 6.

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Class	Supplier	Street and Number	Postal Code	City	Country	Lat	Long	Truck
Accessories	Aquader	Calle Cuarte 59	46113	Moncada, Valencia	Spain	39.550418	-0.392828	4
Accessories	Belcaire SL	Avda. Jaime Chicharro s.n.	12530	Burriana, Castellon	Spain	39.875528	-0.0768323	5
Accessories	Ribloc	Poligono Industrial Mateu Cromo, M-506 K	28320	Pinto, Madrid	Spain	40.2498572	-3.7202675	5
Accessories	Sifonika	C/ Pinar, n. 5	28006	Madrid	Spain	40.4371594	-3.6885836	5
Bitumen	Lemara	Carrer Tabardo, 12	46469	Beniparrell, Val?ncia	Spain	39.3873782	-0.4137267	5
Bitumen	Dummy07					39.822789	-0.216427	5
Bitumen	Dummy08					39.822789	-0.216427	5
Bricks	Vicente Camp SL	Pla de Quart km 4	46960	Valencia	Spain	39.4604071	-0.4657198	5
Cement	Beton Catalan	CTRA. DE TURIS A XIVA	46389	TURIS, VALENCIA	Spain	39.3919001	-0.7059273	5
Coating	Dummy01					38.878839	-1.112118	3
Electrical	Amara	Calle Do vinalop 13	46930	Quart de Poblet, Valencia	Spain	39.4693694	-0.5048442	1
Electrical	Imeaspi SA	Calle Doctor Fleming 14	46930	Quart de Poblet, Valencia	Spain	39.4772252	-0.4551377	1
Electrical	Ribloc	Poligono Industrial Mateu Cromo, M-506 K	28320	Pinto, Madrid	Spain	40.2498572	-3.7202675	1
Epoxi	Hilti	Avda. Pista de Silla, n 22, Pol. Ind. Massana	46470	Massanassa, Valencia	Spain	39.4057645	-0.3842565	1
Epoxi	Lemara	Carrer Tabardo, 12	46469	Beniparrell, Val?ncia	Spain	39.3873782	-0.4137267	5
External Doors	Dummy02					38.083194	-1.190316	4
Fences	Fivi	C/ Dinamarca n. 3	46240	Carlet, Valencia	Spain	39.2292391	-0.5051974	4
Fences	Jardineria Villanueva SL	Autovia Ademuz Salida 12, Valencia	46190	San Antonio de Benageber, V	Spain	39.5629272	-0.499629	4
Fences	Suministros COVAL SL	Pol. Ind. Mas de Tous	46185	La Pobla de Vallbona, Valenc	Spain	39.588301	-0.536187	5
Fire Doors	Imeaspi SA	Calle Doctor Fleming 14	46930	Quart de Poblet, Valencia	Spain	39.4772252	-0.4551377	1
Gabions	Dummy03					37.752536	-0.943976	4

Figure 6: Input data for suppliers.

The meaning of the fields is as follows:

Field	Description	Format
Class	"Macro" type of material	char
Suppliers	Name of the supplier	char
Street and number	Street of the supplier	char
Postal Code	Postal code	integer
City	City	char
Lat	Latitude coordinate of the site	string
Long	Longitude coordinate of the site	string
Truck	Index of the biggest type of truck (see below) that can be used for this supplier	integer

2.1.1.7 CCCs

The possible **CCCs locations** are given by the pilot coordinators after a discussion with the construction companies and/or the municipalities.

The **capacity** in cubic meters is defined according to the location and the possible existing structures. A further capacity in cubic meters can be added, for each material, to avoid that the simulation uses the entire CCC for a single material. As a general rule, these capacities are assumed to be 1/3 of the overall capacity. The capacities are expected to refer to one month. When the simulation considers the week as time unit, the capacities are reduced proportionally.

The figure 7 shows in yellow the possible CCC locations for the city of Valencia, in green the location of the construction sites used for the simulation, and in red the three closest suppliers (other suppliers are outside the map).

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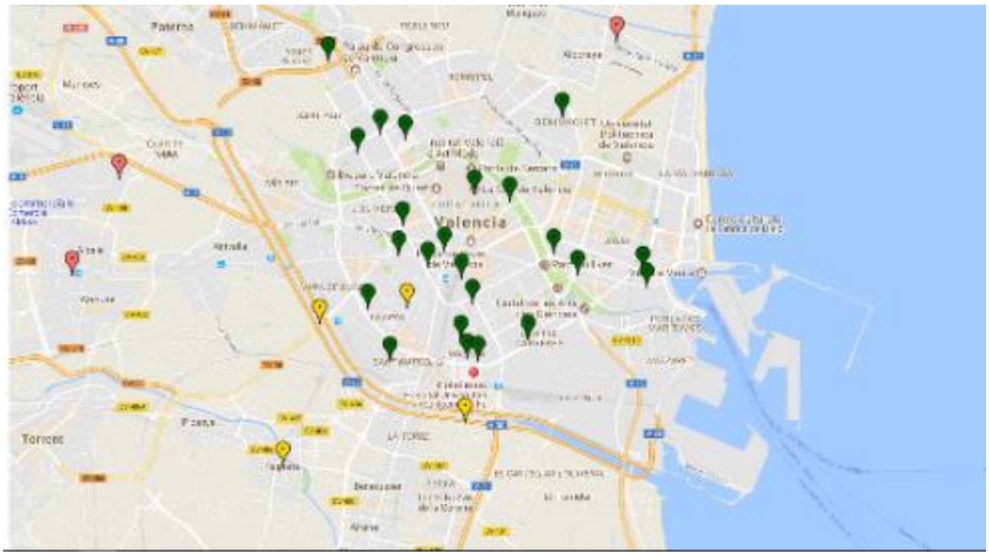

Figure 7: Example of location of sites for Valencia:
CCCs (in yellow), construction sites (in green), suppliers (in red).

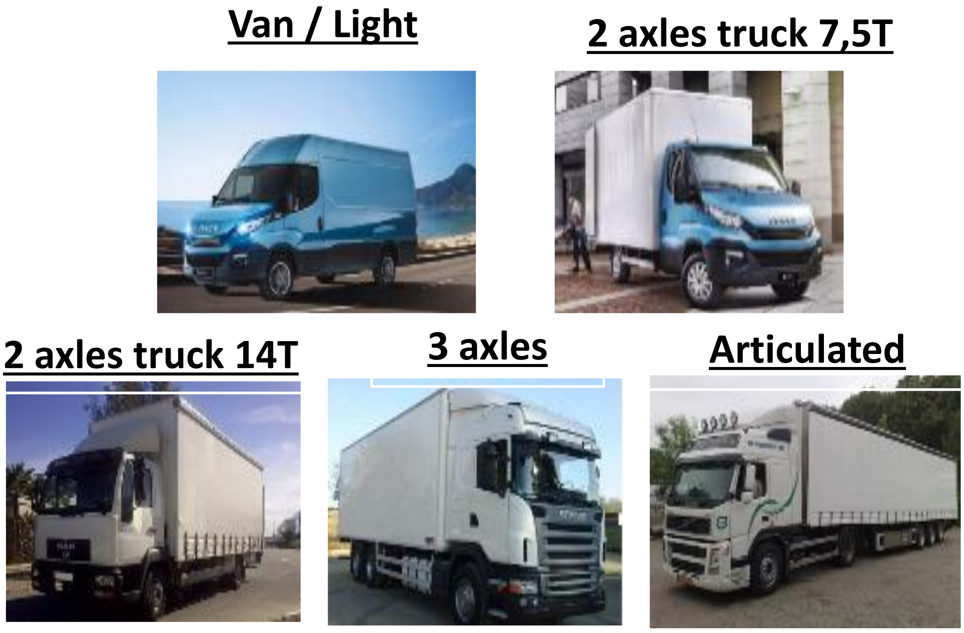

Figure 8: Pictorial representation of the type of trucks selected.

2.1.1.8 Trucks

For the simulation, we selected **five types of trucks,** having different capacity in kilograms and cubic meters.
The types of trucks are indexed by increasing integers from the smallest capacity to the largest one. Restrictions on the size of the trucks that can be used by a supplier or inside the city are given at city level. As a general rule, we do not

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consider articulated trucks to be used starting from a CCC to deliver inside the city.
The Euroclass of the trucks is considered during the computation of the pollutants emissions, but is not relevant when simulating the number of kilometres and trips needed to deliver the required material flows. For this simulation, the **capacity** of the vehicles is the only relevant variable.
The details of the truck types selected are given in the next table.

Type	Capacity in Kg	Capacity in m³
Van / Light Truck	1.500	10
2 Axes Truck 7.5T	4.900	19
2 Axes Truck 14T	10.000	25
3 Axes Truck	16.000	32
Articulated Truck	25.000	75

After some discussions with the construction companies and some logistic operators, we have seen that the **loading factor** of the vehicles starting from suppliers is usually less than 100%, with the exception of very large orders, that are delivered directly to the construction site. We have checked the data collected on the pilot sites and we discovered that the loading factor is usually 65%-85%. Therefore, **we assumed a loading factor equal to 75% for the trucks going from the suppliers to the CCCs**. This loading factor has been also validated with some preliminary sensitivity analysis which showed that the impact on the results is sublinear with the loading factor (i.e., a change of 5% in the input data determine a change in the results which is smaller than 5%). We further discussed this choice with the construction companies partner of the project and with some logistic companies during the local workshops: it was judged very reasonable and, therefore, accepted.
Concerning the loading factor **from the CCC to the construction sites,** we considered that one of the main aims of the CCC is to consolidate different orders and deliver with the maximum efficiency, so a **loading factor 100%** was assumed.
A final decision regards the **tolerance of the loading factors**. Indeed, we have seen on the data collected in WP2, that sometimes there are deliveries that exceed a little the nominal maximum load. We have given the system a small tolerance by assuming that deliveries with a load smaller than 3% of the nominal loading (in weight or volume) are considered to be serviced without the use of an additional vehicle. More precisely, if a deliver should be made by a truck with a total load smaller than 3% of its maximum loading, this trip is not considered, but the materials are supposed to be delivered increasing a little the loads of already existing trips, even if they have reached their nominal maximum.

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2.1.1.8.1 Truck selection procedure

In the simulation, we need some rules to associate one or more types of trucks to each delivery.

Discussing with the construction companies and with some logistic operators, we decided to adopt a rule-of-thumb which minimizes the number of trips by associating with a given delivery the truck type of larger capacity, provided that the same number of trips cannot be done by a smaller vehicle. The residual load is given to the smallest truck that can deliver it.

Let us consider a small example to clarify the rule. Suppose we have to manage a delivery of 35 tons and we are not allowed to use articulated trucks, because we are in the inner city. We start by using the 16tons 3 axes truck type, and we compute the number of trips necessary, i.e., ceil (35/16) = 3, where ceil (*) indicates the first integer greater or equal of its argument. We consider two trips with full load and we compute the residual load: 35 – 16*2 = 3 tons. For this residual load, we look for the smallest truck that can deliver it, namely the 2 axes truck 7.5T, which is the type of vehicle selected for the third and last trip.

In the selection, we consider at the same time both the weight and volume constraints and we use the stricter of the two for the computations.

2.1.1.9 Roads, distances, time

The facility location model and the simulation of the material flows in the different scenarios require the information of the distances and times between the suppliers, construction sites and CCCs.

We have analysed the options available to compute these distances. All these options are based on services or data from companies which produce digital maps. In particular we have considered:

- Openstreetmap;
- Google;
- TomTom;
- Here.

The maps from Openstreetmap (which is a non-profit organization) are widely used by academics, but the quality of the map depends widely from a place to another one. A viable alternative is to use the commercial version of Openstreetmap provided by Geofabrik. However, no service to compute the distance is provided.

The other map providers also make available web API to compute the distances on their map. These are cloud services that do not require to download a map, and can be invoked through a web service application.

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The three providers give similar service. We have selected the **Google Distance Matrix API,** which can be used under a pay-per-use contract.

We have developed a PHP application running under Apache 2.4 which reads a list of coordinates (latitude and longitude), iteratively selects a subset of coordinates (points), invokes the API for the selected points and return two matrices in CSV format: a **distance matrix** (distance in meters for each pair of points) and a time matrix giving the travelling time (in seconds) per pair of points. The **traveling time** is computed by the API considering the speed limits and the real average transit times in each road, computed using historical traffic data. An optional parameter of the API allows to specify the **traffic model** to be used to compute the travel durations (best guess, pessimistic, optimistic). However, we simulate trips on weekly or daily basis without entering into the operational detail, as the time of the day of the trip, so we need a value which is valid in general, as the **average duration** provided by Google is.

2.1.2 Simulation models: Process

The overall simulation process is depicted in the Figure 9 We start from the input data in plain text (CSV), described above, and we apply a C++ program which generates the stochastic scenarios as described in the previous sections. The generated scenarios are used as input of a mathematical model of the stochastic facility location problem (see deliverable D3.3), which gives the optimal choice for the CCCs location and selection. For this step, we use the FICO XPRESS© mixed integer linear programming solver. Using this information and the stochastic data generated, a set of C++ programs execute the simulation for distances and times of the flows in the different SUCCESS scenarios described in deliverable 2.2 and hereafter resumed. The results of this evaluation are next used both by the COPERT© program and by our CBA models to evaluate, respectively, the pollutants emissions and the economical sustainability and opportunity of using the CCCs.

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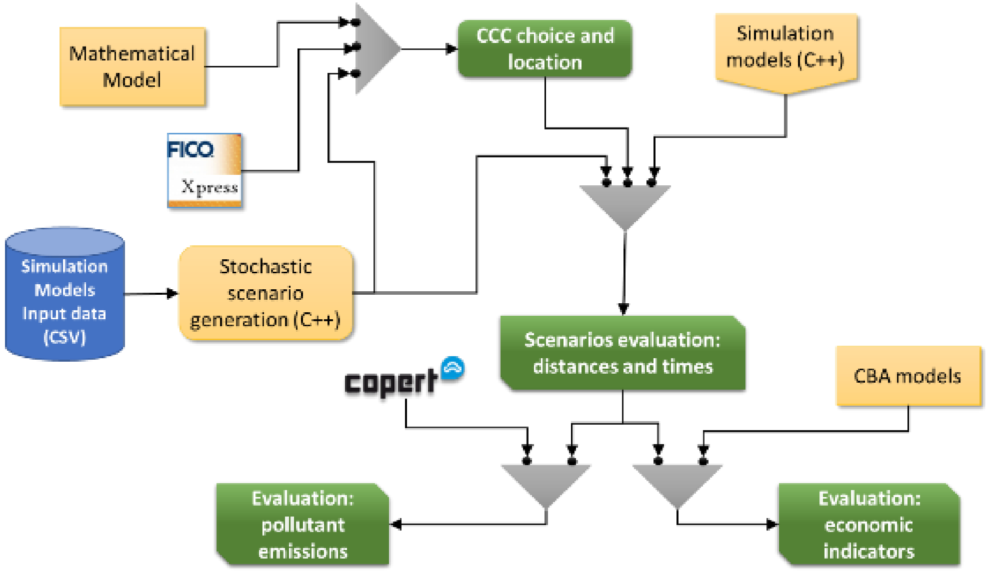

Figure 9: Simulation process overview.

We used several quantitative tools:

- C++ programs to define the stochastic demand, based on the real data from the pilot sites;
- Mathematical models developed in D3.3 to implement the stochastic optimization;
- XPRESS© tool to solve the stochastic optimization;
- C++ programs to simulate the trips in the optimized and non-optimized scenarios;
- COPERT© to compute the emissions in the pilot cities.

During the tuning of the system and interactions with WP5, we have made a set of **assumptions** that we report hereafter:

a) **Cement and bitumen**: we decided to discard these materials in our simulations since they are provided by special vehicles (e.g. cement mixer) and cannot be stored and aggregated with other materials at a CCC.

b) **Reversal flows**: we observed that the reversal flow is mainly due to garbage that must be disposed accordingly to the type and using different bins for different materials, and, in some cases, special procedures. Usually specialized companies are in charge of this process. No consolidation is possible if we want to maintain separate the different materials, and specialized equipment and operators will be necessary. The remaining unsorted garbage (un-differentiable packages etc.) represent a very small quantity (for example a clever use of recycling activities in the pilot of Paris show that more than 95% of the garbage is recycled with differentiate processes). Therefore, we removed the reversal

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flows from simulation. Some considerations on the residual reversal flow will be done in the context of WP5.

c) **Suppliers per site**: we do not know the exact list of suppliers for each of the pilot construction sites, however it is correct to assume that the same set is used for all construction sites. Since we are doing a strategic analysis, we assume that in all construction sites, but the pilot ones, each kind of materials is provided by a single supplier, possibly different site by site.

d) To calculate air pollutants emissions from road transport, we need to know the **Euro class of each vehicle**. Therefore, we have taken the mix from official registration records and used that percentage for the computation. In particular we used the last statistics available for Italy in 2016[1]. We performed some preliminary sensitivity analysis for the largest pilot (Paris) to understand the impact of this choice on the final results. Dividing by 2 the number of Euro 0 trucks gives a reduction in the emissions of CO2 by 4%. Doubling the number of Euro5 or Euro 6 trucks the CO2 emissions change less than 2%. We also observed that our interest is not in the computation of the exact absolute value for each solution, but to identify if an improving trend exists. Indeed, the proposed solutions must be valid not only with today's situation, but also in the future. For these reasons, we adopted the Italian Euro classes mix as reference for all sites.

e) **CCC policy**: the CCC is used on a just-in-time basis. It means that when a CCC is implemented, the deliveries are made on a daily basis according to the materials needs of the construction site.

2.1.2.1 Scenarios implemented (resume)

In this section, we re-describe the macro scenarios that we considered in the simulation. Scenarios 1 and 4 are, respectively, the baseline (AS-IS) situation for the case where no CCC is implemented and 1 big site, or several sites are considered. Scenarios 2, 3, 5, 6, 7 and 8 represent cases with one or two CCCs and different levels of optimization. In particular, we will optimize the deliveries using aggregation by time, by single material class and by all classes combined (see below Section 2.1.2.3 for more details).

[1] Elaborazioni dell'Area Studi e Statistiche di ANFIA su dati del Ministero dei Trasporti, I SEM 2017

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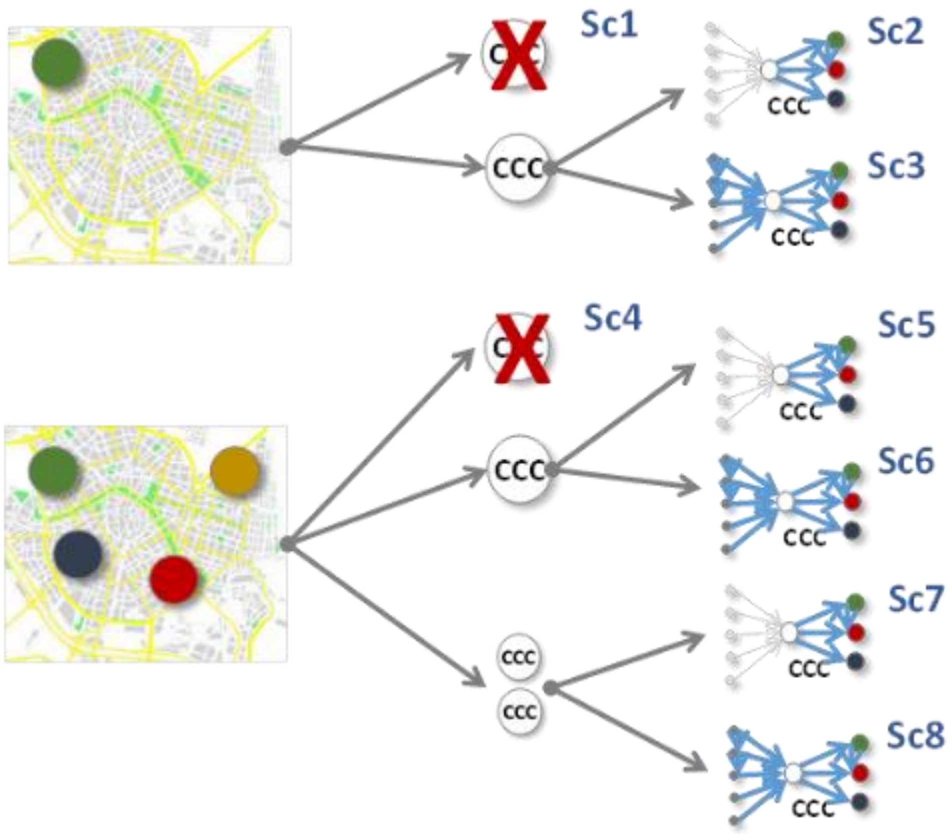

Figure 10: Macro scenarios scheme.

1. **Scenario 1 - no CCC - 1 site:**

In scenario 1 we simulate the presence of only one construction site and no introduction of CCC. In particular we consider the construction site represented by each pilot site. In this scenario, we do not consider the introduction of a CCC, but we evaluate the possibility of consolidating materials headed to the construction sites in different type of vehicles and optimize its delivery. This scenario constitutes the **baseline** for the test with only one big construction site.

2. **Scenario 2 – CCC - 1 site – optimization on the second echelon**

In scenario 2 we consider only one construction site, that is the pilot site for each of the 4 cities. In this scenario, we evaluate the introduction of a CCC and we perform an optimization only on the second echelon, that is to say the network between the CCC and the construction site. We solve optimization problems linked to the introduction of a CCC, such as its location and sizing. To optimize the material flows we solve mathematical models linked to the inventory and the transportation of materials that can be consolidated in different types of vehicles. This leads to consider which option is better in order to minimize traveling and inventory costs and diminish materials stored in the construction site and the travelling costs and externalities.

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3. **Scenario 3 – 1 CCC, 1 site, optimization on both echelons**

In scenario 3 we consider only one construction site, that is the pilot site for each city; we consider the introduction of a CCC, and thus the decisions linked to it, that include the location and sizing, and the inventory quantities. In this scenario, we perform the optimization in both echelons, in the first echelon (that is the network among the suppliers, the dumpsites, and the CCC) and the second one. In this case we perform an optimization of material flows by aggregating the material classes and deciding the used vehicles. We also optimize the flows from CCC to site, to consolidate materials in a smaller number of vehicles and minimize the inventory costs and the material storage in the construction sites.

4. **Scenario 4 – no CCC, all construction sites optimization for each supplier/period/material**

In scenario 4 we introduce a new set of possible construction sites in addition to the pilot site. As previously said, we derive the additional sites to real data gathered from the public administration and construction companies of each city. We reproduce each construction site based on their size and type. In this scenario, we do not consider the introduction of a CCC, however we seek to optimize and consolidate the material flows among the various construction sites. This scenario constitutes the **baseline** for the test with several construction sites, and **approximate what could happen in the next three years in the whole city** (if no CCC is introduced).

5. **Scenario 5 – 1 CCC multiple sites, optimization on the 2nd echelon**

In scenario 5 we consider multiple construction sites as said in scenario 4, however we now introduce a CCC, and thus we study its possible location, size, and the needed inventory. In particular, we will focus on solving vehicle routing problems in the second echelon among the construction sites.

6. **Scenario 6 – 1 CCC multiple sites, optimization on both echelons**

In scenario 6 we consider multiple construction sites, the introduction of a CCC and the optimization problems that are linked to it. Moreover, we consider material aggregation and routing optimization problems in both echelons, among construction sites.

The following scenario will be considered only for one pilot site (Paris):

7. **Scenario 7: multiple CCCs – multiple sites – optimization on 2nd echelon**

In scenario 7 we consider multiple construction sites and multiple CCCs. This situation can only be considered in very big urban areas such as Paris. The location and the sizing of multiple CCCs is more challenging, so as the definition of the allocation problem and the inventory considerations. Once all these points

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have been considered we optimize material flows in the second echelon between CCCs to the related construction sites.

8. Scenario 8: multiple CCCs – multiple sites – optimization on 1st and 2nd echelon

In scenario 8, the most complex one, we consider multiple construction sites and multiple CCCs. As in scenario 7, we can state that considering multiple CCCs is relevant only for very large urban areas as the one of Paris, indeed the introduction of multiple CCC can be justified only in that complex environment. In addition, we consider the optimization problems of locating and sizing the CCCs, the related inventory problems, and the allocation problem of suppliers and construction sites to the CCCs. In this scenario, we consider the optimization of material flow in both echelons considering vehicle routing problems and selecting the best vehicle types.

In table 3 we present the pairs of comparisons for the impact analysis:

- scenarios 2 and 3, focusing on introducing a CCC for one construction site, will be compared to the scenario 1 (hypothetical AS-IS situation);
- scenarios 5, 6, 7, and 8, considering multiple construction sites, will be compared with the simplest sub-scenario of Scenario 4 (hypothetical AS-IS situation).

(Hypothetical) AS IS situation (without a CCC)	TO BE situation (with a CCC)
Scenario 1 (As Is)	Scenario 2
Scenario 1 (As Is)	Scenario 3
Scenario 4	Scenario 5
Scenario 4	Scenario 6
Scenario 4	Scenario 7
Scenario 4	Scenario 8

Table 3: Comparison Table.

2.1.2.2 CCC inventory policy

For the **simulation** of the materials deliveries in presence of a CCC, we considered a weekly plan (and delivery) from suppliers to the CCC and a daily plan and delivery from the CCC to the construction sites. The rationale for this choice is that the CCC must deliver the materials to the construction sites only when they are really needed (just-in-time), while the delivery from the supplier

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can optimize the load by aggregating the orders of a week. Some further aggregation from suppliers to CCC, using a longer period, is possible but it will imply a much bigger storage area and will imply to locate the CCCs in areas much bigger than the ones that were suggested from the pilot coordinators for their cities.

We assume that the planning of the deliveries from the suppliers are weekly based. This means that the supplier that adopts some optimization and aggregation policy, deliveries once a week using a single transport performed by several identical vehicles, or more transports with less vehicles. Since we optimize the deliveries, in order to reduce the number of trips, we start by considering heterogeneous vehicles, but we always select the largest one (respecting possible limitations due to the site or to the supplier), provided that the same transport cannot be executed by a smallest. For example, if we have to deliver Q = 60 tons in an urban area where articulated trucks are not allowed to enter, we use a 3 axes truck (with capacity C=16 tons), thus requiring $\lceil 60/16 \rceil$ = 4 trips. If we use only three 3 axes truck it remains to deliver 12 tons (60 – 16 x 3) that require 2 smallest truck, hence more than 4 trips. The trips with the 3 axes truck can be implemented: (i) by 4 trucks performing each one trip; (ii) by 2 trucks performing each 2 trips; (iii) by one truck performing 4 trips; (iv) by 2 trucks performing one trip and 1 truck performing 2 trips etc. The details of exact implementation depend on the operational organization and are outside of the scope of this study.

Concerning the **planning of the deliveries from the CCC to the sites**, since the main activity of the CCC is to consolidate load and to provide Just-In-Time deliveries, we assume that the CCC planning is made on a daily basis. More specifically we suppose that the suppliers send materials to the CCC on a weekly basis and the CCC delivers these materials day-by-day accordingly to the exact requirements of the sites. For the simulation, we assumed that the site requests are linear over the time, so a CCC receives the materials once a week from the suppliers and stores it. Than it sends the materials day by day to the sites, assuming that the aggregated request is divided by 5, the default number of working days per week.

2.1.2.3 Optimization rules by aggregation

The material flows associated with the construction sites have the following main information:

Supplier	Material	Class of material	Quantity	Day	Trip

Each row corresponds to an order, and to a corresponding transport of material (trip). The same material may appear several times in different periods, but also in the same period (different orders for the same material). The class of material, which represent several materials, may appear several times in the same period.

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The optimization of the deliveries may involve several levels:

- aggregation by time;
- aggregation by class and time;
- aggregation by all classes.

Aggregation by time

In the baseline, the material flows are exactly as in the data recorded in the pilot site. It means that the same material can be delivered in more than one day during the same week.

The first optimization consists in an aggregation by week of the orders of the same material. Consider the deliveries of the following table:

Supplier	Material	Class of material	Quantity (Kg)	Day	Trip
Coiver	Completing plasterboard structure and panels	Plaster	3500	3/10/2017	1 trip with a 2 Axes Truck 7.5 Ton
Coiver	Structure + plasterboard panels	Plaster	500	4/10/2017	1 trip with Van / Light Truck
Coiver	Structure + plasterboard panels	Plaster	6500	5/10/2017	1 trip with 2 Axes Truck 7.5T

An immediate aggregation can be done by observing that all the three days are in the same week (week 40), hence we can have the following alternative weekly deliveries, avoiding a trip of a van.

Supplier	Material	Class of material	Quantity (Kg)	Week	Trip
Coiver	Completing plasterboard structure and panels	Plaster	3500	40	1 trip with a 2 Axes Truck 7.5 Ton
Coiver	Structure + plasterboard panels	Plaster	7000	40	1 trip with 2 Axes Truck 7.5T

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In the simulations we assumed, by default, that the deliveries are optimized by time on a weekly basis. The baseline (scenarios 1 and 4) are the only scenarios in which the material flows are delivered as in the pilot records.

Aggregation by class and time

A further aggregation (after the default aggregation by time) is the aggregation by material class. In this case the supplier, or CCC consider the entire set of materials belonging to the same class and aggregate them in the minimum number of deliveries. Using the above example, we have a solution with a single trip, instead that two trips, but with a bigger truck.

Supplier	Material	Class of material	Quantity (Kg)	Week	Trip
Coiver	various	Plaster	10500	40	1 trip with a 3 Axes Truck 16 ton

Aggregation by all classes (and time)

This case is possible only when delivering from the CCC. Indeed, here we consider the possibility to aggregate materials of different classes into a single trip. This choice aggregates materials coming from different suppliers, therefore it cannot be implemented by a single supplier, but only by a CCC. Alternatively, a round trip with pick-ups from several suppliers and delivery to a same site can be considered, but this organization is quite complex and, for our experience, is possible only when the customer (construction site) has enough contractual strength and management resources to organize by itself the pick-ups from the suppliers. For our simulations, we will consider the aggregation of materials from several suppliers, only starting from the CCC.

2.1.3 Simulation models: Output

The simulation output is quite simple and it always consists of plain text files, possibly in CSV format.

Facility location

The XPRESS algorithm implementing the stochastic optimization provides output in the standard output stream. The model has been implemented including a slightly modification of the theoretical model, in order to have some solution also when the problem is not feasible. More precisely, if no CCC has enough capacity to store the expected flows in each of the three scenarios (globally end for each material), then the theoretical model will give no solution at all. In our implementation, we modified the model including a slack variable for the capacity constraints and penalizing these variables in the objective function with

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a large number. This allows to present some solution also when no feasible one exists. In this case the solution indicates with the slack variables the amount of error with respect to the given capacity. This is useful both to have a sub-optimal solution at hand, or to have a value to be used for a possible adjustment of the CCC capacities.

An example of the output is the following. We refer to the Verona case with five possible CCCs.

```
Begin running model
Instance02_XPRESS.dat
Running optimization...
Writing results...
hh =0 obj value = 5.29576e+06 cost = 5.29576e+06 penalty = 0 penalty materials = 0
Writing results...
hh =1 obj value = 6.39377e+06 cost = 6.39377e+06 penalty = 0 penalty materials = 0
Writing results...
hh =2 obj value = 5.26058e+06 cost = 5.26058e+06 penalty = 0 penalty materials = 0
Writing results...
hh =3 obj value = 5.24046e+06 cost = 5.24046e+06 penalty = 0 penalty materials = 0
Writing results...
hh =4 obj value = 4.88364e+06 cost = 4.88364e+06 penalty = 0 penalty materials = 0

optimize full problem ...
Writing results...
 obj value = 4.68882e+06 penalty = 0 0 0 0 0 penalty material= 0 0 0 0 0 open cccs = 1 3 4
End running model
```

The program computes the optimal CCC location for each CCC (hh index from 0 to 4) and gives the optimal expected cost (obj value), the net cost excluding the slack penalties (cost), the slack penalty value (penalty) and the slack penalty value for each material (penalty materials). The costs in the objective function are the material flows, times the distance and a per km cost. The mathematical model can also consider a fixed setup cost for the CCC, but in these simulations, we removed it, leaving the detailed economic considerations to the Cost-Benefit- Analysis. In the example no penalty is reported, so all the CCC location are able to fully satisfy the demand. In the last computation (**optimize full problem**) we consider the optimal CCC location allowing a fixed maximum number of CCCs to be opened. In this case the solution foresees three CCCs (1, 3 and 4) and the objective value decrease from 4.88364e+06, which is the minimum with a single CCC to 4.68882e+06.

Further evaluations on the viability of a solution with multiple CCCs and their set-up costs are left to the user.

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Material flows and deliveries

The output of the simulation consists of a CSV file giving a table of information for each scenario. The table reports in the rows the type of trucks selected for the simulation (see above). In the columns, there are three sections:

- Urban;
- Non urban;
- To CCC.

Sections "urban" and "non urban" report on the trips performed, respectively, inside the city and outside the city. The last section "To CCC" reports the flows from suppliers to the CCC, when a CCC is included in the simulation. When the CCC is not present, the values refer to the materials sent to the construction sites.

The urban section reports the data as in the following example table.

	Urban					
Truck	N. trips	Avg. Trips (D)	Max. Trips (D)	Km	Hours	%Load
Van / Light Truck	380	0.9	16	2386	41	22.8
2 Axes Truck 7.5T	308	0.8	10	2147	32	31
2 Axes Truck 14T	164	0.4	6	1113	14	41.2
3 Axes Truck	1710	4.2	43	12369	138	96.3

For each type of truck, we report the following information, which refer to the overall simulation period:

- **N. trips** = number of trips performed.
- **Avg. Trips (W/D)** = average number of trips per week (W) or day (D).
- **Max Trips (W/D**) = maximum number of trips per week (W) or day (D).
- **Km** = total number of kilometres performed.
- **Hours** = number of hours for traveling (loading and unloading times are not included).
- **%Load** = percentage of the material transported over the truck capacity. This value is the stricter between the percentage load in kilograms and the percentage load in cubic meters.

The non-urban section reports the data as in the following example table.

	Outside city					
	N.trips	Avg.Trips (W)	Max.Trips (W)	Km out.city	Hours	%Load
Van / Light Truck	497	7.8	16	153,563	2076	22.9%
2 Axes Truck 7.5T	270	4.2	15	52,486	761	43.0%
2 Axes Truck 14T	249	3.9	10	44,532	620	51.2%
3 Axes Truck	179	2.8	11	43,514	605	52.9%
Articulated Truck	3035	47.4	317	567,437	7935	72.5%

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In this case the distances refer to the path from the supplier to the border of the city, if no CCC exists, or from the supplier to the CCC. These are the same values of the urban section, but here the averages and maxima are computed over the week beside that over the day. The reason has been explained in 2.1.2.2 where we reported that the material flows form the suppliers are always based on a weekly time horizon. The non-urban trips refers, indeed, to the trips from suppliers to the border of the city or to the CCC.

The "to CCC" section reports the data as in the following example table.

	to CCC			
Truck	**Avg. Kg (W)**	**Max Kg (W)**	**Avg. Mc (W)**	**Max Mc (W)**
Van / Light Truck	2430.54	8981.8	8.79	33.1
2 Axes Truck 7.5T	10896.79	25232.1	12.47	58.6
2 Axes Truck 14T	9860.41	31434.7	14.21	52.7
3 Axes Truck	18968.85	45236.8	233.27	855.0
Articulated Truck	2858.27	75991.9	247.85	782.7

The figures refer to the quantity of the materials transported with each type of truck, during the overall simulation period. These quantities are delivered to the CCC, if the simulation includes a CCC, otherwise are delivered to the construction sites. The values given are:

- **Avg. Kg (W)** = average number of kilograms transported in a Week.
- **Max Kg (W)** = maximum number of kilograms transported in a Week.
- **Avg. Mc (W)** = average number of cubic meters transported in a Week.
- **Max Mc (W)** = maximum number of cubic meters transported in a Week.

2.2 Cost Benefit Analysis

In this section, we present the models and data used to assess the economic benefit, if any, of using a CCC for materials distribution inside the city.

2.2.1 CBA description

The Work Package 4 of the SUCCESS project "WP4 Solutions Design and Test" aims to define and design new scenarios for the whole construction supply chain and its associated logistics in four different pilot sites assessed (Luxembourg, Paris, Valencia and Verona). For this reason, different simulation models were run in order to test the set of scenarios proposed with and without CCCs (Figure 10).

The results of the simulation models representing different scenarios are shown in this deliverable by pilot and by scenario. These simulation models address the optimization of the transport and material flows but they do not cover the economic point of view of the different scenarios. Because of this, a feasibility

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study needs to be done and for this reason, a Cost Benefit Analysis was carried out in each pilot for those scenarios and business models previously selected by the SUCCESS partners (WP3-T3.3 about business models).

A Cost-Benefit Analysis (CBA) is a tool that provides support for decision-making. It provides evidence whereas the project is feasible or not from an economic point of view. For the analysis of the benefits of the implementation of a Construction Consolidation Centre (CCC), two different types of Cost-Benefit Analysis were carried out based on the two main business models identified in the WP3:

- **Business Model 1:** the business model of a CCC operated by the construction company as a cost centre, where the main benefits come from the optimisation and the savings in the core operations of the construction company (i.e. construction activity).
- **Business Model 2**: the business model of a CCC operated by an external operator (public or private) that is managed as a profit centre and in which the revenues come from services provided to the companies of the construction industry.

2.2.1.1 *Pilot Approach – CBA per pilot*

The cities of the SUCCESS project have carried out a Cost-Benefit Analysis based on the simulation results of the previously selected scenarios. In the WP3 the different cities selected those business models more likely to be implemented in their cities. Then, the during the simulation process, the different scenarios were tested in the different cities:

- Paris: SC1, SC2, SC3, SC4, SC5, SC6, SC7 and SC8;
- Luxembourg, Valencia and Verona: SC1, SC2, SC3, SC4, SC5 and SC6.

The following figure summarizes the link between the business models identified in the WP3 and the scenarios selected for each of the cities of the SUCCESS project.

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Pilot	Description	Nb CCC	Duration	CCC operated by	1st echelon managed	2nd echelon managed	Nb Construction Companies	Nb Sites	**Scénario 1** no CCC - 1 site	**Scénario 2** 1 CCC - 1 site optimisation on 2nd echelon	**Scénario 3** 1 CCC - 1 site optimisation on 1st and 2nd echelons	**Scénario 4** no CCC - multiple sites	**Scénario 5** 1 CCC - multiple sites optimization on 2nd echelon	**Scénario 6** 1 CCC - multiple sites optimization on 1st and 2nd echelons	**Scénario 7** multiple CCCs - multiple sites optimization on 2nd echelon	**Scénario 8** multiple CCCs - multiple sites optimization on 1st and 2nd echelons
Luxembourg	Public-Private Agreement (PPP)	1	Temporary	Construction company		X	1	1 (several buildings)		X						
Luxembourg	Promoted by private sector	1	Permanent	Logistics operator		X	Several	Several (<10M€)					X			
Paris	Promoted by private sector	1	Permanent	Construction company	X	X	1	Several						X		
Paris	Promoted by private sector (consortium)	1	Permanent	Logistics operator	X	X	Several	Several						X		
Paris	Promoted by the public sector	1	Permanent	Logistics operator	X	X	Several	Several						X		
Paris	Promoted by private sector		Permanent						N/A							
Verona	Public-Private Agreement (PPP)	1	Permanent	Logistics operator	X	X	Several	Several						X		
Verona	Promoted by private sector	1	Temporary	Construction company	X	X	1	Several						X		
Valencia	Promoted by private sector	1	Temporary	Logistics operator	X	X	1	Several						X		
Valencia	Promoted by private sector	1	Permanent	Construction company	X	X	1	Several						X		
Valencia	Public-Private Agreement (PPP)	1	Permanent	Logistics operator	X	X	Several	Several						X		
Valencia	Promoted by private sector	1	Permanent	Logistics operator	X	X	1	Several						X		

Figure 11. Link between business models and scenarios simulated

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As it can be seen from the previous figure, most of the cities selected the Scenario 6 (i.e. single CCC implementation with transport optimization in both echelons) as the most likely for the implementation of a CCC. Then, the CBA will be carried for the selected scenarios in each city taking into account the two previously mentioned business models:

1. The CCC managed by the construction company;
2. The CCC managed by an external logistics operator.

The two different Cost Benefit Analysis present similarities and are based in the same outputs from the simulation models (e.g. total kilometres, capacity requirements, etc.). Besides, the output of the CBA is the same in both analysis because in both cases the NPV (Net Present Value) is evaluated, which is one of the most commonly used indicators for projects assessment. However, due to the relevant differences in both business models for a CCC implementation, the assumptions taken into account are different in the CBAs done for the two business models identified (CBA of a CCC managed by a construction company and CBA of a CCC managed by an external operator).

The assumptions considered in the CBAs have been agreed among the group of experts of the SUCCESS project, which includes construction companies, research centres and logistics experts. Besides, the state of the art on construction consolidation centres carried out in the WP3 was the baseline for the discussion of the set of assumptions and hypothesis to be considered in the analyses.

2.2.2 CBA of a CCC managed by a Construction Company

In the Business Model 1, the CCC is operated as a cost centre by the construction company (although its operations could be outsourced). The business model from the construction company's point of view allows it to optimise their site operations thanks to the benefits of the CCC (e.g. Just-In-Time deliveries, higher reliability, labour performance improvement, etc.).

In this first case the construction company manages the CCC but the core business is construction activity, being the CCC a cost centre for the company (as any other horizontal department).

The cost structure of this Business Model is composed among others, by the cost of the facility, the fleet, the labour of the CCC and other investments required for the daily operations.

The revenue streams come from the core business (i.e. construction activity) in terms of savings and performance improvement on site.

Regarding the customer segment and its relationships, this business model of the CCC is focused on the construction industry; nevertheless, the daily operations of the facility could be outsourced to specialised logistics operators. The main

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characteristics of this Business Model make this specific case more appropriate for CCCs that only operate for a single construction company (serving one or more sites) and that could operate either on temporary or on permanent basis.

This business model of a CCC is most likely to be implemented by a single construction company for one or several sites and used by several suppliers and/or trade contractors. Because of this, the time framework for the CBA was set in five years. Besides, as a single construction company uses the CCC, the number of sites served by the CCC was also reduced compared to the other business model. Consequently, in the CBA of this particular case, the CCC only serves the construction sites classified as "apartments" in the simulation models, being the rest of construction typologies dismissed in the CBA. This simplification was done because the apartment's buildings are the typology most likely to obtain benefits from the implementation of a CCC. Besides, in the data they were the majority of the future construction sites to be developed in the four pilots.

As previously mentioned, the construction company is in charge of the investments required for the CCC implementation. However, there are no revenues as the construction company is at the same time the client and the promotor of the CCC. Thus, the benefits of the CCC are assessed globally for the construction company by estimating the savings that the CCC brings to the core business (i.e. construction activity).

Inputs of the CBA

The CBA is based on one of the scenarios that were previously shown in Figure 10 and that were selected by the cities participating on the SUCCESS project (Figure 11). Then, the simulation models provided the data needed to carry out the CBA of the specific scenario selected. In this regard, the CBA considers the following outputs from the simulations:

- **Number of construction sites**: this parameter is based on the data provided by the four pilots of the SUCCESS project in which they provided a list of construction projects to be developed in the near future. The list is composed of four types of construction projects that are assigned to each pilot typology: offices (Paris), apartments (Luxembourg), public works (Valencia) and hospital (Verona). In the case of the business model of a CCC managed by a construction company, it was only considered for the CBA the sites with the typology « apartments ».

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					Cost (euro)							
Id ca	Public/Private	Pilot	Lat	Long	2017	2018	2019	start	end	Months	Total Value	Size m^2
2	Private	Luxemburg	39,45472	-0,3993	0	9.416.667	18.833.333	01/07/18	30/11/19	17,0	28.250.000	15.450
4	Private	Luxemburg	39,46057	-0,35221	0	7.788.462	5.711.538	01/04/18	31/05/19	14,0	13.500.000	9.530
5	Private	Luxemburg	39,48172	-0,40168	8.107.143	24.321.429	24.321.429	01/09/17	31/12/19	28,0	56.750.000	42.300
10	Private	Luxemburg	39,44609	-0,37697	0	9.715.263	5.667.237	01/01/18	31/07/19	19,0	15.382.500	9.150
12	Private	Luxemburg	39,44934	-0,36324	0	14.719.258	16.354.732	01/04/18	31/10/19	19,0	31.073.990	19.235
13	Private	Luxemburg	39,44572	-0,37461	4.352.759	5.357.241	0	01/06/17	31/08/18	15,0	9.710.000	8.210
14	Private	Luxemburg	39,46203	-0,38582	0	4.002.540	2.668.360	01/05/18	01/06/19	13,0	6.670.900	3.421
15	Private	Luxemburg	39,46390	-0,39237	0	3.575.398	2.258.146	01/03/18	01/07/19	16,0	5.833.544	3.081
16	Private	Luxemburg	39,45559	-0,37578	0	12.511.871	11.374.429	01/02/18	01/11/19	21,0	23.886.300	11.825
17	Private	Luxemburg	39,46426	-0,35751	0	7.524.079	6.771.671	01/03/18	30/09/19	19,0	14.295.750	5.835
18	Private	Luxemburg	39,46131	-0,33744	6.396.821	3.553.789	0	01/04/17	30/05/18	14,0	9.950.610	5.370

Figure 12. Example of the future projects categorized as apartments (Pilot Luxembourg) selected in Valencia for the Cost Benefit Analysis in the pilot of Valencia.

- **Average daily deliveries per construction site**: this parameter was obtained from the simulations carried out in each scenario and in each pilot. It only considers the deliveries that pass via the CCC. Other deliveries that do not pass through the CCC (e.g. as the concrete) are not considered.
- **Average yearly budget of the construction projects**: this parameter is obtained as the annual average of the ongoing construction projects by pilot. The data was provided by the four pilot sites of the SUCCESS project considering a set of construction projects to be developed in the near future. In this specific case, only were considered the projects classified as « apartments ». Besides, the percentage of the annual budget of the typology "apartments" was used to estimate the material flows of this type of construction. For instance, if the total annual budget of all the building typologies is 100M€ and the annual budget of the typology "apartments" represents the 80% (80M€) then the weekly material flows of the typology "apartments" was set at 80% of the total weekly material flows.
- **Average weekly storage capacity:** this parameter is obtained from the simulations carried out in each scenario and in each pilot.
- **Maximum weekly storage capacity:** this parameter is obtained from the simulations carried out in each scenario and in each pilot.
- **Number of trucks by type:** this parameter is obtained indirectly from the simulations carried out in each scenario and in each pilot. For the estimation of the number of trucks per type, it was considered the average number of daily deliveries, the loading and unloading time, the time needed to access the site and come back to the CCC and finally, the maximum number of daily trips that a truck can do considering the working hours.
- **Annual km of the trucks by type:** this parameter measures the average kilometres travelled per truck and was obtained from the simulations carried out in each scenario and in each pilot.

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Besides, in the Cost Benefit Analysis it was also considered an inflation rate of 1.65% [1](average of the EU28 between 2008-2017) and a discount rate of 5%.

Methodology of the Cost Benefit Analysis* of CCC for Construction Companies *based on simulation results:

The Cost Benefit Analysis is based firstly, in the simulation outputs provided by the simulation models previously explained, and secondly, on a set of assumption for the CCC operations that were discussed among the SUCCESS partners and then validated (when possible) with external sources. Following figure illustrates a schematic of the methodology followed in the CBA for the business model 1 (CCC managed by a construction company).

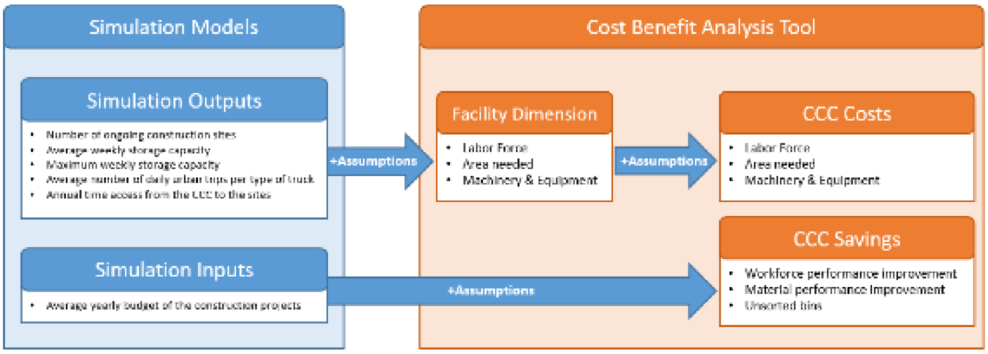

Figure 13. Schematic of the methodology of the CBA for the CCC managed by construction companies.

Outputs from the simulation models:

- Number of ongoing construction sites [units]
- Average yearly budget of the construction projects [€/year]
- Average weekly storage capacity [m^3/week]
- Maximum weekly storage capacity [m^3/week]
- Average number of daily urban trips per type of truck [units]
- Average time access from the CCC to the sites [min]

These outputs of the simulation were used to estimate an average daily and weekly material flows that pass via the CCC.

The materials from the suppliers to the CCC were calculated in the simulation models in m^3/week. Besides, in this business model only the typology "apartments" was considered so that the flows were weighted with the percentage of the budget that represent this building typology compared to the complete set.

Then, the flows (in m^3/week) were used the facility considering that the materials are storage at the CCC for seven days (own assumption). These material flows

[1] Eurostat: inflation rate average in EU28 from 2018-2017

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and the number of daily deliveries were also used to dimension the vehicle fleet and the labour force of the CCC.

Once the facility is dimensioned, the CBA calculates in yearly basis the difference between the incurred cost due to the CCC operations and the potential benefits that the CCC produced thanks to the optimization of the tasks on site. In this regard, the annual budget of the construction project was used to estimate the potential yearly savings that the CCC could bring to the construction company thanks to the logistics optimization. For the estimation of the annual cost, there were considered the cost of the facility, labour force and equipment needed to run the CCC.

Following assumptions were considered for the Cost Benefit Analysis and the CCC dimensioning:

Assumptions for the CCC facility dimensioning

For the dimensioning of the facility area in squared meters (m^2), the following assumptions were considered in order to convert the simulation outputs in terms of the material flows passing through the CCC (m^3/week) into the total squared meters (m^2) needed for the facility dimensioning. For this estimation, it was considered an average height of the cargo of 1.2m. Then, there were considered other hypothesis for the dimensioning of the total area needed of the facility such as the number of shelves, the percentage of stackable materials, average stock time, etc.

- Average stock time in the CCC [Days]
- Percentage of the total materials storage in shelves [%]
- Average Height of the cargo [m]
- Storage levels of shelves in the CCC [Nº of Shelves]
- Daily average storage occupancy [%]
- Ratio corridors/stacking area surface [dimensionless]
- Space for Loading/Unloading operations [%]
- Space for other common areas [%]

For more information about the assumptions considered in the analysis, a complete description of the assumptions is in Annex 1.

The final result is an estimated value of the overall surface needed for the CCC expressed in m^2 including corridors, common areas, loading and unloading operations, etc.

Assumptions for the CCC fleet dimensioning

For the dimensioning of the CCC fleet there were considered the following outputs of the simulation:

- Average number of daily urban trips per type of truck [units]
- Annual time access from the CCC to the sites [min]

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In case of the average number of trips was not an integer number, the highest integer was considered to estimate the number of vehicles (e.g. 0.2 trips/day → 1 trip/day).

For the calculation of the average number of trucks needed per type, the following assumptions were considered for the fleet dimensioning.

- Operational hours per day in the CCC [h]
- Average time needed for unloading trucks [min]
- Average time needed for loading trucks [min]

These set of assumptions and the time needed to access the site from the CCC and come back to the centre (output of the simulation) allowed us to estimate the round-trip time. Considering the round-trip time and the average number of daily trips per type of vehicle (simulation output), it was possible to dimension the fleet of the CCC.

For more information about the assumptions considered in the analysis, a complete description of the assumptions is in Annex 1.

Assumptions for the CCC operations dimensioning

For the dimensioning of the CCC operations (labour force and equipment), the following assumptions were considered in order to estimate the requirements for the CCC loading/unloading and storage operative.

- Labor force working hours per day [hours/day]
- Average time Needed for unloading trucks [min]
- Average time Needed for loading trucks [min]
- Average personnel needed for unloading trucks [operator/s]
- Average personnel needed for loading trucks [units]
- Average forklifts needed for unloading trucks [units]
- Average forklifts needed for loading trucks [units]
- Average pallet trucks needed for unloading trucks [units]
- Average pallet trucks needed for loading trucks [units]

These set of assumptions and the average number of daily deliveries (output of the simulation) allowed us to estimate the total number of forklifts and pallet trucks needed at the CCC but also to estimate the dimensioning of the labor force needed for the CCC operations. In this regard, for the loading/unloading operations it was fixed the time, the machinery and the personnel needed to perform each operation. Then, the material flows and the number of deliveries allowed estimating the requirements in terms of personnel and equipment needed for each scenario.

In addition, for running the CCC is needed other personnel and equipment that cannot be calculated from simulation outputs such as the manager or administrative staff needed. In those cases, the necessary staff for the CCC was set manually case by case based on the partners' experience.

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- Manager [units]
- Drivers [units]
- Other personnel [units]
- Housekeeping & Repacking Operations inside CCC [operator/s]

In addition, some machinery needed for the CCC operations was set manually case by case for those equipment and tasks that cannot be calculated directly from the simulation outputs.

- Housekeeping & Repacking Operations (Forklifts) [units]
- Housekeeping & Repacking Operations (Pallet Trucks) [units]

The estimation of the equipment and labor force needed in the different scenarios was done taking into account the total material flows and the benchmark carried out in the deliverable D3.3 of the WP3 that included a state of the art of CCCs in Europe.

Assumptions for the estimation of CCC cost and potential benefits of the CCC

In the Business Model 1 (CCC managed by the construction company), for the assessment of the potential feasibility of a CCC is needed to estimate the benefits and savings that the facility could produce in the main core business of the construction company (i.e. the construction activity). Thus, based on the average annual budget of all the ongoing construction projects, following assumptions were considered to quantify the annual savings that the CCC implementation could produce annually in the construction projects.

- Average labor force costs [%]
- Labor force productivity improvement [%]
- Average material cost [%]
- Reduction of material wasted, damaged and stolen [%]
- Reduction of material acquisition cost [%]
- Cost of Unsorted Bins [%]
- Cost Reduction of Unsorted Bins [%]

Example of the calculation of the annual potential savings thanks to the CCC operations:

- *Total annual budget of the ongoing projects* → *10M€/year*
- *Average labor force cost [30%]* → *3M€/year*
- *Labor force productivity improvement [5%]* → *150.000€/year*

Thus, a CCC implementation could bring a potential saving of 150.000€/year thanks to the improvement of the labor force performance on site.

The savings of the rest of inputs were calculated in the same manner.

The average value of these assumptions was discussed among the members of the SUCCESS project and set according to our measurements and calculations.

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For more information about the assumptions considered in the analysis, a complete description of the assumptions is in Annex 1.

For the cost structure of the CCC, there were considered two types of cost: implementation cost and operational cost.

Implementation cost:

The implementation cost includes in one side, a fixed cost for the CCC project implementation in the beginning of the project and in the other side, the purchase cost of the machinery (pallet trucks and forklifts). Besides, a renovation of the pallet trucks was considered in year five due to their shorter lifespan (5 years). These costs remained constant for all the CBA done in the different pilots and scenarios.

- CCC facility project & Implementation [€]
- Forklifts [€/unit]
- Pallet trucks [€/unit]

Operational cost:

The operational costs include all the cost needed for running the CCC such as the personnel, tucks, etc. In this case, the value of some assumptions was fixed for all the pilots (e.g. truck leasing costs). However, other cost such as the personnel cost and the facility rental were set pilot by pilot due to the important differences between the cities.

In reference to the cost of the trucks, as the construction company manages the CCC as a cost center, it was assumed a monthly renting for the trucks. The renting costs vary depending on the truck size but were considered constant for all the pilot cases.

- 25t - 3 Axes Truck Costs: Average Cost per unit [€/month]
- 14t - 2 Axes Truck Costs: Average Cost per unit [€/month]
- 7.5t - 2 Axes Truck Costs: Average Cost per unit [€/month]
- Van/Light Truck Costs: Average Value per unit [€/month]

In other cases, due to the important difference between the countries, some other assumption of the CCC cost structure were considered pilot by pilot (e.g. personnel cost or the rental price in €/m2/month). Following table summarizes the cost of the different pilots:

Cost	Luxembourg	Paris	Valencia	Verona
Manager [€/year]	47.918	58.800	50.000	67.500
Logistic Operator [€/year]	38.786	28.200	25.000	48.500
Driver [€/year]	35.229	44.400	38.000	46.500
Administrative & Technical Staff [€/year]	39.000	38.400	35.000	52.500
Rental Price [€/m2/month]	12,0	8	4,0	5,3

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The cost of the general expenses of the CCC and the maintenance costs were set as a fixed percentage of the total rental costs of the facility.

- General expenses of the CCC [% of the monthly rent]
- Maintenance cost of the CCC [% of the monthly rent]

The percentage is constant in all the pilots but the monthly costs vary in the different scenarios due to the different dimensioning in each case.

For the estimation of the transport cost in urban areas, it was used the software ACOTRAM. ACOTRAM is a free software of the Spanish ministry of transport that allows estimating the transport costs per kilometers by introducing a set of hypothesis. These costs include spare parts, fuel consumption, insurances, etc. The driver and the renting costs were not included in the transport cost because they are already considered separately in the analysis.

As the transport costs depends on the cost of the fuel, they were calculated separately for the four pilots based on the fuel cost of each of them. Following table illustrates the diesel cost of the four pilots:

Cost	Luxembourg	Paris	Valencia	Verona
Diesel Price [€/l]	1,06	1,40	1,25	1,41

In conclusion, the dimensioning of labor force, the machinery and the estimation of the implementation and operational cost allowed us to define the cost structure of the CCC and its potential savings based on the simulation outputs. Thus, to carry out a CBA for the feasibility assessment of the different scenarios.

2.2.3 CBA of a CCC managed by a Logistics Operator

In the Business Model 2, the CCC operates as a profit centre and it is managed and operated by a logistics operator, being the construction companies the users of the CCC that contract the services offered (e.g. delivery management, storage, material repacking, etc.). The construction company pays for the CCC services and benefits in terms of cost savings in the construction activity thanks to CCC operations. On the contrary, the logistics operator gets revenues from the services that provides to the construction companies but also to contractors and suppliers.

From the point of view of the construction company, the fewer control of the supply chain in this business case, thus less potential savings compared to the previous one, and the payment for the CCC services, makes this business model less profitable for the construction company but also less risky than the first one.

From the point of view of the CCC operator, as it manages the CCC and the construction company is the client, this CCC can work for several companies and trade contractors simultaneously. For this reason, this specific business model

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is recommended to work on permanent basis with several clients in order to benefit from economies of scale.

In this business case, the CBA has been assessed from the point of view of the Logistics Operators for a 10 years period. The logistics operator manages the CCC and is responsible of the investments required (e.g. vehicle fleet, labour force, etc.) and get incomes from the services provided to the companies of the construction industry.

Inputs of the CBA

Following the same approach than in the case of the CBA of the CCC managed by the construction company, the CBA of the logistics operator is also carried out for one of the scenarios that were previously shown in Figure 10 and that were selected by the cities participating on the SUCCESS project (Figure 11). Consequently, the simulation models provided the data needed to carry out the CBA of the scenario selected.

The outputs from the simulation models are the key inputs for the Cost Benefit Analysis because they allow the dimensioning of the facility and the estimation of the material flows and revenues of the CCC. In the business case of a CCC managed by a logistic operator, the outputs used to carry out the CBA are the same than in the business model of the construction companies. These outputs are listed below and there are described only in the case that they vary compared to previous CBA for construction companies.

- **Number of construction sites**: this parameter varies slightly from the previous CBA because it considers all the building typologies that are assigned to different pilots: offices (Paris), apartments (Luxembourg), public works (Valencia) and hospital (Verona) and not only the typology "apartments" as in the previous CBA. The parameter is based in the data provided by the four pilot sites of the SUCCESS project in which they provided a list of construction projects to be developed in the near future.
- **Average yearly budget of the construction projects:** This parameter is not considered in this CBA because in this business model a logistic operator manages the CCC and its main business is to provide services to the construction industry. The logistics operator considers the CCC as a profit centre and gets revenues from the services provided to the construction companies. This business case focuses in the profitability of the CCC itself, considering the costs and the revenues. It does not estimate the potential savings for the construction companies.
- **Average daily deliveries per construction site.**
- **Average weekly storage capacity**.
- **Maximum weekly storage capacity.**
- **Number of trucks by type.**
- **Annual km of the trucks by type.**

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Besides, in the Cost Benefit Analysis it was also considered an inflation rate of 1.65% [1](average of the EU28 between 2008-2017) and a discount rate of 5%.

					Cost (euro)							
ID	Public/Private	Pilot	Lat	Long	2017	2018	2019	start	end	Months	Total Value	Size m^2
1	Private	Paris	39,47322	-0,36743	14.000.000	21.000.000	0	01/07/17	30/09/18	15,0	35.000.000	15.000
2	Private	Luxemburg	39,45472	-0,3993	0	9.416.667	18.833.333	01/07/18	30/11/19	17,0	28.250.000	15.450
3	Public	Valencia	39,49753	-0,40825	3.015.444	861.556	0	01/06/17	28/02/18	8,9	3.877.000	44.500
4	Private	Luxemburg	39,46057	-0,35221	0	7.788.462	5.711.538	01/04/18	31/05/19	14,0	13.500.000	9.530
5	Private	Luxemburg	39,48172	-0,40168	8.107.143	24.321.429	24.321.429	01/09/17	31/12/19	28,0	56.750.000	42.300
6	Public	Valencia	39,48791	-0,35567	0	3.448.852	0	01/01/18	30/10/18	10,0	3.448.852	21.170
7	Public	Verona	39,48394	-0,39092	34.509.091	63.709.091	47.781.818	01/06/17	30/09/19	28,0	146.000.000	64.407
8	Private	Paris	39,48495	-0,39652	0	45.000.000	45.000.000	01/01/18	31/12/19	24,0	90.000.000	64.500
9	Public	Valencia	39,46897	-0,39149	2.625.000	4.375.000	0	01/07/17	30/10/18	16,0	7.000.000	16.736
10	Private	Luxemburg	39,44609	-0,37697	0	9.715.263	5.667.237	01/01/18	31/07/19	19,0	15.382.500	9.150
11	Public	Valencia	39,44927	-0,37839	3.347.434	0	0	01/01/17	31/12/17	12,0	3.347.434	69.925
12	Private	Luxemburg	39,44934	-0,36324	0	14.719.258	16.354.732	01/04/18	31/10/19	19,0	31.073.990	19.235
13	Private	Luxemburg	39,44572	-0,37461	4.352.759	5.357.241	0	01/06/17	31/08/18	15,0	9.710.000	8.210
14	Private	Luxemburg	39,46203	-0,38582	0	4.002.540	2.668.360	01/05/18	01/06/19	13,0	6.670.900	3.421
15	Private	Luxemburg	39,46390	-0,39237	0	3.575.398	2.258.146	01/03/18	01/07/19	16,0	5.833.544	3.081
16	Private	Luxemburg	39,45559	-0,37578	0	12.511.871	11.374.429	01/02/18	01/11/19	21,0	23.886.300	11.825
17	Private	Luxemburg	39,46426	-0,35751	0	7.524.079	6.771.671	01/03/18	30/09/19	19,0	14.295.750	5.835
18	Private	Luxemburg	39,46131	-0,33744	6.396.821	3.553.789	0	01/04/17	30/05/18	14,0	9.950.610	5.370
19	Public	Valencia	39,47455	-0,3754	0	2.894.595	3.055.405	01/04/18	30/11/19	20,0	5.950.000	7.360
20	Public	Valencia	39,44557	-0,39429	3.604.440	0	0	01/01/16	31/12/16	12,0	3.604.440	36.778
21	Public	Paris	39,45840	-0,33664	2.726.975	0	0	01/01/17	31/10/17	10,0	2.726.975	4.200
22	Public	Paris	39,46454	-0,38211	3.250.250	506.200	0	01/01/17	31/03/18	15,0	3.756.450	2.680

Figure 14. Example of the future projects selected for the Cost Benefit Analysis in Valencia.

Methodology of the Cost Benefit Analysis of a CCC for logistics operators *based on simulation results:*

In the same way than for the CBA of the construction companies, the Cost Benefit Analysis is based in the simulation outputs and in a set of assumption for the CCC operations that were discussed among the SUCCESS partners and then validated (when possible) with external sources. Following figure illustrates the methodology followed in the CBA of the business model 2.

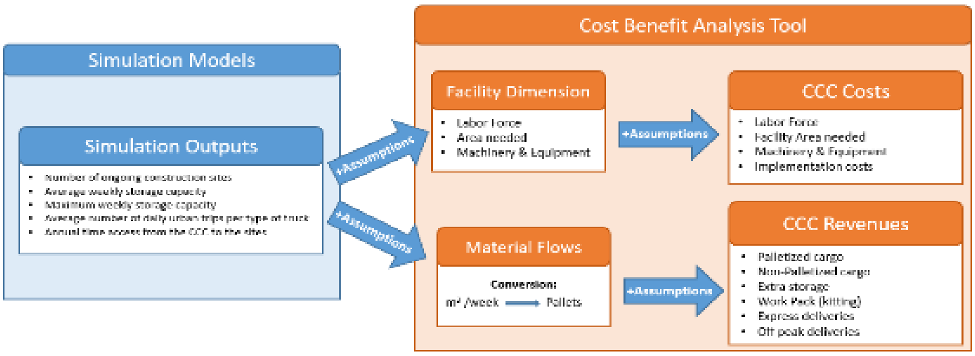

Figure 15. Schematic of the methodology of the CBA for the CCC managed by logistics operator.

Outputs from the simulation models:

- Number of ongoing construction sites [units]
- Average daily deliveries per construction site [units]

[1] Eurostat: inflation rate average in EU28 from 2018-2017

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- Average weekly storage capacity [m^3/week]
- Maximum weekly storage capacity [m^3/week]
- Average number of daily urban trips per type of truck [units]
- Average time access from the CCC to the sites [min]
- Average distance from the CCC to the sites [km]

These outputs of the simulation were used to estimate an average daily and weekly material flows that pass via the CCC.

The materials from the suppliers to the CCC were calculated in the simulation models in m^3/week. Then these flows (in m^3/week) were used to dimension the facility considering that the materials are storage at the CCC for seven days (own assumption). These material flows and the number of daily deliveries were also used to dimension the vehicle fleet and the labour force of the CCC.

Once the facility is dimensioned, the CBA calculates in yearly basis the difference between the incurred cost due to the CCC operations and the revenues of the CCC due to the services provided to the construction industry. In this regard, the material flows in m^3/week are converted into different unit prices from where the CCC gets revenues (e.g. from m^3 to pallets and then from pallets to euros).

For more information about the assumption considered in the analysis, a complete description of the assumptions is in Annex 2.

For the annual cost estimation, there were considered the cost of the facility, labor force and equipment needed to run the CCC.

Following assumptions were considering for the Cost Benefit Analysis and the CCC dimensioning:

Assumptions for the CCC facility dimensioning

In the same way than in the previous business model for the dimensioning of the facility area in squared meters (m^2), the following assumptions were considered for the conversion of the simulation outputs (material flows passing through the CCC in m^3/week) into the total squared meters (m^2) needed for the facility dimension:

- Average stock time in the CCC [Days]
- Percentage of the total materials storage in shelves [%]
- Average Height of the cargo [m]
- Storage levels of shelves in the CCC [N° of Shelves]
- Daily average storage occupancy [%]
- Ratio corridors/stacking area surface [dimensionless]
- Space for Loading/Unloading operations [%]
- Space for other common areas [%]

Firstly, the weekly material flows (simulation outputs) were converted into squared meters based on the percentages of palletized and non-palletized

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cargo and an average height of 1.2m. The size of the Standard Euro-pallet (1200mmx800mm) was considered for the palletized cargo.

Besides, to dimension the total area needed of the facility there were assumed other hypothesis such as the number of shelves, the percentage of stackable pallets, the average stock time, space dedicated for loading/unloading operations and common areas, etc.

In this manner, it was possible to quantify the space requirements of the different areas of the CCC (storage, corridors, loading/unloading operations, etc.).

For more information about the assumption considered in the analysis, a complete description of the assumptions is in Annex 2.

The final result is an estimated value of the overall surface needed for the CCC expressed in m^2 including corridors, common areas, loading and unloading operations, etc.

Assumptions for the CCC fleet dimensioning

For the dimensioning of the CCC fleet there were considered the following outputs of the simulation:

- Average number of daily urban trips per type of truck [units]
- Annual time access from the CCC to the sites [min]

In case of the average number of trips was not an integer number, the highest integer was considered to estimate the number of vehicles (e.g. 0.2 trips/day → 1 trip/day).

For the calculation of the average number of trucks needed per type, the following assumptions were considered for the fleet dimensioning.

- Operational hours per day in the CCC [h]
- Average time needed for unloading trucks [min]
- Average time needed for loading trucks [min]

These set of assumptions and the time needed to access the site from the CCC and come back to the centre (output of the simulation) allowed us to estimate the round-trip time. Considering the round-trip time and the average number of daily trips per type of vehicle (simulation output), it was possible to dimension the fleet of the CCC.

For more information about the assumption considered in the analysis, a complete description of the assumptions is in Annex 2.

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Assumptions for the CCC operations dimensioning

For the dimensioning of the CCC operations (labour force and equipment), the following assumptions were considered in order to estimate the requirements for the CCC loading/unloading and storage operative.

- Labor force working hours per day [hours/day]
- Average time needed for unloading trucks [min]
- Average time needed for loading trucks [min]
- Average personnel needed for unloading trucks [operator/s]
- Average personnel needed for loading trucks [units]
- Average forklifts needed for unloading trucks [units]
- Average forklifts needed for loading trucks [units]
- Average pallet trucks needed for unloading trucks [units]
- Average pallet trucks needed for loading trucks [units]

These set of assumptions and the average number of daily deliveries (output of the simulation) allowed us to estimate the total number of forklifts and pallet trucks needed at the CCC but also to estimate the dimensioning of the labour force needed for the CCC operations. In this regard, for the loading/unloading operations it was fixed the time, the machinery and the personnel needed to perform each operation. Then, the material flows and the number of deliveries allowed estimating the requirements in terms of personnel and equipment.

In addition, for running the CCC is needed other personnel and equipment that cannot be calculated from simulation outputs such as the manager or administrative staff needed. In those cases, the necessary staff for the CCC was set manually case by case based on the partners' experience and the state of the art of CCCs done in WP3.

- Manager [units]
- Drivers [units]
- Other personnel [units]
- Housekeeping & Repacking Operations inside CCC [operator/s]

Same as before, some machinery needed for the CCC was set manually case by case for those equipment and operations that cannot be calculated directly from the simulation outputs.

- Housekeeping & Repacking Operations (Forklifts) [units]
- Housekeeping & Repacking Operations (Pallet Trucks) [units]

The estimation of the equipment and labour force needed in the different scenarios was done taking into account the total material flows and the benchmark carried out in the deliverable D3.3 of the WP3 that included a state of the art of CCCs in Europe.

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Assumptions for the estimation of the CCC costs

In the feasibility assessment of the Business Model 2 (CCC managed by the logistics operator), it is needed to estimate in one side, the revenues and in the other side, the cost of the CCC operations.

For the cost structure of the CCC, there were considered two types of cost: implementation cost and operational cost.

<u>Implementation cost:</u>

The implementation cost includes in one side, a fixed cost for the CCC project implementation in the beginning of the project and in the other side, the purchase cost of the machinery (pallet trucks and forklifts) and vehicles. Besides, a renovation of the pallet trucks was considered in year five due to their shorter lifespan considered (5 years). These costs remained constant for all the CBA done in the different pilots and scenarios.

- CCC facility project & Implementation [€]
- Forklifts [€/unit]
- Pallet trucks [€/unit]
- 25t - 3 Axes Truck Costs: Average Cost per unit [€]
- 14t - 2 Axes Truck Costs: Average Cost per unit [€]
- 7.5t - 2 Axes Truck Costs: Average Cost per unit [€]
- Van/Light Truck Costs: Average Value per unit [€]

For more information about the assumptions taken into account in the CBA of the CCC managed by a logistics operator, check the Annex 2.

In other cases, the cost variation between countries was important, so some assumption of the CCC cost structure were considered pilot by pilot such as the personnel cost or the rental price in €/m2/month.

<u>Operational cost:</u>

The operational costs include the all the cost needed for running the CCC (e.g. personnel). In this case, the value of some assumptions was fixed for all the pilots (e.g. truck purchasing costs). However, other cost such as the personnel cost and the facility rental were set pilot by pilot due to the important differences between the cities.

In reference to the cost of the trucks, as the logistics operator manages the CCC as a profit centre, it was assumed a truck fleet acquisition in the beginning of the project implementation. The truck acquisition costs vary depending on the truck size but were considered constant for all the pilot cases.

In reference to other assumptions, due to the important variation between the countries, some other were considered pilot by pilot (e.g. personnel cost or the

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rental price in €/m2/month). Following table summarizes the cost of the different pilots:

Cost	Luxembourg	Paris	Valencia	Verona
Manager [€/year]	47.918	58.800	50.000	67.500
Logistic Operator [€/year]	38.786	28.200	25.000	48.500
Driver [€/year]	35.229	44.400	38.000	46.500
Administrative & Technical Staff [€/year]	39.000	38.400	35.000	52.500
Rental Price [€/m2/month]	12,0	8	4,0	5,3

The cost of the general expenses of the CCC and the maintenance costs were set as a fixed percentage of the rental costs of the facility.

- General expenses of the CCC [% of the monthly rent]
- Maintenance cost of the CCC [% of the monthly rent]

These percentages are constant in all the pilots. However, as the facility monthly costs depend on the facility dimensioning (different scenarios assessed, thus different dimensioning in each case) the final costs also vary pilot by pilot.

For the estimation of the transport cost in urban areas, it was used the software ACOTRAM. ACOTRAM is a free software of the Spanish ministry of transport that allows estimating the transport cost per kilometer travelled by introducing a set of hypothesis.

In the case of the CCC managed by a logistics operator, the trucks are acquired (assumption of this business model) in year one of the CBA. In this case, the transport costs consider spare parts, fuel consumption, insurances, taxes etc. The driver and the purchasing costs were not included in the calculation of the transport cost because they were already considered separately in the analysis.

The transport costs depend in the cost of the fuel, so they were calculated separately for the four pilots based on the fuel cost of each of them. Following table illustrates the diesel cost of the four pilots:

Cost	Luxembourg	Paris	Valencia	Verona
Diesel Price [€/l]	1,06	1,40	1,25	1,41

In conclusion, the dimensioning of labor force, the machinery and the estimation of the implementation and operational cost allowed us to define the cost structure of the CCC based on the simulation outputs. Thus, to carry out a CBA in order to assess the feasibility of the different scenarios.

For more information about the assumptions taken into account in the CBA of the CCC managed by a logistics operator, check the Annex 2.

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Assumptions for the estimation of CCC revenues

For the estimation of the CCC revenues, the main objective was to convert the outputs of the simulation into some quantitative variables. Thus, the solution adopted was convert the material flows (m3/week) into units of standard pallets (euro-pallet size was considered as the standard one).

Following assumptions were considered to convert the material flows (m3/week) into units of standard pallets (euro pallet size) and non-palletized cargo.

- Percentage of Palletized Cargo [%]
- Average Height of the Cargo [m]

In the analysis, there were also considered percentages of non-standard pallets.

- % of daily Standard Pallets Moved [%]
- % of daily Standard & Non-Stackable Pallets Moved [%]
- % of daily Non-Standard & Non-Stackable Pallets Moved [%]

Besides, the CCC provides other services to the construction industry (e.g. kitting, off peak deliveries, etc.), so other types of variables were considered as a percentage of the daily pallets moved in order to estimate the total incomes of the CCC:

- % of daily Work Packs Prepared as a % of Daily Pallets moved;
- % of Units Extra-stored 1 week as a % of Daily Pallets moved;
- % of Units Extra-stored 2 weeks as a % of Daily Pallets moved;
- % of Units Extra-stored 1 Month as a % of Daily Pallets moved;
- % of Daily Express Deliveries as a % of Daily Pallets moved;
- % of Daily Off-Peak Deliveries as a % of Daily Pallets moved.

Then, once there were defined the number of units of all the different quantitative variables, there were assigned the prizes per unit moved.

The prize per m^3 or pallet moved includes the loading/unloading operations and one-week storage in the CCC

- Price per Standard Pallet Moved [Euros/pallet]
- Price per Standard & Non-Stackable Moved [Euros/pallet]
- Price per Non-Standard & Non-Stackable Pallet Moved [Euros/pallet]
- Price per Non-Palletized Units Moved [Euros/m3]

In addition, there were also considered prizes for the other services provided by the CCC:

- Price per Working Pack done [€/WP]
- Rental Space for pre-construction activity [m2]
- Rental Price per m2 for pre-construction activity [€/week/m2]
- Average Occupancy Rate of space for pre-construction activity [%]

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- Price per Unit Extra-Stored 1 week [€/m3]
- Price per Unit Extra-Stored 2 weeks [€/m3]
- Price per Unit Extra-Stored 1 month [€/m3]
- Price per Express Delivery [€/Delivery]
- Price per Off-Peak Delivery [€/Delivery]

Example of the calculation of the incomes of the CCC:

- *Total daily material moved (simulation output)* → *115.2m³*
- *% of palletized cargo [80%]* → *92.16m³*
- *Average height of the cargo (1.2m)* → *76,8m²*
- *Euro-pallet size (1200x800mm)* → *80 Pallets*
- *% of standard pallets [50%]* → *40 pallets*
- *Prize per standard pallet moved [10€/pallet]* → *400€*

Thus, the CCC gets 400€ per day in standard pallets moved.

The incomes of the rest of the services are calculated in the same manner.

For more information about the assumptions taken into account in the CBA of the CCC managed by a logistics operator, check the Annex 2.

In summary, the methodology followed in this business model allowed us, firstly, to dimensioning the facility in terms of labor force, machinery, implementation and operational cost. Thus, the cost structure of the CCC.

Secondly, the output of the simulation in terms of material flows allowed us to estimate the revenues of the CCC services by converting this output (m^3/week) into quantitative variables. Consequently, we are able to carry out a CBA for the feasibility assessment of the different scenarios where the CCC is managed by a logistics operator.

2.2.4 CBA output

The results of the Cost-Benefit Analysis for the different pilots and scenarios assessed are expressed in terms of the Net Present Value. The economic NPV was calculated by discounting the difference between costs and benefits back to the present. This value indicates how much the investment has increased after recovering their initial expending. NPV is calculated using the following formula:

$$NPV = -I_o + \sum_{j=1}^{n} \frac{Fj}{(1+r)^j}$$

Where F_j is flow of net benefits (benefits – costs) for t = j; I_o is the investment in t = 0; r is the discount rate and n is the time horizon or lifespan of the project (10 years in the case of the CCC managed by the logistics operator and 5 in the case of the construction companies).

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NPV is one of the most commonly used measures to decide whether or not to go ahead with a project. A project is profitable for an investor if NPV is greater than zero. Therefore, the decision-making rule is as follows:

NPV > 0 ⇒ Profitable Project (go-ahead recommended);

NPV < 0 ⇒ NON Profitable Project (should be rejected);

NPV = 0 ⇒ Going ahead with the project would yield the same return as the alternative that was used to calculate the opportunity cost.

Year	ALTERNATIVE 2 CCC	ALTERNATIVE 2. Using CCC											TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
		Additional Cost of CCC					Savings			CCC Summary			
	INVESTMENTS (EUROS)	Facility Rent Costs (€)	Workforce Costs (€)	General expenses CCC (€)	Transport Costs (€)	Maintenance Costs (€)	Labor Force Savings [€/year]	Material Savings [€/year]	Unsorted Bins [€/year]	TOTAL ANNUAL COSTS	TOTAL ANNUAL SAVINGS	BENEFITS	
1	**217.000**	355.560	555.000	35.556	266.200	6.000	1.614.777 €	1.255.938 €	254.919 €	**1.218.316 €**	**3.125.634 €**	**1.907.318 €**	**1.690.318**
2	**0**	362.671	566.100	36.267	271.524	6.120	1.647.072 €	1.281.056 €	260.018 €	**1.242.682 €**	**3.188.147 €**	**1.945.465 €**	**1.945.465**
3	**0**	369.925	577.422	36.992	276.954	6.242	1.680.014 €	1.306.678 €	265.218 €	**1.267.536 €**	**3.251.910 €**	**1.984.374 €**	**1.984.374**
4	**0**	377.323	588.970	37.732	282.493	6.367	1.713.614 €	1.332.811 €	270.523 €	**1.292.886 €**	**3.316.948 €**	**2.024.062 €**	**2.024.062**
5	**-13.200**	384.870	600.750	38.487	288.143	6.495	1.747.887 €	1.359.467 €	275.933 €	**1.318.744 €**	**3.383.287 €**	**2.064.543 €**	**2.077.743**

Figure 16. Example of the CBA output of the business model of a CCC managed by a Construction Company

Moreover, in the case of the business model of a CCC managed by a construction company, it was also estimated the percentage of benefits compared to the annual budget of all the construction sites that a CCC could bring to the company if they decide to implement a CCC.

Finally, a sensitivity analysis (see Annex 3) was done in order to assess the variability of the Cost Benefits Analyses carried out for the two business models evaluated (CCC managed by a construction company and CCC managed by a logistics operator).

For the sensitivity analyses, there were used the average values of the simulation outputs of the four pilots in terms of material flows, trucks needed, budget, etc. Besides, the assumptions concerning the costs were also averaged (personnel costs, rental, etc.).

The sensitivity analyses help to understand which are the most important parameters and inputs in each of the business models assessed. Thus, they help decision makers to focus on those inputs that are most relevant for the success of the CCC.

It is important to notice that the values obtained from the CBA are estimations based on a set on assumptions that may vary depending on the city and sites characteristics. Thus, the CBA tool provides a useful estimation that the potential benefits that a CCC could bring but it must be followed by more detailed and tailored analysis for the specific CCC case.

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2.3 Assessment of environmental impact of simulated scenarios

For each of the scenarios simulated in every pilot city, indicators have been computed, to assess the environmental impact of transport, mainly due to the combustion of fuel in trucks thermal engines. The emissions assessed are the following:

- Particle matters (PM2.5 & PM10);
- Nitrogen oxides (NOx) and carbon monoxide (CO);
- Greenhouse gases (mainly CO2).

The computation is done using the following input data:

- The number of kilometers made by each category of trucks to operate 1st and 2nd echelon deliveries, both outside and inside the cities.
- A series of assumptions made about:
  - For each truck category, the actual truck mix: Euro class, fuel type, using:
    - the data available in COPERT for each country;
    - or what-if analysis;
  - The share of kilometers made during peak hours / off-peak hours;
  - The average speed of trucks used for deliveries.

For each scenario simulated, a series of assumptions will be made about some key drivers to emissions which are not part of the simulation variables or parameters, like the type of fuel used by trucks or their Euro class.

Cumulated emissions will be calculated for the whole simulation perimeter and timespan.

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  - the data available in COPERT for each country;
  - or what-if analysis;

o The share of kilometres made during peak hours / off-peak hours;

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- The average speed of trucks used for deliveries.

For each scenario simulated, a series of assumptions will be made about some key drivers to emissions which are not part of the simulation variables or parameters, like the type of fuel used by trucks or their Euro class.

Cumulated emissions will be calculated for the whole simulation perimeter and timespan.

2.4.1 Emissions computation process

The emissions have been computed using the COPERT software, that we are going to describe in the next section.

2.4.1.1 COPERT tool

COPERT is a software program, supported by the European Environmental Agency (EEA), developed as a European tool for the calculation of emissions from the road transport sector. The emissions calculated include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation, etc.). Energy consumption and GHG emissions are also computed. COPERT is published with national up to date databases describing most EU national vehicle fleets, from personal cars to heavy duty vehicles.

In order to compute energy consumption and emissions, COPERT uses:

- **truck characteristics**: category and number of axles, Euro class, fuel type, but also load factor (by default, a 50% load is assumed);
- **driving conditions**, distinguishing between highway, rural and urban, with a further distinction between peak and off-peak kilometres. They impact the average speed of vehicles, which influences the emissions per km. COPERT can also include input regarding the use of A/C;
- **country-specific parameters**, like average monthly outdoor temperatures.

There are more parameters that the tool can use to compute countrywide vehicle emissions, but they are not relevant to the SUCCESS framework.

2.4.1.2 Using the COPERT tool to assess the environmental KPIs

The following diagram summarizes the processing done before running the COPERT tool.

Note that the urban and non-urban shares will be assumed to be identical for all journeys of each echelon.

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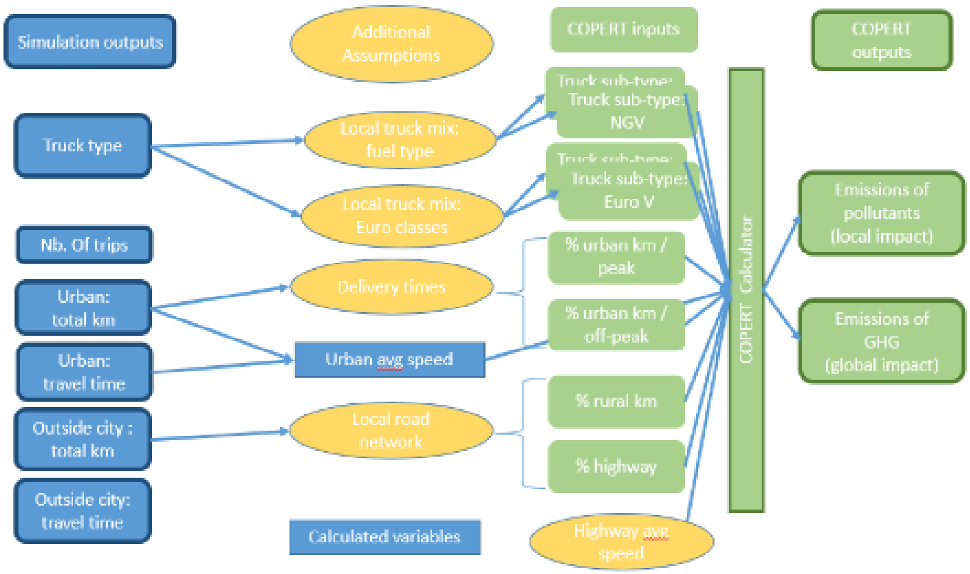

Figure 17: Diagram of environmental post-simulation computations.

Indicators used

The following indicators have been selected to compare scenarios from an environmental perspective:

Abbrev.	Full name	Main impacts
PM2.5	(Airborne) Particulate Matters <= 2.5 μ	Health (lung cancers, heart attacks…)
PM10	(Airborne) Particulate Matters <= 10 μ	Health (lungs, heart)
CO	Carbon monoxide	Health (heart, brain, lungs)
NO_x	Nitrogen oxides	Ground-level ozone (asthma, lung cancer) & PM2.5 (see above)
CO_2	Carbon dioxide	Global warming

Table 4: Environmental indicators computed in SUCCESS scenarios.

We computed emissions for each scenario, distinguishing between emissions made inside and outside the cities.

Adaptation of the COPERT tool to the needs of the SUCCESS project

Since our simulations use a fixed and limited set of trucks (see above), we extracted the "implied emission factors" to avoid a time consuming post-processing of simulation results in COPERT for:

- 5 truck types x 6 Euro classes;
- 4 kinds of journeys (depending on the traffic – peak hours- and kind of roads);
- 4 pollutants + CO_2.

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This has been done for each of the 4 countries. Since the only difference in input parameters from one city to another one is the average outdoor temperatures, with an average difference of less than 3% (7% max for peak time CO emissions with Euro 0 vehicles, no difference for CO2) impact between values from Luxembourg and Valencia, we decided to use a unique set of emission factors for all computations. In addition, the main purpose of the SUCCESS project is not to get precise absolute values for the emissions associated with each scenario, but rather to compare scenarios in each city.

The 600 emission factors were put in an Excel simplified tool, which allows to quickly make some "what if" analyses regarding:

- the share of urban kilometres made under congested traffic (peak times);
- the Euro class mix for each type of trucks.

In particular, we considered that the share of peak and non-peak travel time is 50% and, as already discussed in the simulation process section above, we have taken the mix of Euroclass from official registration records and used that percentage for the computation. In particular we used the last statistics available for Italy in 2016[1], but we checked that this choice, which does not consider a specialized mix per country, does not affect the validity of the overall results. See Section 2.1.2.

2.4.2 Emissions computation output

For each scenario, the following emissions are computed, for each type of truck, inside and outside the city.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	100,69	22,34	23,94	194,91	38,69
2 Axes Truck 7.5T	91,15	13,80	14,61	223,65	20,29
2 Axes Truck 14T	71,63	11,25	12,55	260,00	13,06
3 Axes Truck	983,05	143,69	148,55	3.907,00	113,76
Tot	**1.246,52**	**191,08**	**199,65**	**4.585,56**	**185,80**

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1.102,2	289,7	300,3	1.931,0	438,1
2 Axes Truck 7.5T	906,1	132,6	138,6	3.560,4	389,2
2 Axes Truck 14T	674,5	90,8	99,7	3.271,0	306,0
3 Axes Truck	6.862,7	973,7	1.003,3	31.669,6	3.190,2
Tot	9.545,5	**1.486,80**	**1.541,90**	**40.432,00**	

Table 5: Example of emissions computed for a multi-site scenario.

[1] Elaborazioni dell'Area Studi e Statistiche di ANFIA su dati del Ministero dei Trasporti, I SEM 2017

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The output of the computation is reported in an Excel file giving the emissions computed for each:

- scenario;
- truck type;
- environment (urban / outside city).

For each truck type, a distribution for Euro classes has been assumed, based on values observed on pilot sites and country statistics. It is important to note that the actual mix has a large impact on absolute values for emissions, but also when comparing scenarios. In fact, since the mixes are different from one truck category to the others, when a scenario switches from one truck type to a larger one for example, it can drastically reduce the emissions.

Finally, comparisons of emissions are computed between scenarios associated to the same context.

	SC6 / SC4		
Pollutant	**Inside city**	**Outside city**	**Total**
CO	-29%	-30%	-30%
PM2.5	-32%	-27%	-27%
PM10	-33%	-25%	-26%
NOx	-24%	-41%	-39%
CO2	-44%	-31%	-31%

Table 6: Comparison of emissions for 2 scenarios.

In the above example emissions are compared for Valencia, between Scenario 6 (with CCC, full optimization) and Scenario 4 (reference scenario, no CCC).

3 Simulation results

3.1 Introduction

This section reports in detail the results obtained with the simulation process.

For each pilot city, we start by summarizing the main figures of the pilot (number of construction sites, number of potential CCCs location, budget, etc.), then we give the results reporting the following indicators:

- CCC location selected by the stochastic optimization model;
- travel distance, travel time, number of trips and load factor;

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- pollutants emissions (CO, PMx, Nox, CO2);
- cost-benefit-analysis.

These indicators allow to compute the following SUCCESS KPIs:

KPI	Description
KPI1	Travel time (outside and in the city centre)
KPI15	CO_2 equivalent
KPI16	PM (PM2.5 and PM10)
KPI18	Number of deliveries

In addition, we report the emissions of Nitrogen oxides (NOx) and carbon monoxide (CO).

With respect to the **expected impacts** foreseen in the proposal, the simulation gives a quantitative evaluation to the following ones:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%
Reduction of noise caused by transport	Noise level (dB(A))	-10%
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%
	Small deliveries (fewer than 4 pallets)	-50%
Maximise load factor	% Increase load factor	30%

Concerning the "Noise level" has not been computed directly, since we have not a mathematical model of the noise emission of the trucks and their effect on the ears of the surrounding people, however, since we will show that the number of daily deliveries is drastically reduced (see next sections), so we can be confident that the required reduction (only 10%) has been meet.

Concerning the "small deliveries (fewer than 4 pallets)" we have seen that using the CCC they have been never done. Indeed, one of the main aims of the CCC is the consolidation of the deliveries, and we adopted a loading policy (see

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Section 2.1.1.8) that avoids any trip with a load smaller than 3% of the loading factor.

The other indicators are computed using the simulation data as follows:

Indicators	Simulated indicator
Daily number of freight vehicles both for direct and reverse logistics	Number of trips
CO_2 emissions (gram/km) NO_x emissions (gram/km) PM10 emissions (gram/km)	Direct computation, plus computation of PM2.5 and CO emissions
Noise level (dB(A))	See above
Kilometres / day travelled by vehicles	Kilometres in urban area and outside the city
Small deliveries (fewer than 4 pallets)	See above
% Increase load factor	Load factor

For the computations, we first consider the three scenarios with a single big-site, namely scenarios 1-3, and later the scenarios with several construction sites, scenarios 4-6. For each of these groups of scenarios we report a comparison for each of the key indicators. In the case of Paris, we simulate also the scenarios 7 and 8 with several sites and two CCCs.

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3.2 Luxembourg site

The main figures of the Luxembourg simulation are as follows:

Number of construction sites	16
Number of suppliers	30
Number of potential CCC locations	6
Total budget for the construction sites	Euro 714.350.000

Pilot Site

Total budget	Euro 20.8000.000
Total tons delivered	13.305
Total cubic meters delivered	9.839
Average tons delivered per week	162
Average m3 delivered per week	119

All construction sites

Total budget	Euro 714.350.000
Total tons delivered	659.262
Total cubic meters delivered	509.554
Average tons delivered per week	4.226
Average m3 delivered per week	3.266

In the figure, the possible CCC locations are indicated by yellow icons, while the green icons indicate the positions of the construction sites.

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Figure 18: Luxembourg CCCs and construction sites.

The positions of the suppliers are indicated in the next figure, by the red icons. Most of them are close to the city, but a few ones are some hundreds of kilometres far.

Figure 19: Suppliers of the Luxembourg simulation site.

3.2.1 CCC location

The stochastic model has been used to determine the best CCC location among the 6 potential locations. The expected values of the locations, expressed in kilometres times cubic meters are the following:

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Location	Expected objective value
Terminal Bettembourg	4.79568e+07
Porte d'Hollerich	4.09287e+07
Villeroy & Boch	4.03130e+07
ZI Gasperich	4.01785e+07
ZI Howald	4.01568e+07
Z.I. Bombicht	4.47855e+07

The best choice is the fifth location, highlighted in the following figure. The first and last locations, which are far from the city (outside the area represented by the figure) have the worst values. The other locations have similar values.

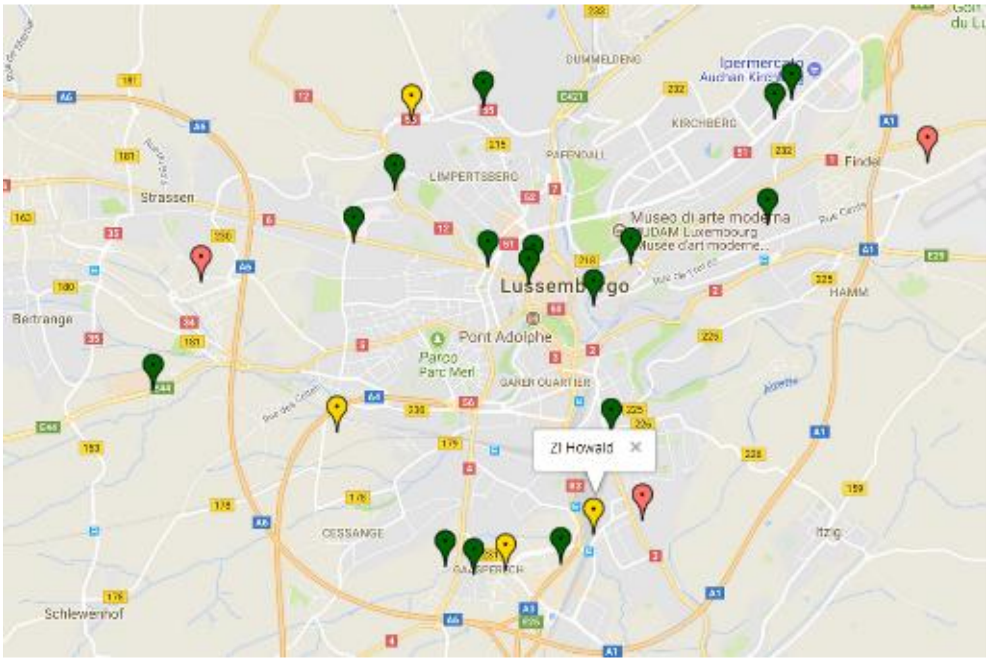

Figure 20: Best CCC location for Luxembourg.

In the next pictures and tables, we will report the following quantitative indicators for the tested scenarios:

- Travel time outside and inside the city;
- Travel distance outside and inside the city;
- Truck load factor;
- Air pollutants emissions caused by transport outside and inside the city.

3.2.2 Comparison of the scenarios with a single big site

In this section, we compare the results obtained without CCC (Scenario 1 – baseline) with the results with a single CCC and optimization on one or both echelons (Scenarios 2 and 3). The complete set of data for each scenario can be found in the appendix.

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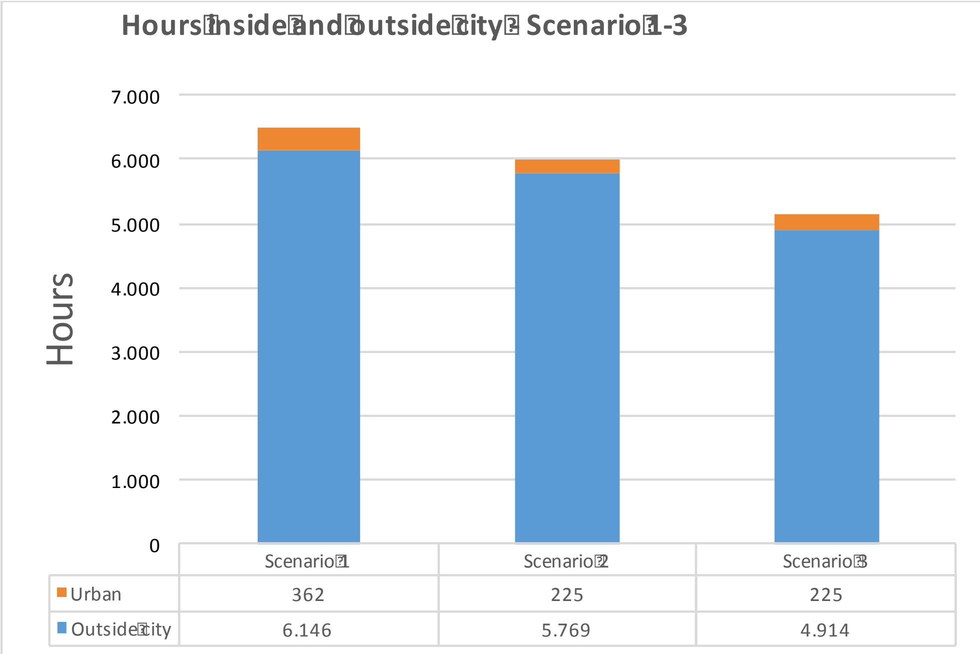

Figure 21: Comparison of traveling times - Luxembourg - Scenario 1-3.

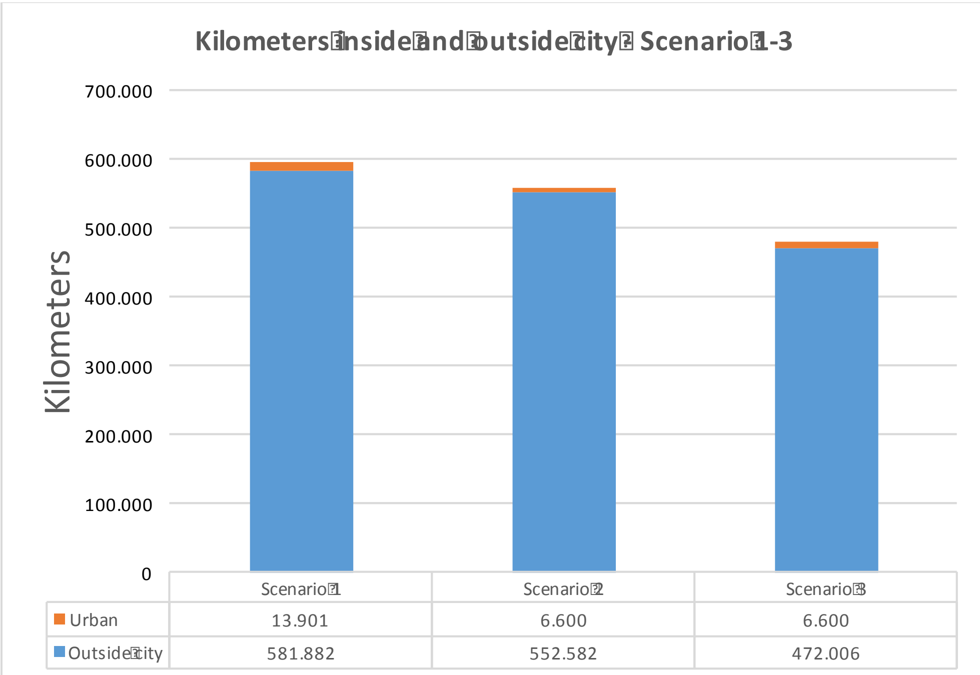

Figure 22: Comparison of travel distances – Luxembourg - Scenario 1-3.

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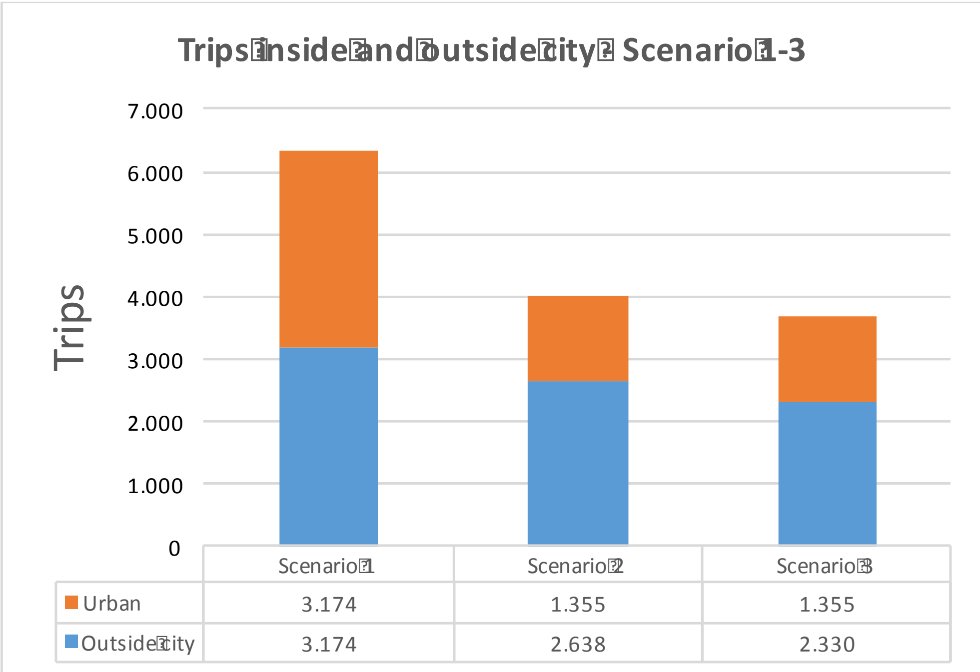

Figure 23: Comparison of number of trips - Luxembourg - Scenario 1-3.

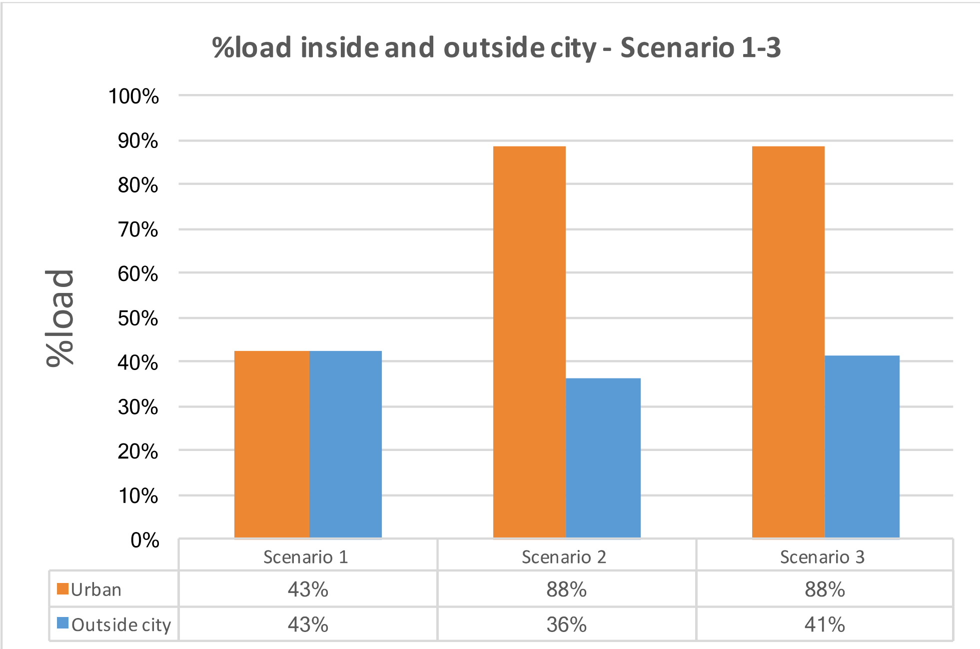

Figure 24: Comparison of % loads - Luxembourg - Scenario 1-3.

The pictures and tables show a clear advantage in the use of a CCC. Indeed, there is a reduction in kilometres travelled, number of trips and trips duration.

The next table reports the percentage advantages in terms of trips, kilometres travelled, traveling time and truck load.

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SC1 --> SC3			
Indicator	Inside city	Outside city	Total
Daily number of freight vehicles	-57%	-27%	-42%
Kilometres / day travelled by vehicles	-53%	-19%	-20%
% Increase load factor	107%	-3%	52%
Travel time	-38%	-20%	-21%

All the figures are almost halved inside the city and reduce by at least 20% outside the city. In particular, the large reduction inside the city allows to state without any doubt, that the CCC is a very good solution to reduce the impact on the citizens. The next economic analysis in the Cost Benefit Analysis section will discuss the sustainability of the use of a CCC.

The following pictures report on the pollutant emissions in the three scenarios. We can anticipate here that also in this case there is a clear and large advantage in the use of the CCC.

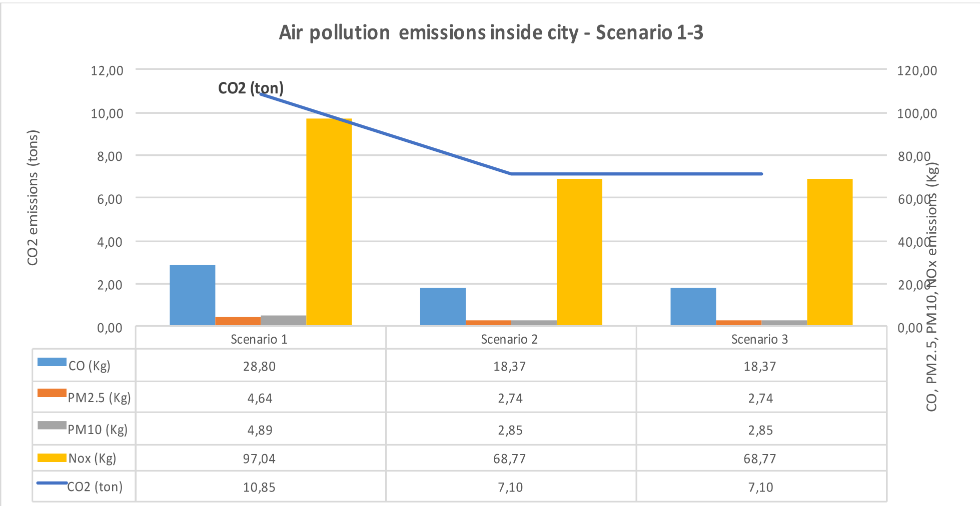

Figure 25: Air pollutant emissions caused by transport inside the city - Luxembourg - Scenario 1-3.

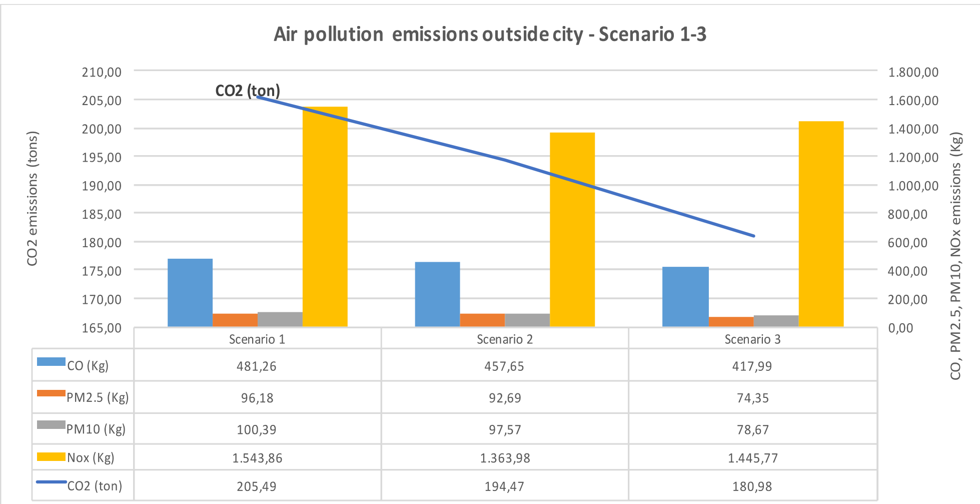

Figure 26: Air pollutant emissions caused by transport outside the city- Luxembourg – Scenario 1-3.

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The tables show a clear advantage in the use of a CCC, in term of air pollution emissions, which monotonically decrease for all pollutants, both in the urban and non-urban area. In the next table, we present in detail the percentage decrease of pollutants from Scenario 1 (baseline) to Scenario 3 (one CCC, both echelons optimized). We have very positive advantages, in particular in term of CO2 emissions inside the city: the total emission due to the transport to the construction site is halved.

SC1 --> SC3			
Polluttant	**Inside city**	**Outside city**	**Total**
CO	-36%	-13%	-14%
PM2.5	-41%	-23%	-24%
PM10	-42%	-22%	-23%
NOx	-29%	-6%	-8%
CO2	-35%	-12%	-13%

The expected benefits for Luxembourg are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-42%**
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%	**-14%** **-8%** **-23%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-20%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+52%**

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3.2.3 Comparison of scenarios with multiple construction sites

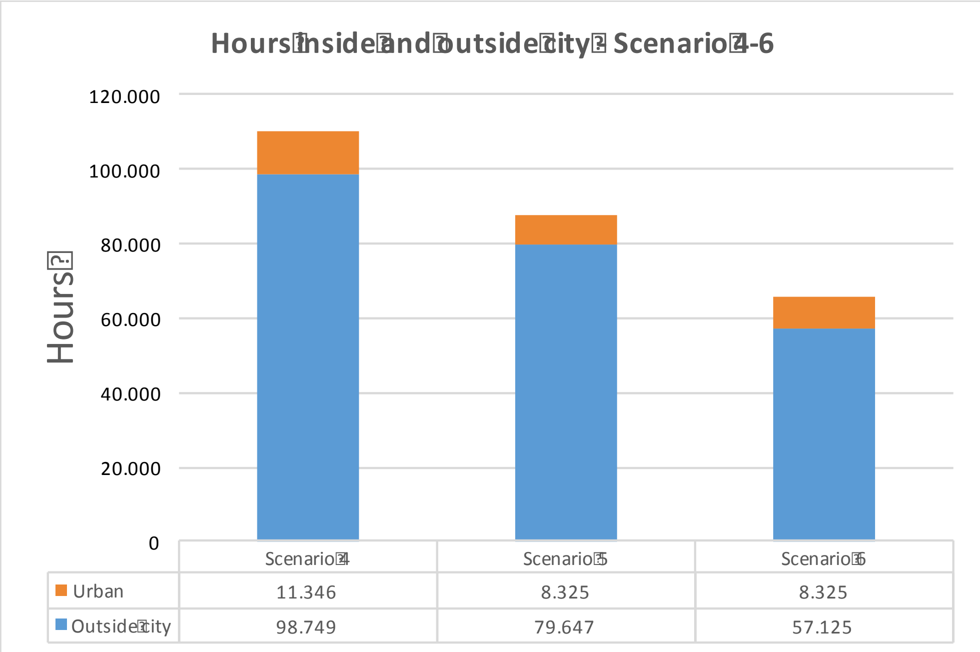

Figure 27: Comparison of traveling times – Luxembourg -Scenario 4-6.

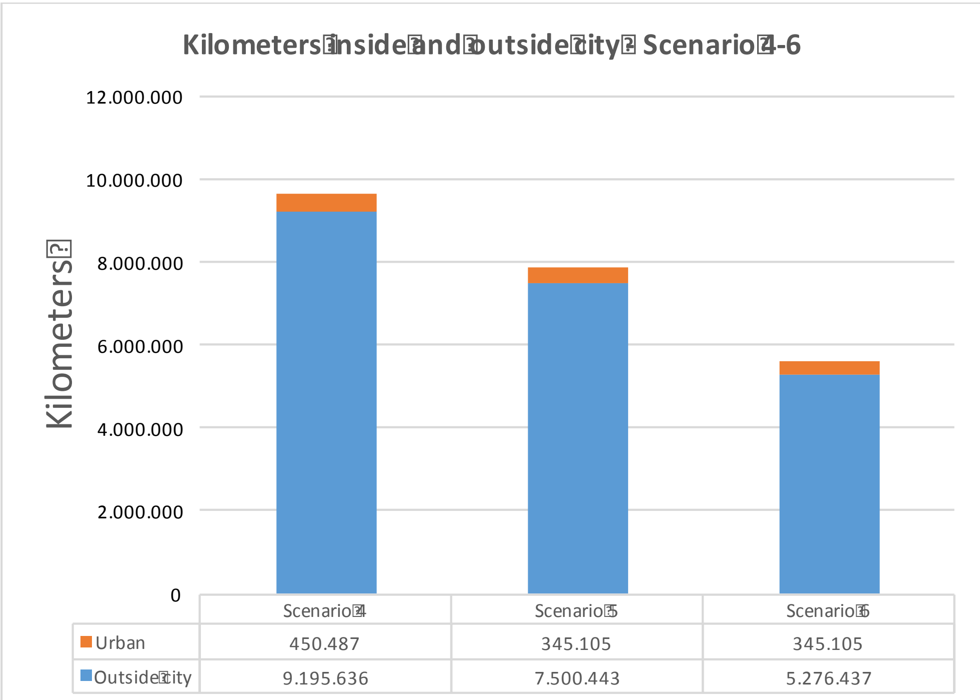

Figure 28: Comparison of distance travelled – Luxembourg - Scenario 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

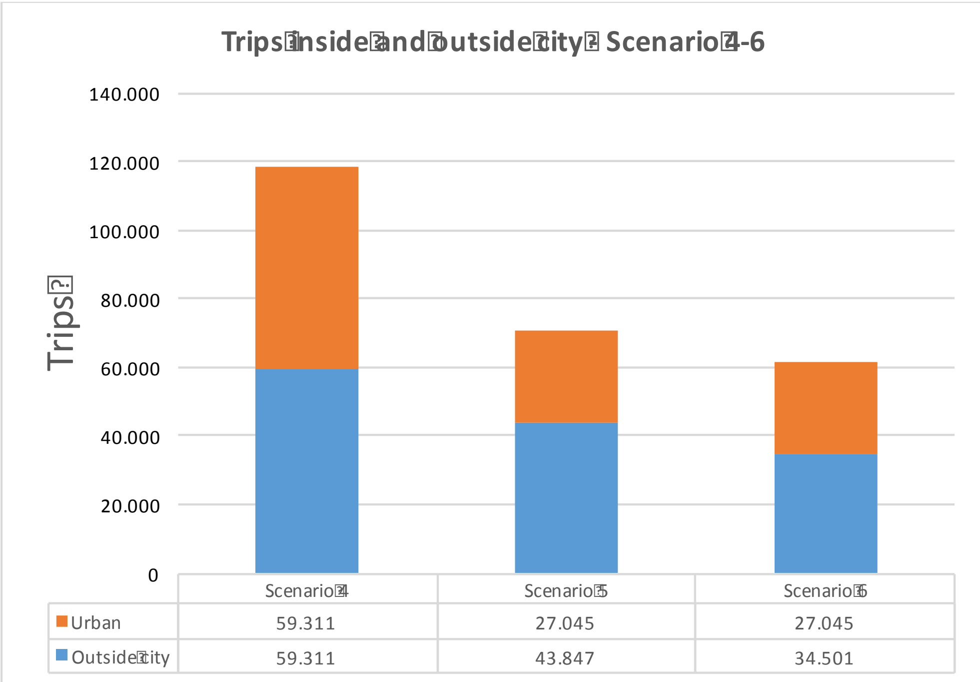

Figure 29: Comparison of number of trips - Luxembourg - Scenario 4-6.

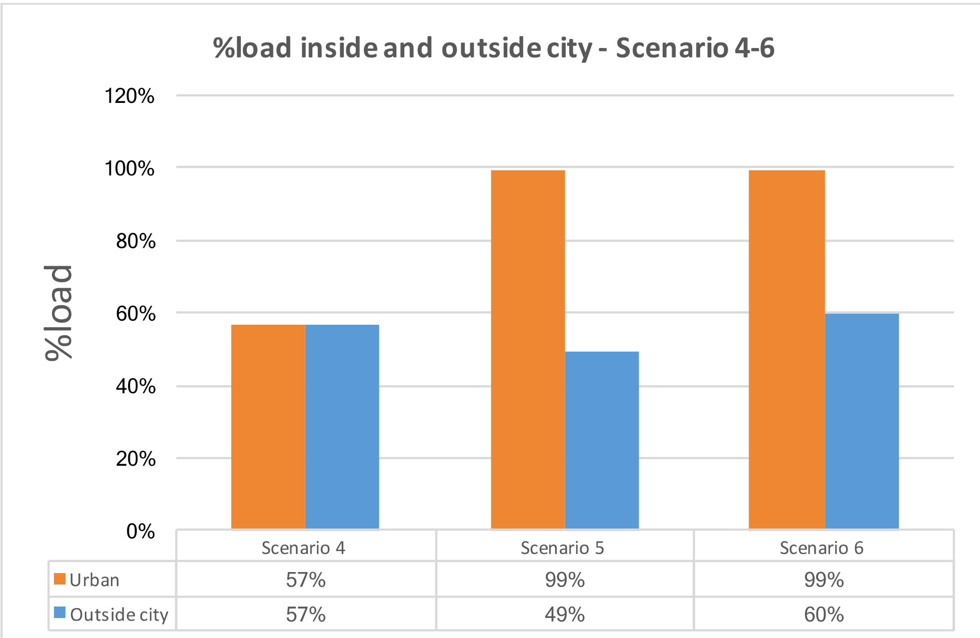

Figure 30: Comparison % load – Luxembourg -Scenario 4-6.

The percentage gains with respect to the baseline (Scenario 4) are reported in the next table for the four indicators.

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SC4 --> SC6			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-54%	-42%	-48%
Kilometres / day travelled by vehicles	-23%	-43%	-42%
% Increase load factor	75%	5%	40%
Travel time	-27%	-42%	-41%

Concerning the air pollution, the comparison is in the next two pictures.

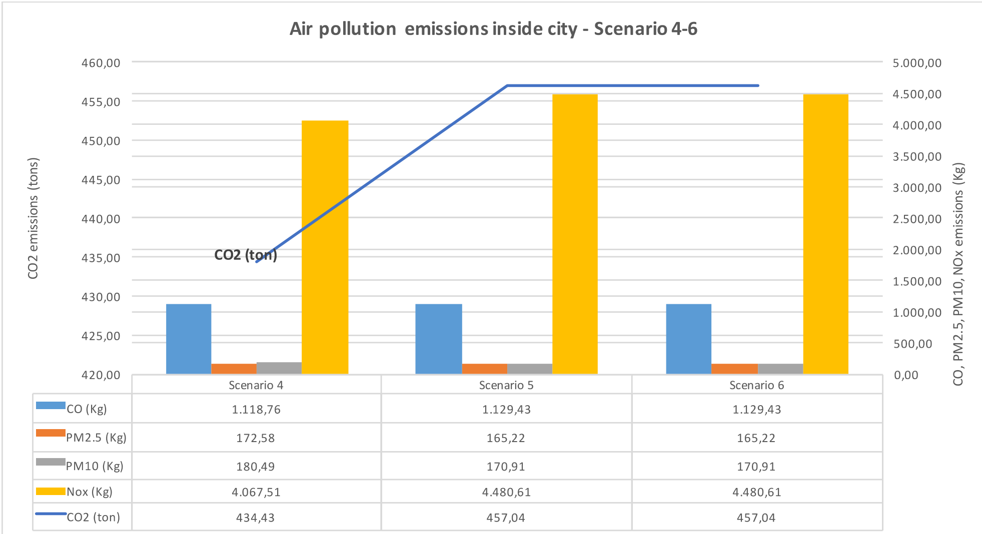

Figure 31: Air pollution emissions in the urban area – Luxembourg - Scenario 4-6.

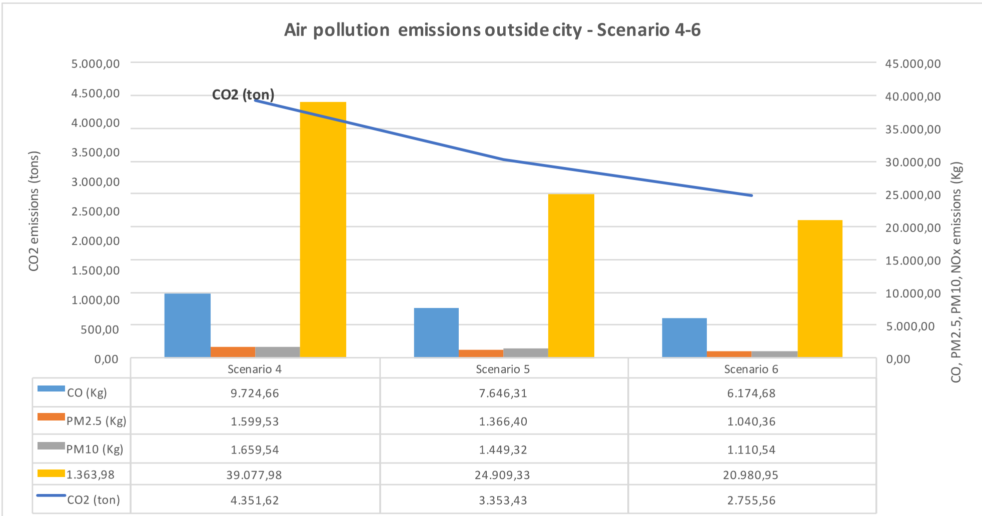

Figure 32: Air pollution emissions outside the city – Luxembourg - Scenario 4-6.

The table below report the percentages improvements from scenario 4 to scenario 6, i.e., without CCC and with CCC and optimization on both echelons.

There is an overall improvement from 20% to 40%. Inside the city there are gains and worsening depending on the pollutant. This is due to the fact that the optimized scenarios use less trucks, but bigger than that in the basic scenario 4.

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A multi-criteria optimization could be adopted to balance the improvements due to the reduction of the number of traveling trucks, with the air pollutant emissions. **The use of special vehicles inside the city is potential technical solution which capture both the goals.**

Outside the city there are always significant gains.

SC4 -->SC6			
Polluttant	Inside city	Outside city	Total
CO	1%	-37%	-33%
PM2.5	-4%	-35%	-32%
PM10	-5%	0%	-30%
NOx	10%	-46%	-41%
CO2	5%	-37%	-33%

The expected benefits of scenario 6 for Luxembourg, are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results – Total**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-48%**
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%	**-33%** **-41%%** **-30%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-42%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+40%**

3.2.4 Cost-Benefit-Analysis

3.2.5 Cost-Benefit-Analysis

3.2.5.1 Business Model 1: CCC managed by a Construction Company

Input data

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The following list contains the input data of the Luxembourg pilot for the business model of a CCC that is managed by a construction company:

Parameter	Value	Unit
Average yearly Budget of all the Construction Projects	10,400,000	€
Number of Construction Sites	1	sites
Daily Average Deliveries per Construction Site	3	deliveries
Average Weekly Storage Capacity needed [m3]	120	m3
Maximum Weekly Storage Capacity needed [m3]	280.5	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks (average per unit)	195	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t (average per unit)	584	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t (average per unit)	268	km
Number of 3 Axes Truck <25t	1	Units
Annual km of 3 Axes Truck <25t (average per unit)	2,252	km

The input data was obtained from the simulations of the Scenario 2 in the Luxembourg pilot, which considers the implementation of a CCC for the supply chain management of a single site. The average yearly budget of the construction site was calculated considering a 2 years construction project and an overall budget of 20.8M€.

Results

The CBA results provide, firstly, an approximate dimensioning of the CCC facility based on the simulation outputs and a set of assumptions previously considered. The results of the facility and operations dimensioning based on the simulation results of the scenario 2 (CCC managed by a construction serving one single construction site) were:

CCC Dimensioning		
CCC Facility Dimensioning		
Storage Area Needed in the CCC [m2]	69	m2
Final Facility Dimensioning [m2]	170	m2
CCC Labor Force and Machinery Dimensioning		
Manager	1	
Other Personnel	0	
Operators	1	
Drivers	4	
Forklifts	1	
Orther Machinery	1	

For the facility dimensioning and considering 4 levels of shelves, the facility needs a very small surface, only 170m^2 to store the average weekly material flows

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(120m³ per week) including the area dedicated to corridors, loading and unloading operations and common areas. This means that the site has to manage only 24m³ of material per day, which do not seem a big quantity that could justify the implementation of a CCC.

For the delivery operations, the outputs of the simulation resulted in 4 trucks needed to cover all the daily deliveries. However, the yearly kilometres done per vehicle are less than 2.300km and, in some cases even less than 200, which also seems very poor distance to be covered by the fleet. For the drivers, as in the other cases, it was assumed one driver per truck. Thus, in this specific case, it seems that there is no enough material flows that justifies the implementation of the CCC.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that is needed one single operator plus a forklift and a pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities.

In reference to the Cost Benefit Analysis carried out for a period of two years (the duration of the pilot construction), the results obtained for the Luxembourg case were:

Year	ALTERNATIVE 2 CCC	ALTERNATIVE 2. Using CCC											TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	INVESTMENTS (EUROS)	Additional Cost of CCC					Savings			CCC Summary			
		Facility Rent Costs (€)	Workforce Costs (€)	General expenses CCC (€)	Transport Costs (€)	Maintenance Costs (€)	Labor Force Savings [€/year]	Material Savings [€/year]	Unsorted Bins [€/year]	TOTAL ANNUAL COSTS	TOTAL ANNUAL SAVINGS	BENEFITS	
1	**97.000**	24.473	227.620	2.447	87.924	1.224	156.000 €	145.600 €	7.738 €	**343.687 €**	**309.338 €**	**-34.350 €**	**-131.350**
2	**0**	24.877	231.376	2.488	89.374	1.244	158.574 €	148.002 €	7.865 €	**349.358 €**	**314.442 €**	**-34.917 €**	**-34.917**
												NPV	**-156.765 €**

Year	Percentage of benefits compared to the annual budget of all the projects served via the CCC
1	-1.26%
2	-0.34%

In this case, the implementation of a CCC produces negative effects (NPV< 0€) and the potential savings due to the performance improvements on site do not cover the extra cost of the CCC implementation. The CCC produce other positive effects in the supply chain management (i.e. punctuality, reliability, etc.), but from the economic point of view, the assumptions considered in this analysis about the improvements in the core activity of the construction company are not enough to compensate the additional cost of the CCC implementation.

In addition, the potential savings that the CCC could bring to the main activity (i.e. the construction activity) are due to performance improvement on site, but

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the outputs of the simulation pointed out a very small quantity of material to be managed. Consequently, it seems difficult that this performance improvement on site can be really obtained thanks to the CCC implementation because is a small quantity easy to manage directly in the construction site.

In this regard, a more detailed study about this specific scenario is required to explain the reduced figures of materials flows of the construction site in which the CBA is based.

3.2.5.2 *Business Model 2: CCC managed by a Logistics Operator*

Input data

The input data requirements for the business model in which the CCC is managed by a logistics operator in Luxembourg pilot are listed below:

Parameter	Value	Unit
Average Distance from CCC to Construction Sites [km]	15,12	km
Number of Construction Sites	14	sites
Daily Average Deliveries per Construction Site	3,86	deliveries
Average Weekly Storage Capacity needed [m3]	3,266.4	m3
Maximum Weekly Storage Capacity needed [m3]	5,403.4	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks (average per unit)	170	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t (average per unit)	680.7	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t (average per unit)	1,084.7	km
Number of 3 Axes Truck <25t	8	Units
Annual km of 3 Axes Truck <25t (average per unit)	15,022.8	km

This input data was obtained from the simulation of the Scenario 5 in the Luxembourg pilot.

Results

Firstly, the CBA results provide the dimensioning of the CCC facility based on the simulation outputs and a set of assumptions considered. The CCC dimensioning includes an estimation of the size of the facility, the labour force and machinery needed. Following figure shows a table with the main results:

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CCC Dimensioning		
CCC Facility Dimensioning		
Storage Area Needed [m2]	1.905	m2
Facility Dimensioning - Total Area Needed [m2]	4.860	
Final Facility Dimensionng [m2]	6.075	m2
CCC Labor Force and Machinery Dimensioning		
Manager	1	
Other Personnel	2	
Operators	12	
Drivers	11	
Forklifts	6	
Other Machinery	6	

In total, the facility needs around 6000m^2 to be able to accommodate the average weekly material flows (3.266,4m^3), including the area dedicated to corridors, loading and unloading operations and common areas.

For the delivery operations, the outputs of the simulation resulted in 11 trucks needed to cover all the daily deliveries. For the drivers, it was assumed one driver per truck needed.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that are needed 13 operators and 7 forklifts and 7 pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities. It is important to remark that in the analysis 8h working day shifts and 12h of CCC open hours are considered in the analysis. The results show an approximation of the staff needed based on constant assumptions (see section 2.2 and annex 1 and 2), so working shifts and schedule management could lead to more adjusted figures regarding staff dimensioning.

Secondly, the CBA analysis also estimates the potential feasibility of the CCC implementation. In one side, the analysis considers the total costs (facility dimensioning, staff, trucks, etc.) and in the other side, the potential incomes due to the services provided by the CCC (see section 2.2 and annexes).

In this regard, in the case of the scenario 5 for the Luxemburg city (one single CCC operated by a logistics operator and serving several construction sites) seems to be feasible in long-term basis (NPV>3.9M€). Following figure shows the main results for the scenario assessed:

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ESTIMATED COSTS AND BENEFITS FOR A LOGISTIC OPERATOR

Year	Alternative 1: Current Situation Without CCC	Alternative 2: CCC Implementation									TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	Investments	Investments	Vehicles Operational Costs (Euros)	CCC General Expenses (Euros)	CCC Rental Cost (Euros)	CCC Personnel Costs (Euros)	Total Revenues (Euros)	TOTAL ANNUAL COSTS	TOTAL ANNUAL REVENUES	BENEFITS	
1	0	908.200	208.200	131.224	874.827	1.017.655	2.803.549	2.231.905 €	2.803.549 €	571.644 €	-336.556
2	0	0	212.364	133.848	892.323	1.038.008	2.859.620	2.276.543 €	2.859.620 €	583.077 €	583.077
3	0	0	216.611	136.525	910.170	1.058.768	2.916.813	2.322.074 €	2.916.813 €	594.738 €	594.738
4	0	0	220.943	139.256	928.373	1.079.944	2.975.149	2.368.516 €	2.975.149 €	606.633 €	606.633
5	0	0	225.362	142.041	946.941	1.101.542	3.034.652	2.415.886 €	3.034.652 €	618.766 €	618.766
6	0	28.000	229.869	144.882	965.879	1.123.573	3.095.345	2.464.204 €	3.095.345 €	631.141 €	603.141
7	0	0	234.467	147.780	985.197	1.146.045	3.157.252	2.513.488 €	3.157.252 €	643.764 €	643.764
8	0	0	239.156	150.735	1.004.901	1.168.966	3.220.397	2.563.758 €	3.220.397 €	656.639 €	656.639
9	0	0	243.939	153.750	1.024.999	1.192.345	3.284.805	2.615.033 €	3.284.805 €	669.772 €	669.772
10	0	-59.200	248.818	156.825	1.045.499	1.216.192	3.350.501	2.667.334 €	3.350.501 €	683.167 €	742.367

NPV 3.945.506,99 €

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3.3 Paris site

The main figures of the Paris simulation are as follows:

Number of construction sites	10
Number of suppliers	129
Number of potential CCC locations	10
Total budget for the construction sites	Euro 1,569,000,000

Pilot Site

Total budget	Euro 230,000,000
Total tons delivered	85,006
Total cubic meters delivered	28,088
Average tons delivered per week	914
Average m3 delivered per week	302

All construction sites

Total budget	Euro 1,569,000,000
Total tons delivered	560,586
Total cubic meters delivered	357,984
Average tons delivered per week	3,593
Average m3 delivered per week	2,294

In the following figure, the possible CCC locations are indicated by yellow icons, while the green icons indicate the positions of the construction sites (note that two CCCs are located at Porte de Champerret, one very close to the other, so in the picture we can see a single yellow icon instead of two).

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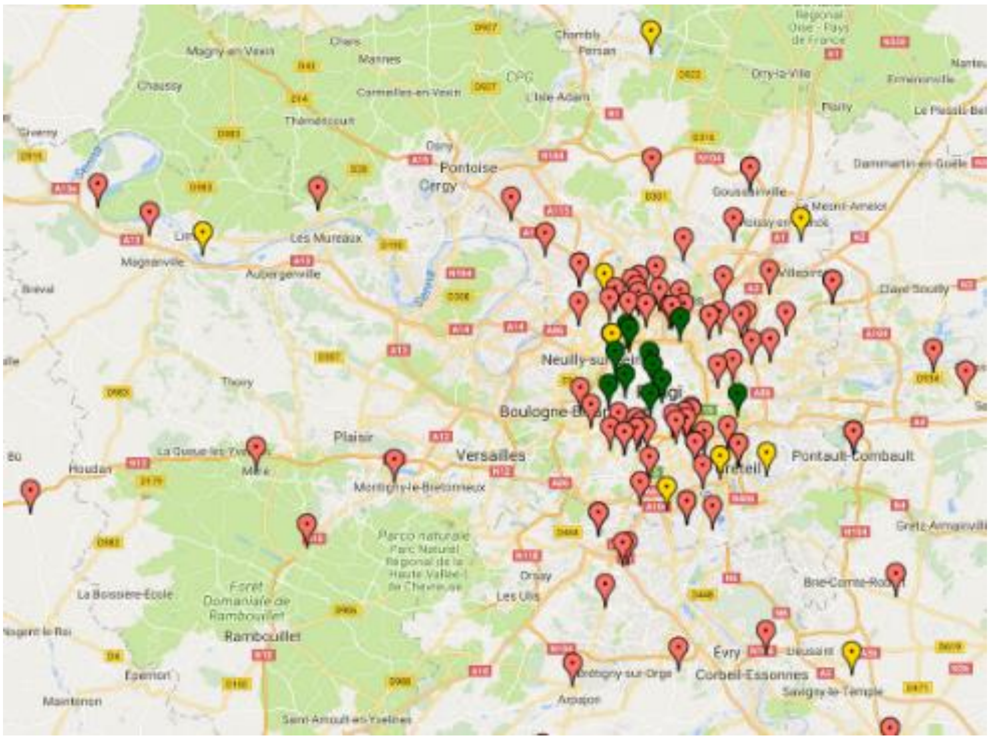


Figure 33: Paris CCCs and construction sites.

The positions of the suppliers are indicated in the next figure, by the red icons. Most of them are close to the city, or inside the city, but a few ones are very far: in Poland and in Spain.

Figure 34: Suppliers of the Paris simulation site.

3.3.1 CCC location

The stochastic model has been used to determine the best CCC location among the 6 potential locations. The expected values of the locations, expressed in kilometres x cubic meters are the following:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

N.	Location	Expected objective value
1	Porte de Champerret 75017 Paris	2.66317e+07
2	Porte de Champerret 75017 Paris	2.66267e+07
3	Route principale du port 92230 Gennevilliers	3.18727e+07
4	Route de l'île Barbière 94380 Bonneuil-sur-Marne	3.35398e+07
5	Route du Hazay 78520 Limay-Porcheville	5.63985e+07
6	Voie Nouvelle du Port 95820 Bruyère-sur-Oise	5.39573e+07
7	Porte de Fresnes 94150 Rungis	3.03332e+07
8	Rue du Pavé 93290 Tremblay-en-France	3.69842e+07
9	Impasse des Marais 94000 Créteil	3.26273e+07
10	Rue Louis de Brigolis 77550 Moissy-Cramayel Réau	4.80853e+07
1-4	Porte de Champerret + Route de l'île Barbière	2.56794e+07

Note that the second potential CCC, which is very close to the first one, is highlighted in red since the given expected capacity in cubic meters (4662) is not enough to accommodate all the flows in the expanded scenario. The first CCC is the best choice when a single CCC must be selected.

When we allow to open two CCCs the best choice is to select CCC 1 and 4. Note that CCC 4 is not the best second choice from the list of the ten CCCs, but remind that the figures in the first ten lines of the table give the objective value for the selection of a single CCC. The objective function is the same of the cases with one CCC, namely the material flows, times the distance and a per kilometres cost. The optimizer finds the optimal solution using mathematical programming methods, specifically a branch-and-cut method. The result for the optimization when two CCCs may be opened is given in the last row. The objective value is smaller than the one obtained by using the single CCC 1. The two CCCs are located at opposite side of the city centre, as one can expect.

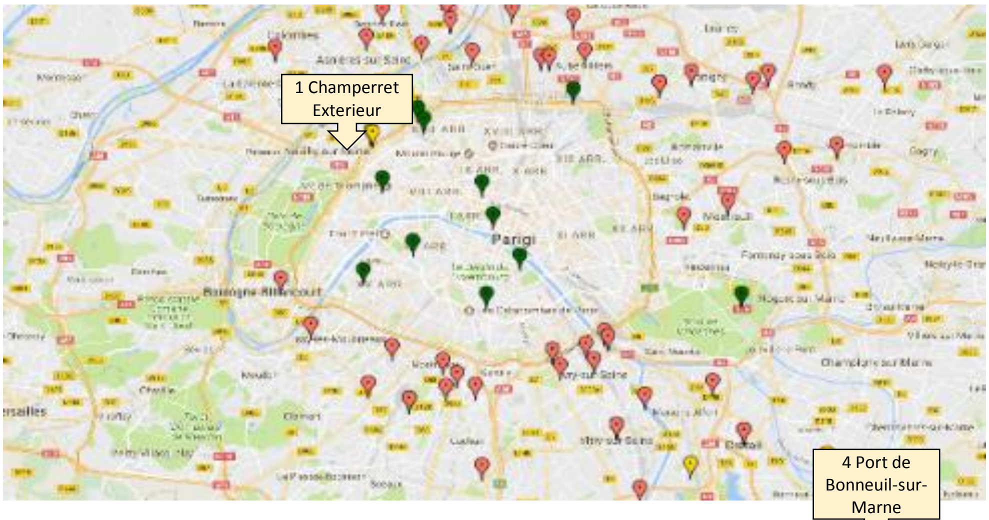
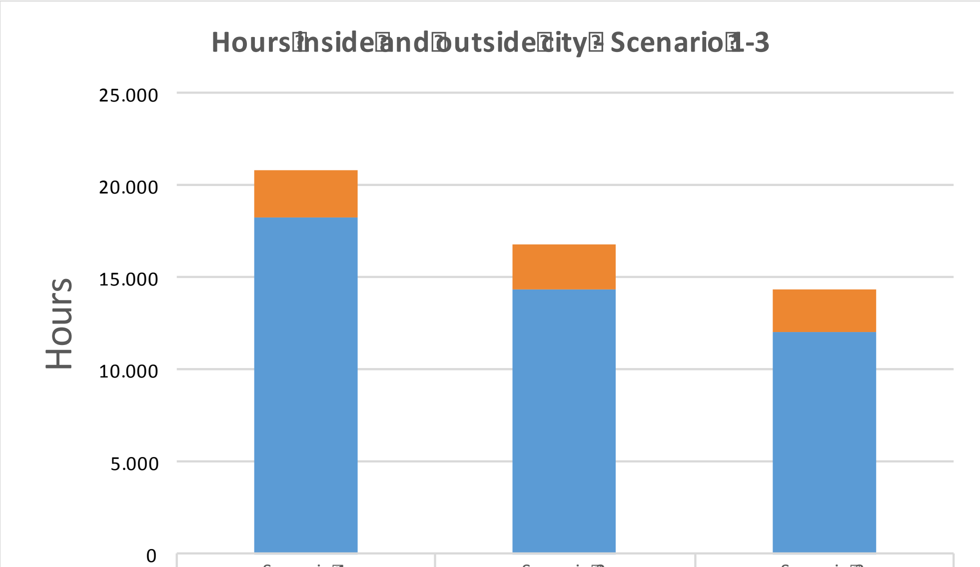


Figure 35: Best CCC locations for Paris.

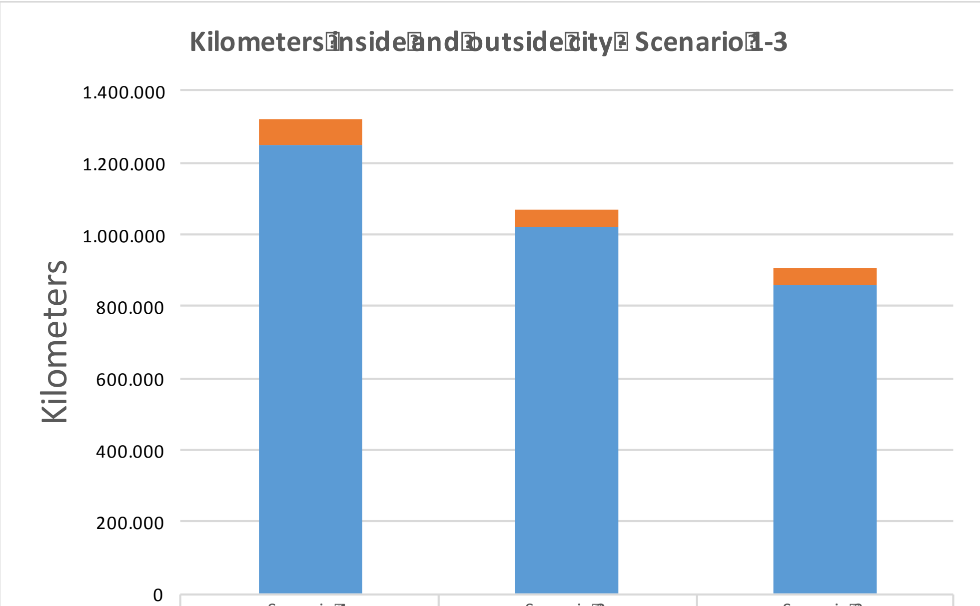
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

3.3.2 Comparison of the scenarios with a single big site



	Scenario 1	Scenario 2	Scenario 3
Urban	2.645	2.417	2.417
Outside city	18.242	14.395	11.997

Figure 36: Comparison of traveling times – Paris - Scenario 1-3.



	Scenario 1	Scenario 2	Scenario 3
Urban	72.411	44.876	44.876
Outside city	1.250.205	1.022.455	861.532

Figure 37: Comparison of distance travelled – Paris - Scenario 1-3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Figure 38: Comparison of number of trips – Paris - Scenario 1-3.

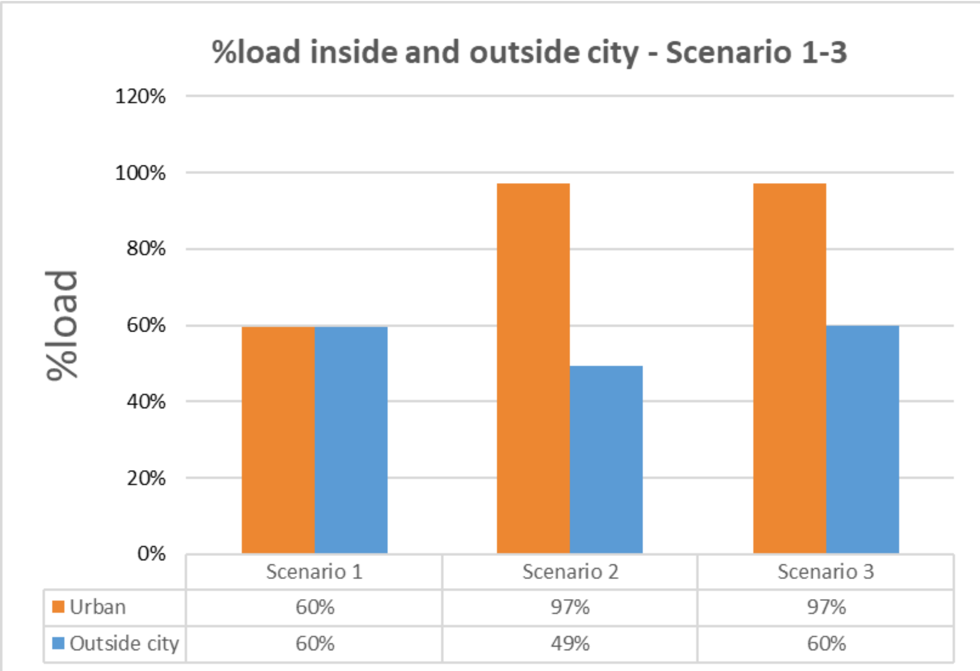


Figure 39: Comparison of % loads - Paris - Scenario 1-3.

The pictures and tables show a clear advantage in the use of a CCC. Indeed, there is a reduction in kilometres travelled, number of trips and trips duration. IN Scenario 2, outside the city there is a small worsening of the truck load, which is recovered when we go to scenario 3 where also the second echelon is optimized.

The next table reports the percentage advantages in terms of trips, kilometres travelled, traveling time and truck load.

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SC3 / SC1			
Indicator	Inside city	Outside city	Total
Daily number of freight vehicles	57%	27%	42%
Kilometres / day travelled by vehicles	53%	19%	20%
% Increase load factor	107%	-3%	52%
Travel time	38%	20%	21%

All the figures are almost halved inside the city and reduce by at least 20% outside the city. In particular, the large reduction inside the city allows to state without any doubt, that the CCC is a very good solution to reduce the impact on the citizens. The next economic analysis in the Cost Benefit Analysis section will discuss the sustainability of the use of a CCC.

The following pictures report on the pollutant emissions in the three scenarios. We can anticipate here that also in this case there is a clear and large advantage in the use of the CCC.

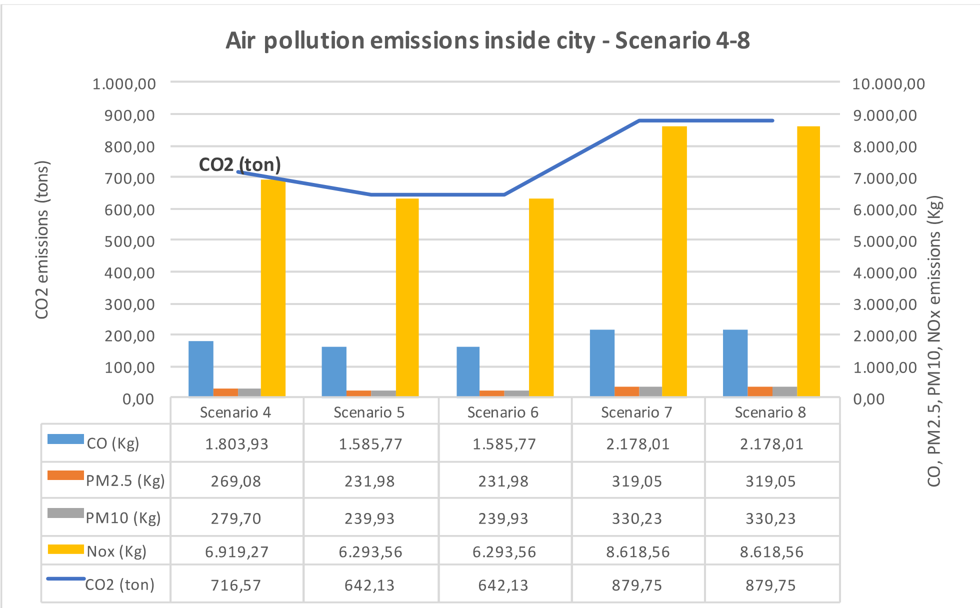
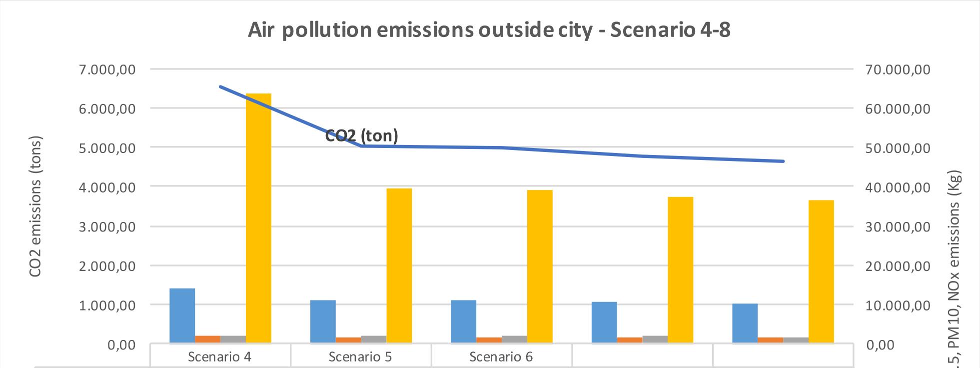


Figure 40: Air pollution emissions in the urban area – Paris - Scenario 1-3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Scenario 4	Scenario 5	Scenario 6		
CO (Kg)	14.247,33	11.132,56	11.026,60	10.543,61	10.237,49
PM2.5 (Kg)	2.102,97	1.790,48	1.770,05	1.696,27	1.630,81
PM10 (Kg)	2.177,50	1.921,08	1.899,98	1.819,67	1.751,93
PM10 (Kg)	63.403,15	39.531,65	39.176,20	37.474,91	36.579,26
CO2 (ton)	6.538,22	5.023,59	4.979,18	4.756,99	4.630,02

Figure 41: Air pollution emissions outside the city – Paris - Scenario 1-3.

The tables show a clear advantage in the use of a CCC, in term of air pollution emissions, which monotonically decrease for all pollutants, both in the urban and non-urban area. In the next table, we present in detail the percentage decrease of pollutants from Scenario 1 (baseline) to Scenario 3 (one CCC, both echelons optimized). We have very positive advantages, in particular in term of CO2 emissions inside and outside the city.

	SC1 --> SC3		
Polluttant	Inside city	Outside city	Total
CO	-36%	-13%	-14%
PM2.5	-41%	-23%	-24%
PM10	-42%	-22%	-23%
NOx	-29%	-6%	-8%
CO2	-35%	-12%	-13%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The expected benefits for Paris are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-42%**
Reduction of transport related pollutant emissions	CO_2 emissions NOx emissions PM10 emissions	-40%	**-13%** **-8%** **-23%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-20%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+52%**

3.3.3 Comparison of the scenarios with multiple construction sites

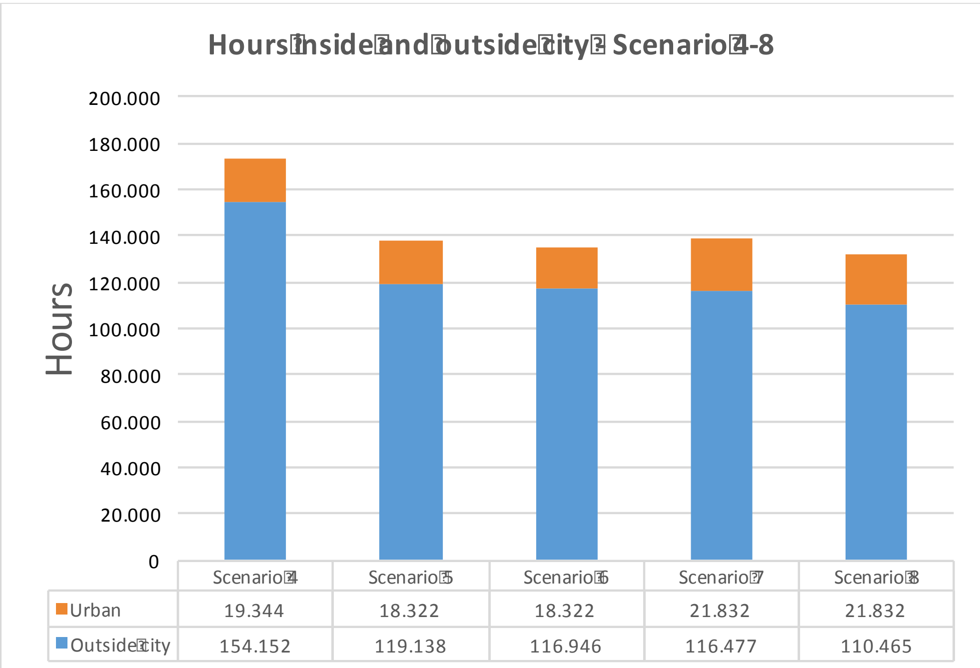
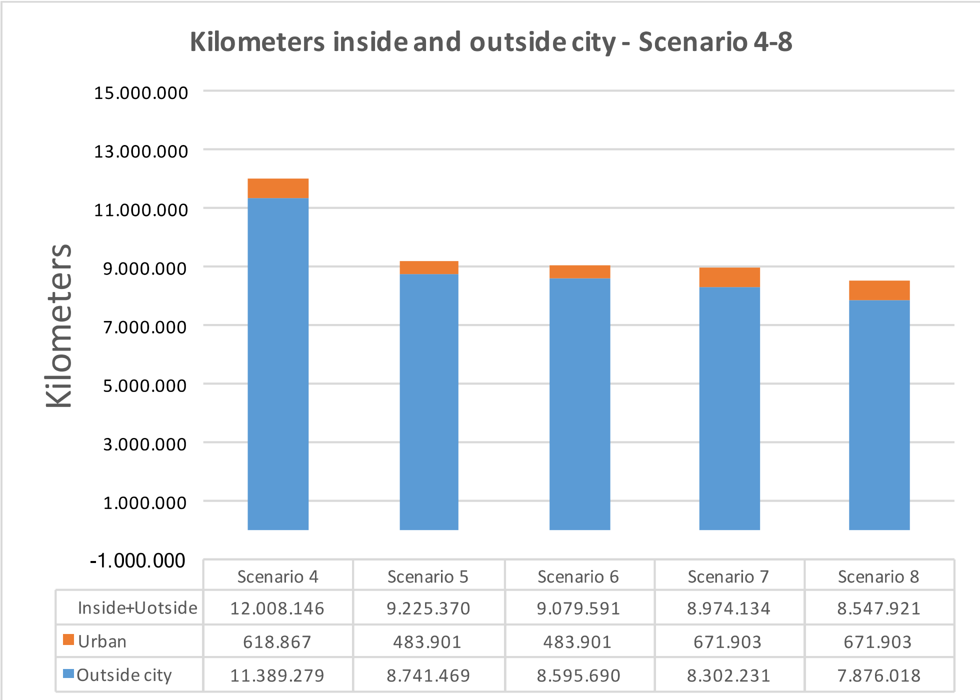


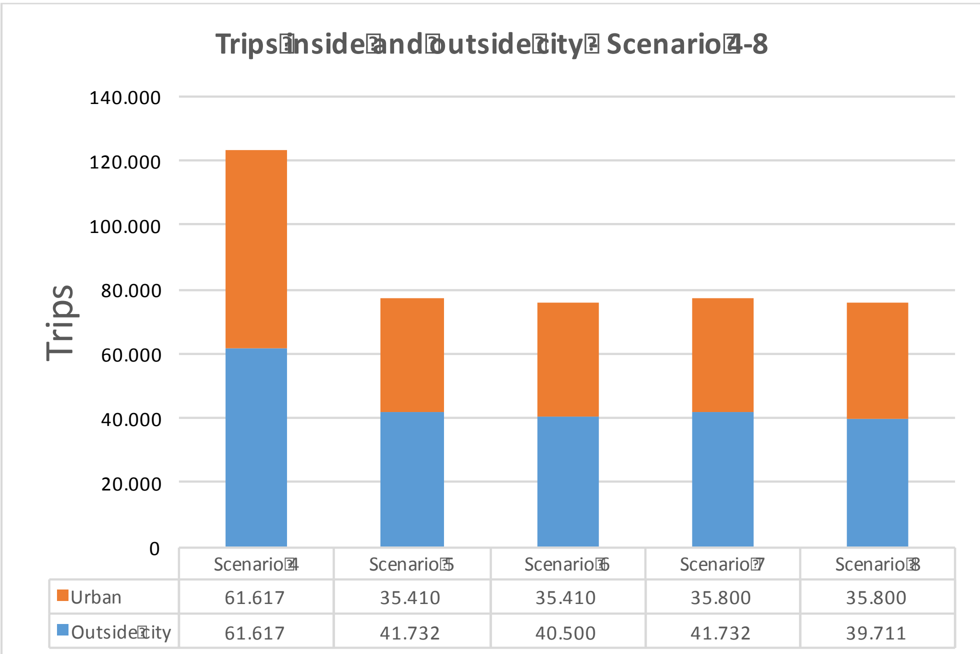
Figure 42: Comparison of traveling times – Paris - Scenario 4-8.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Inside+Uotside	12.008.146	9.225.370	9.079.591	8.974.134	8.547.921
Urban	618.867	483.901	483.901	671.903	671.903
Outside city	11.389.279	8.741.469	8.595.690	8.302.231	7.876.018

Figure 43: Comparison of distance travelled – Paris - Scenario 4-8.



	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Urban	61.617	35.410	35.410	35.800	35.800
Outside city	61.617	41.732	40.500	41.732	39.711

Figure 44: Comparison of number of trips – Paris - Scenario 4-8.

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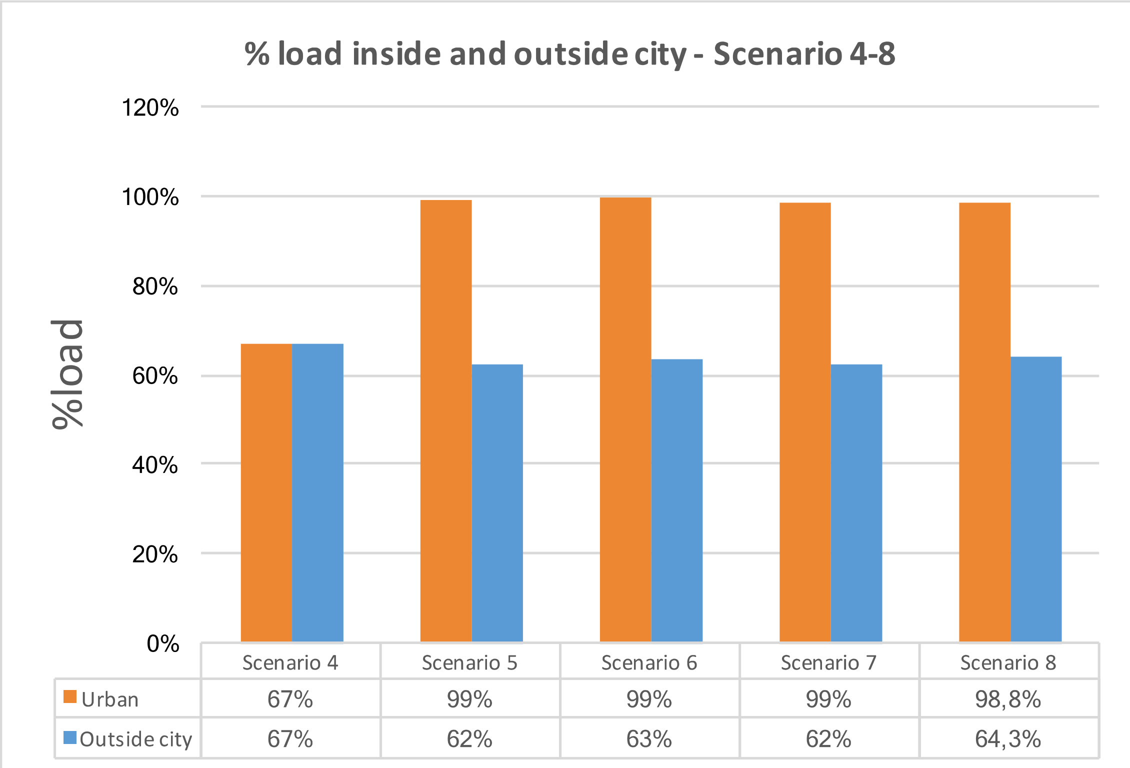

Figure 45: Comparison of % loads - Paris - Scenario 4-8.

SC4 --> SC6			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-43%	-52%	-38%
Kilometres / day travelled by vehicles	-22%	-32%	-24%
% Increase load factor	48%	-6%	21%
Travel time	-5%	-32%	-22%

SC4 --> SC8			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-42%	-55%	-39%
Kilometres / day travelled by vehicles	9%	-45%	-29%
% Increase load factor	48%	-4%	22%
Travel time	13%	-40%	-24%

The above figures show that there is a decrease in term of time, kilometres and number of trips, going from scenario 4 (no CCC) to scenario 5 and 6 (1 CCC, different optimizations). The percentage loading of the trucks has a worsening outside the city, but the total figure (urban and non-urban area) is increasing.

However, when **two** CCCs are considered the situation is different.

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We observe a decrease of time, kilometres and trips, outside the city, but an increase inside the city of kilometres travelled and traveling time. The loading factor has the same behaviour as in scenario 6.

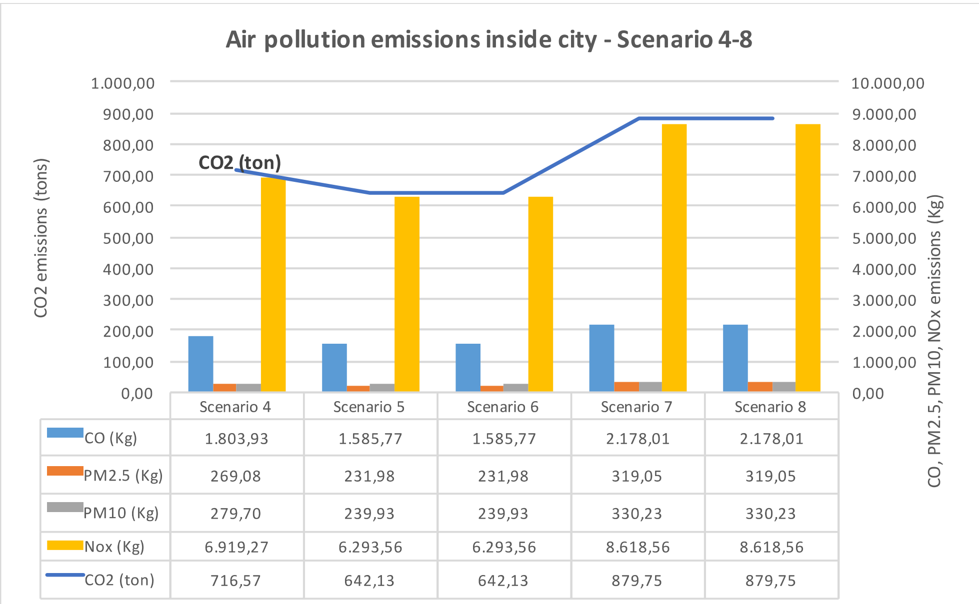
There are a few elements to be considered to understand this behaviour.

The first one is that using two CCCs we have less possibilities to optimize at city level. Indeed, the same quantities are delivered starting from two different locations, so we have less possibilities to aggregate the flows.

Another element is that the first CCC is very close to the city centre and to most of the construction sites, whereas the second CCC is located at a bigger distance, inducing an increase in the travels in the city.

The last element, possibly the most important, is that the stochastic optimization model that choose the two CCCs has an objective function which consider the global flows (suppliers to CCC to sites), hence it minimizes the global distances. This point will be clear looking at the emissions reported below.

We finally remind that the optimal solution with two CCCs has an objective function value equal to 2.56794e+07, while the value with one CCC is 2.66317e+07. The improvement using two CCCs is only 4%.



	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
CO (Kg)	1.803,93	1.585,77	1.585,77	2.178,01	2.178,01
PM2.5 (Kg)	269,08	231,98	231,98	319,05	319,05
PM10 (Kg)	279,70	239,93	239,93	330,23	330,23
Nox (Kg)	6.919,27	6.293,56	6.293,56	8.618,56	8.618,56
CO2 (ton)	716,57	642,13	642,13	879,75	879,75

Figure 46: Air pollution emissions in the urban area – Paris - Scenario 4-8.

Inside the city the emissions increase when two CCCs are used, since the kilometres travelled increase. However, outside the city we have an improvement, as shown by the next figure:

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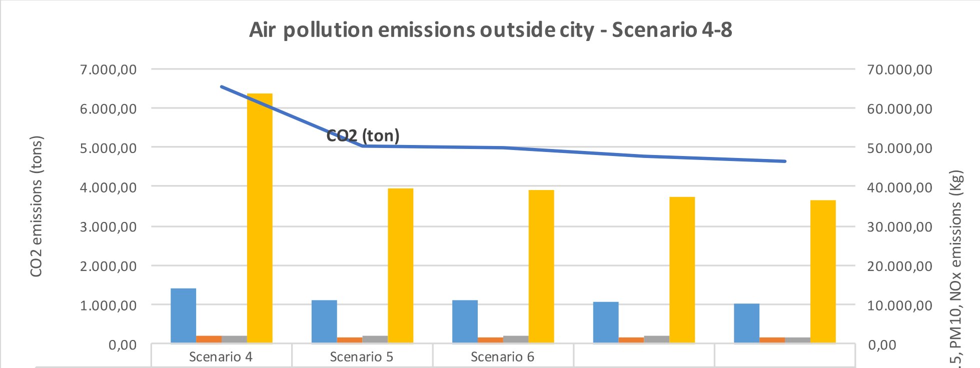
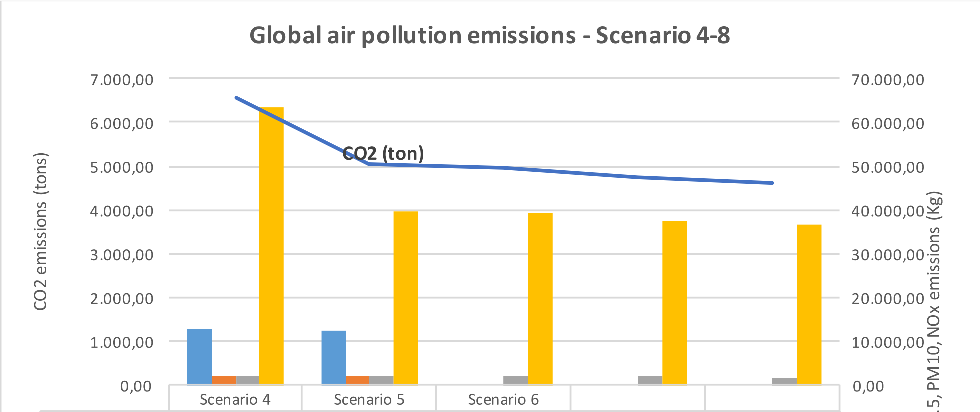


	Scenario 4	Scenario 5	Scenario 6		
CO (Kg)	14.247,33	11.132,56	11.026,60	10.543,61	10.237,49
PM2.5 (Kg)	2.102,97	1.790,48	1.770,05	1.696,27	1.630,81
PM10 (Kg)	2.177,50	1.921,08	1.899,98	1.819,67	1.751,93
PM10 (Kg)	63.403,15	39.531,65	39.176,20	37.474,91	36.579,26
CO2 (ton)	6.538,22	5.023,59	4.979,18	4.756,99	4.630,02

Figure 47: Air pollution emissions outside the city – Paris - Scenario 4-8.

When we consider the global emissions of the complete traveling inside and outside the city, scenarios 7 and 8, with two CCCs shows a global improvement, but this is obtained with a solution that increases the pollution inside the city and decreases it outside.



	Scenario 4	Scenario 5	Scenario 6		
CO (Kg)	12.721,62	12.415,50			
PM2.5 (Kg)	2.015,32	1.949,86			
PM10 (Kg)	2.177,50	1.921,08	1.899,98	1.819,67	1.751,93
PM10 (Kg)	63.403,15	39.531,65	39.176,20	37.474,91	36.579,26
CO2 (ton)	6.538,22	5.023,59	4.979,18	4.756,99	4.630,02

Figure 48: Global air pollutant emissions (inside and outside the city) – Paris – Scenario 4-8.

The tables below report the percentages improvements from scenario 4 to scenario 6, i.e., without CCC and with one CCC and optimization on both echelons, and from scenario 4 to scenario 8, i.e., without CCC and with two CCC and optimization on both echelons.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

SC4 --> SC6			
Pollutant	Inside city	Outside city	Total
CO	-12%	-23%	-21%
PM2.5	-14%	-16%	-16%
PM10	-14%	-13%	-13%
NOx	-9%	-38%	-35%
CO2	-10%	-24%	-23%

SC4 --> SC8			
Pollutant	Inside city	Outside city	Total
CO	21%	-28%	-23%
PM2.5	19%	-22%	-18%
PM10	18%	-20%	-15%
NOx	25%	-42%	-36%
CO2	23%	-29%	-24%

As already observed scenario 8 presents a global improvement on the entire supply chain, but a worsening if we look at the inner city.

The expected benefits for Paris are as follows:

Scenario 4-6			
Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-38%**
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%	**-23%** **-35%** **-13%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-24%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+20%**

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3.3.4 Cost-Benefit-Analysis

3.3.4.1 Business Model 1: CCC managed by a Construction Company

Input data

The following list contains the input data for the case of the Paris pilot regarding the business model of a CCC that is managed by a construction company:

Parameter	Value	Unit
Average yearly Budget of all the Construction Projects	148,148,347	€
Number of Construction Sites	3	sites
Daily Average Deliveries per Construction Site	4.6	Deliveries
Average Weekly Storage Capacity needed [m3]	759.75	m3
Maximum Weekly Storage Capacity needed [m3]	1927.6	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	464	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	602	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	971	km
Number of 3 Axes Truck <25t	7	Units
Annual km of 3 Axes Truck <25t	21,330	km

The input data was obtained from the simulations of the Scenario 6 in the Paris pilot, which considers the implementation of a CCC for the supply chain management several sites in the urban area of Paris. The average yearly budget of the construction sites was estimated considering only the construction sites of the typology "apartments", which corresponds to the pilot from Luxembourg.

Results

The results of the facility and operations dimensioning based on the simulation outputs of the scenario 6 are listed below:

CCC Dimensioning

CCC Facility Dimensioning		
Storage Area Needed in the CCC [m2]	435	m2
Final Facility Dimensioning [m2]	1.076	m2

CCC Labor Force and Machinery Dimensioning	
Manager	1
Other Personnel	1
Operators	3
Drivers	10
Forklifts	2
Other Machinery	2

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For the facility dimensioning and considering 4 levels of shelves in the storage, the facility needs 1,076m^2 to store the average weekly material flows (760m^3 per week) including the area dedicated to corridors, loading and unloading operations and common areas.

For the delivery operations, the outputs of the simulation resulted in 10 trucks needed to cover all the daily deliveries. However, in some cases it is important to notice that they do less than 500 km per year. For the drivers, as in the other cases and scenarios, it was assumed that is needed one driver per truck.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that there are needed 3 operators plus 2 forklifts and 2 pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities.

In reference to the Cost Benefit Analysis carried out for single construction company that operates a CCC for a period of five years, the results obtained were:

Year	ALTERNATIVE 2 CCC	ALTERNATIVE 2. Using CCC											TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
		Additional Cost of CCC					Savings			CCC Summary			
	INVESTMENTS (EUROS)	Facility Rent Costs (€)	Workforce Costs (€)	General expenses CCC (€)	Transport Costs (€)	Maintenance Costs (€)	Labor Force Savings [€/year]	Material Savings [€/year]	Unsorted Bins [€/year]	TOTAL ANNUAL COSTS	TOTAL ANNUAL SAVINGS	BENEFITS	
1	**119.000**	103.295	625.800	10.330	306.511	5.165	2.222.225 €	2.074.077 €	110.222 €	**1.051.101 €**	**4.406.524 €**	**3.355.423 €**	**3.236.423**
2	**0**	105.000	636.126	10.500	311.569	5.250	2.258.892 €	2.108.299 €	112.041 €	**1.068.444 €**	**4.479.232 €**	**3.410.788 €**	**3.410.788**
3	**0**	106.732	646.622	10.673	316.710	5.337	2.296.164 €	2.143.086 €	113.890 €	**1.086.074 €**	**4.553.139 €**	**3.467.066 €**	**3.467.066**
4	**0**	108.493	657.291	10.849	321.935	5.425	2.334.050 €	2.178.447 €	115.769 €	**1.103.994 €**	**4.628.266 €**	**3.524.272 €**	**3.524.272**
5	**-4.400**	110.283	668.136	11.028	327.247	5.514	2.372.562 €	2.214.391 €	117.679 €	**1.122.210 €**	**4.704.633 €**	**3.582.423 €**	**3.586.823**
												NPV	**14.880.772 €**

Year	Percentage of benefits compared to the annual budget of all the projects served via the CCC
1	**2.18%**
2	**2.30%**
3	**2.34%**
4	**2.38%**
5	**2.42%**

In this case, the CBA of a CCC implementation in Paris shows positive effects with an NPV>14M€ after 5 years and potential savings between 2.18-2.42% of the annual budget of the ongoing construction projects. Nevertheless, it is important to remember that this positive effect is explained due to the assumptions of average performance improvement on site, thus is recommended a more detailed study project by project about the possibility to reach these potential improvements in order to get a tailored result per construction project.

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1.1.1.1 Business Model 2: CCC managed by a Logistics Operator

Input data

The input data from the Paris pilot of the business model for a CCC implementation that is managed by a logistics operator is listed below:

Parameter	Value	Unit
Average Distance from CCC to Construction Sites [km]	7.979	km
Number of Construction Sites	10	sites
Daily Average Deliveries per Construction Site	4.6	Deliveries
Average Weekly Storage Capacity needed [m3]	2,295.00	m3
Maximum Weekly Storage Capacity needed [m3]	5,822.70	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	465	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	602	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	971	km
Number of 3 Axes Truck <25t	6	Units
Annual km of 3 Axes Truck <25t	21,330	km

The input data was obtained from the simulations of the Scenarios 6 in the Paris pilot. The average yearly budget of the construction sites was estimated considering all the different typologies of construction sites of the SUCCESS project.

Results

The CBA results provide the dimensioning of the CCC facility based on the simulation outputs listed above and a set of assumptions that are explained in section 2.2. The CCC dimensioning includes an estimation of the size of the facility, the labour force and machinery needed for its operations. Following figure shows a table with the main results:

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CCC Dimensioning

CCC Facility Dimensioning		
Storage Area Needed [m2]	1.339	m2
Facility Dimensioning - Total Area Needed [m2]	3.459	
Final Facility Dimensionng [m2]	4.324	m2

CCC Labor Force and Machinery Dimensioning	
Manager	1
Other Personnel	2
Operators	11
Drivers	10
Forklifts	5
Other Machinery	5

In total, the facility needs an area of around 4,500m^2 to be able to accommodate and store the average weekly material flows (2,2295m^3), including the area dedicated to corridors, loading and unloading operations and common areas.

For the delivery operations, the outputs of the simulation resulted in 10 trucks of different sizes needed to cover all the daily deliveries. For the drivers, it was assumed one driver per truck needed.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that are needed 11 operators and 5 forklifts and 5 pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities. It is important to remark that in the analysis 8h working day shifts and 12h of CCC open hours are considered in the analysis. The results show an approximation of the staff needed based on constant assumptions (see section 2.2 and annex 1 and 2), so working shifts and schedule management could lead to more adjusted figures regarding staff dimensioning.

The CBA analysis also estimates the potential feasibility of the CCC implementation. In one side, the analysis considers the total costs (facility dimensioning, staff, trucks, etc.) and in the other side, the potential incomes due to the services provided by the CCC (see section 2.2 and annexes).

In this regard, in the case of the scenario 6 for the city of Paris (one single CCC operated by a logistics operator and serving several construction sites with both echelons optimization) is feasible from its economic point of view in long-term basis (NPV>2.3€). Following figure shows the main results for the scenario assessed:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Year	Alternative 1: Current Situation Without CCC	Alternative 2: CCC Implementation									TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	Investments	Investments	Vehicles Operational Costs (Euros)	CCC General Expenses (Euros)	CCC Rental Cost (Euros)	CCC Personnel Costs (Euros)	Total Revenues (Euros)	TOTAL ANNUAL COSTS	TOTAL ANNUAL REVENUES	BENEFITS	
1	0	785.867	285.112	62.269	415.127	889.800	2.030.724	1.652.308 €	2.030.724 €	378.416 €	-407.450
2	0	0	289.816	63.296	421.976	904.482	2.064.231	1.679.571 €	2.064.231 €	384.660 €	384.660
3	0	0	294.598	64.341	428.939	919.406	2.098.291	1.707.284 €	2.098.291 €	391.007 €	391.007
4	0	0	299.459	65.402	436.016	934.576	2.132.913	1.735.454 €	2.132.913 €	397.459 €	397.459
5	0	0	304.400	66.482	443.211	949.996	2.168.106	1.764.089 €	2.168.106 €	404.017 €	404.017
6	0	19.333	309.423	67.579	450.524	965.671	2.203.879	1.793.196 €	2.203.879 €	410.683 €	391.350
7	0	0	314.528	68.694	457.957	981.605	2.240.243	1.822.784 €	2.240.243 €	417.459 €	417.459
8	0	0	319.718	69.827	465.514	997.801	2.277.207	1.852.860 €	2.277.207 €	424.347 €	424.347
9	0	0	324.993	70.979	473.195	1.014.265	2.314.781	1.883.432 €	2.314.781 €	431.349 €	431.349
10	0	-53.200	330.356	72.150	481.002	1.031.000	2.352.975	1.914.509 €	2.352.975 €	438.466 €	491.666
										NPV	2.397.983,09 €

The positive NPV and the number of material flows and construction sites served via the CCC (10 sites with an average of near 5 daily deliveries per site), make the CCC a facility potentially feasible under the framework of the assumptions taken into account.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

3.4 Valencia site

The main figures of the Valencia simulation are as follows:

Number of construction sites	23
Number of suppliers	35
Number of potential CCC locations	4
Total budget for the construction sites	Euro 535,814,744.00

Pilot Site

Total budget	Euro 15,800,000.00
Total tons delivered	17,438
Total cubic meters delivered	22,037
Average tons delivered per week	212,66
Average m3 delivered per week	268,74

All construction sites

Total budget	Euro 535,814,744.00
Total tons delivered	528,631
Total cubic meters delivered	462,220
Average tons delivered per week	3,388
Average m3 delivered per week	2,962

In Figure 49 the possible CCC locations are indicated by yellow icons, while the green icons indicate the positions of the construction sites.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

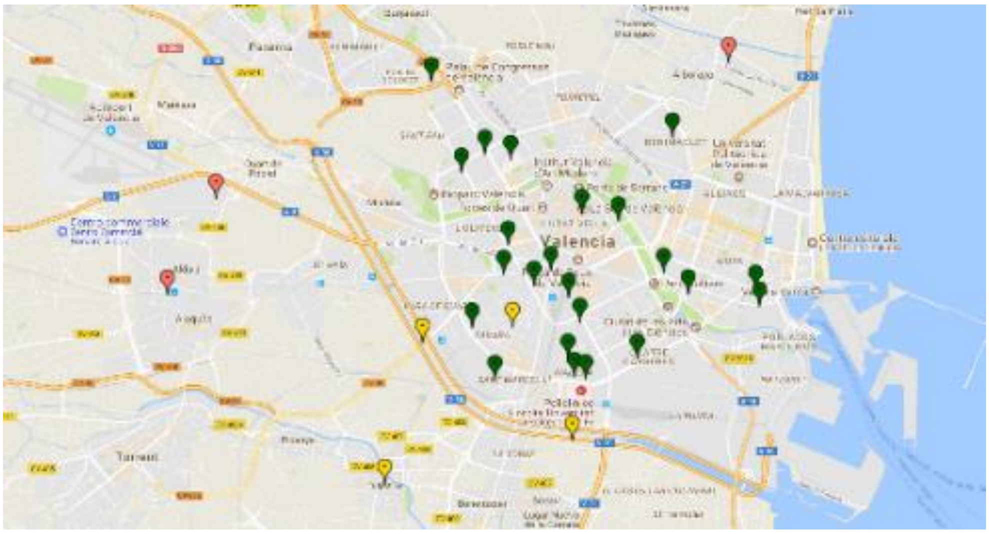

Figure 49: Valencia CCCs and construction sites.

The positions of the suppliers are indicated in the Figure 50, by the red icons. Most of them are close to the city, but a few ones are some hundreds of kilometres far, in Spain and one in Portugal.

Figure 50: Suppliers of the Valencia simulation site.

3.4.1 CCC location

The stochastic model has been used to determine the best CCC location among the 4 potential locations. The expected values of the locations, expressed in kilometres x cubic meters are the following:

Location	Expected objective value
Calle Santander 7, Valencia	4.84779e+10
Poligono Industrial la Mina, Paiporta	3.93602e+07
Av. Europa, Valencia	3.97751e+07
Polígono Vara de Quart, Valencia	3.84117e+07

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 633338.

The best choice is the fourth location, highlighted in the following figure.

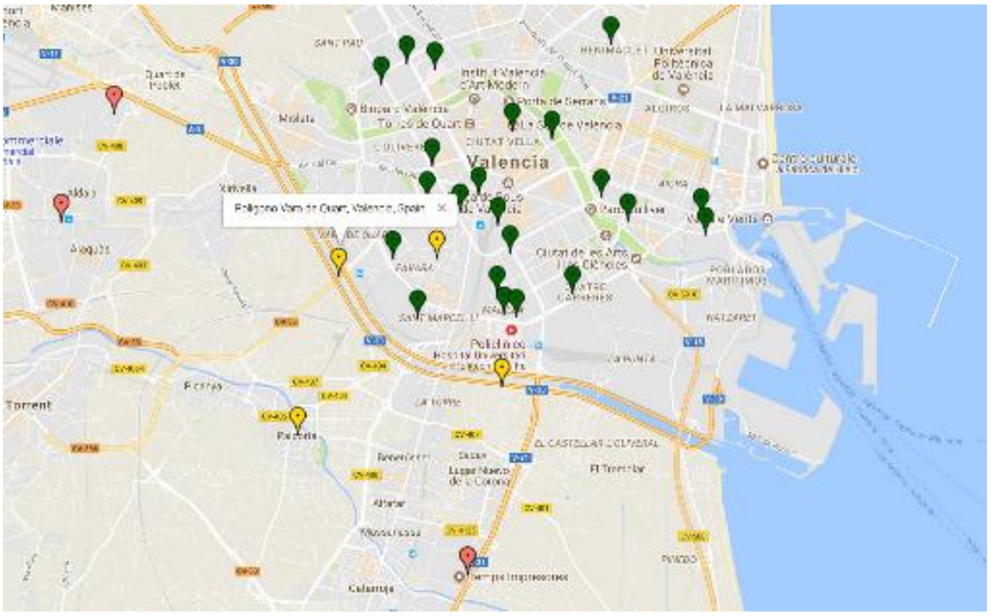

Figure 51: Best CCC location for Valencia.

3.4.2 Comparison of the scenarios with a single big site

The comparison of the baseline (scenario 1) with the two scenarios using a CCC is as follows.

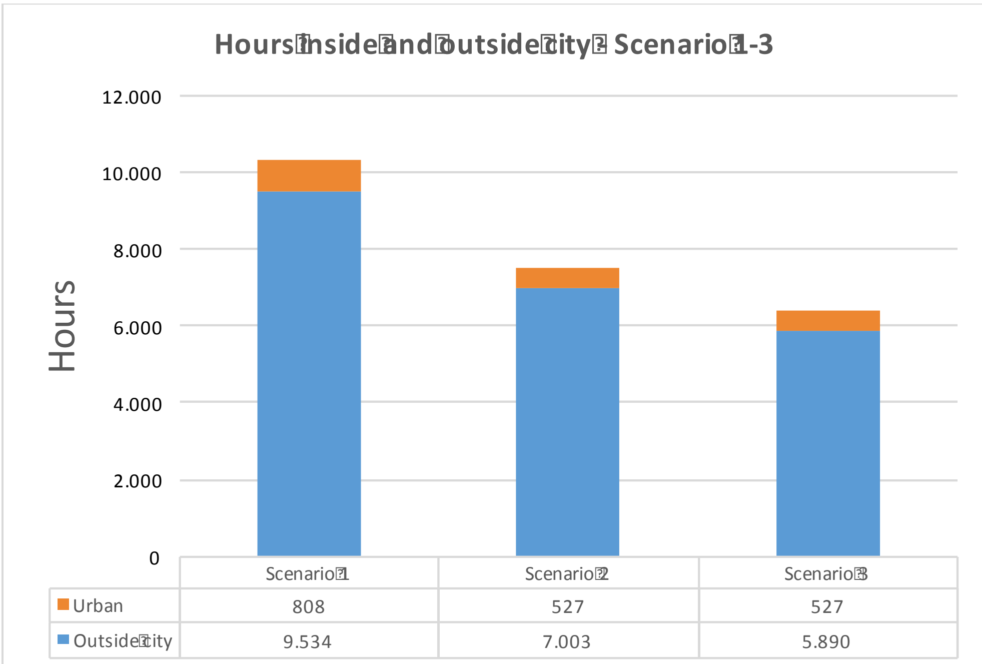

Figure 52: Comparison of traveling times – Valencia - Scenarios 1-3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

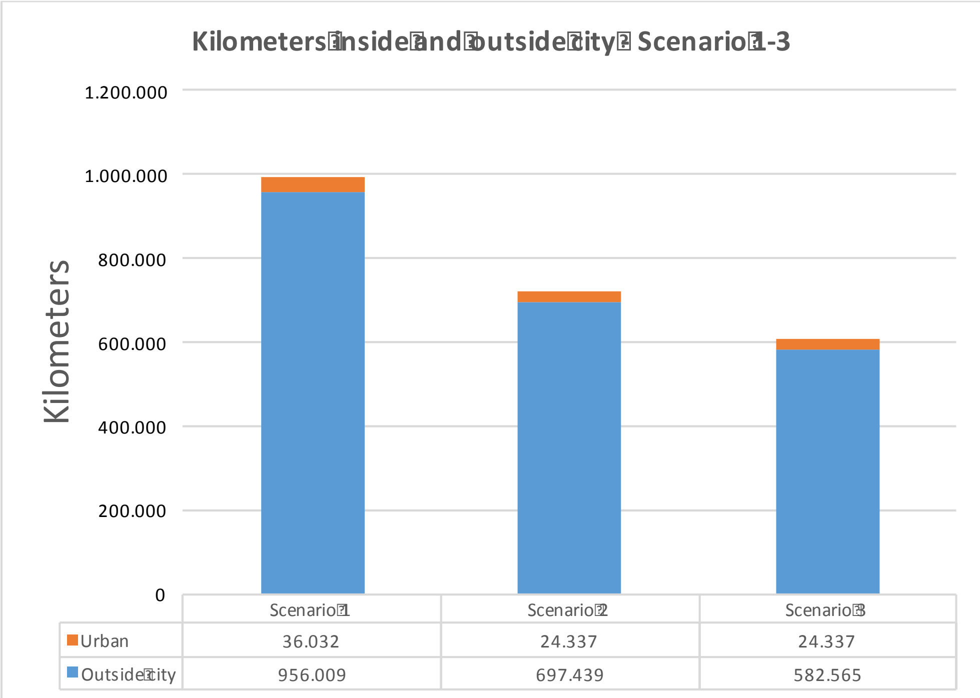

Figure 53: Comparison of distances travelled – Valencia - Scenarios 1-3.

The two above figures show that the deliveries improve when a CCC is used. In scenario 2 the total number of kilometres and the total duration of the deliveries reduce by more than 20%. In scenario 3 where the optimization is on both echelons there is further improvements.

Figure 54: Comparison of number of trips – Valencia - Scenarios 1-3.

The number of trips drastically reduces when a CCC is used.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

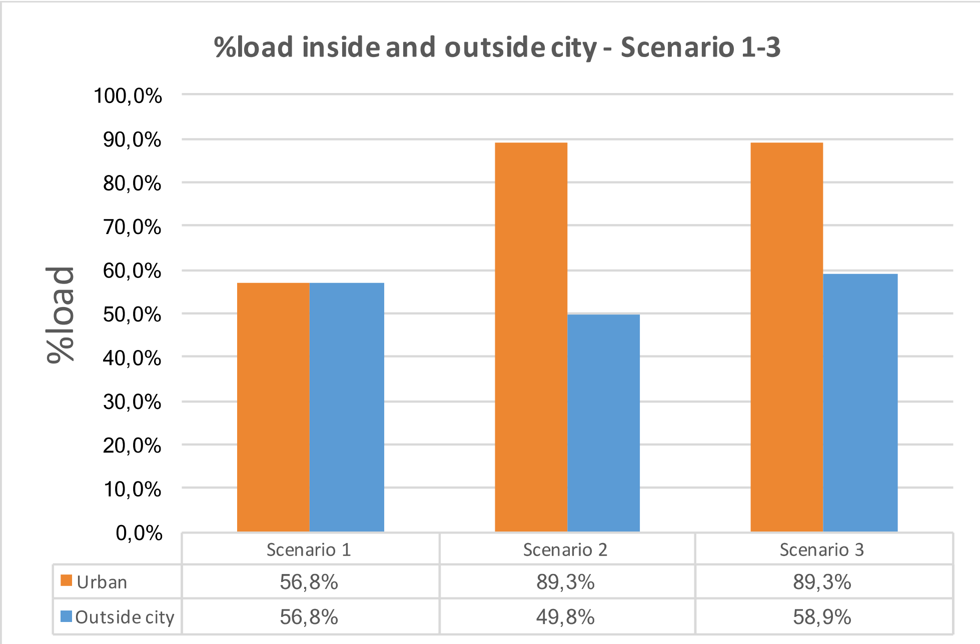

Figure 55: Comparison of % loads - Valencia - Scenario 1-3.

The pictures and tables show a clear advantage in the use of a CCC. Indeed, there is a reduction in kilometres travelled, number of trips and trips duration. The loading factor inside the cities increases, while outside the city it increases when the echelon is optimized (scenario 3).

The next table reports the percentage advantages in terms of trips, kilometres travelled, traveling time and truck load.

SC1 --> SC3			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-42%	-42%	-42%
Kilometres / day travelled by vehicles	-32%	-39%	-39%
% Increase load factor	57%	4%	30%
Travel time	-35%	-38%	-38%

Inside and outside the city the reduction is comparable and always relevant (close to 40%).

The following pictures report on the pollutant emissions in the three scenarios. We can anticipate here that also in this case there is a clear and large advantage in the use of the CCC.

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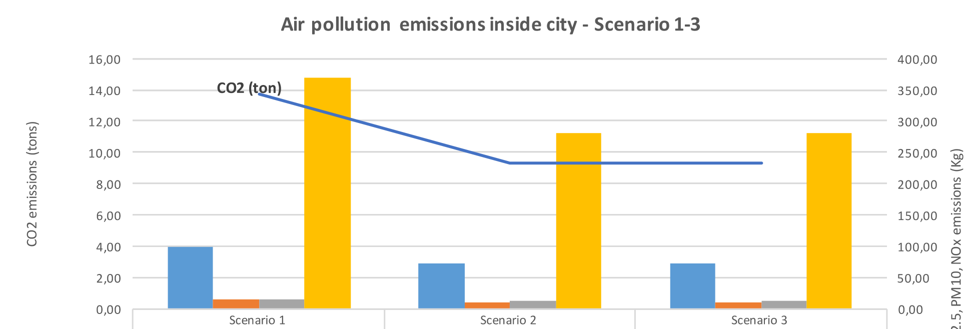
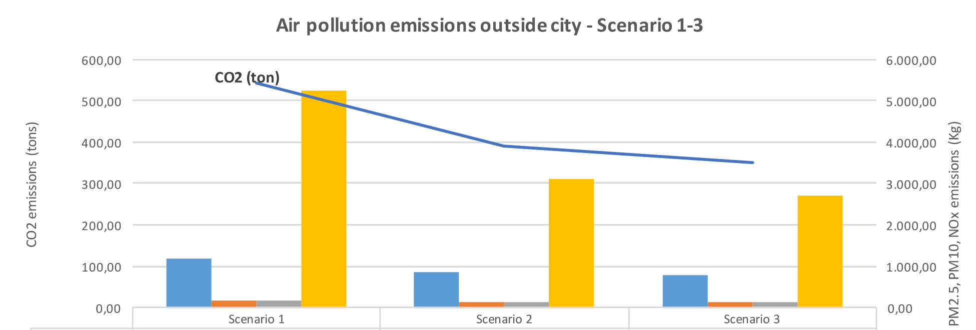


	Scenario 1	Scenario 2	Scenario 3
CO (Kg)	98,32	72,85	72,85
PM2.5 (Kg)	14,82	10,79	10,79
PM10 (Kg)	15,45	11,22	11,22
Nox (Kg)	368,33	281,51	281,51
CO2 (ton)	13,75	9,28	9,28

Figure 56: Air pollution emissions in urban area - Valencia- Scenario 1-3.



	Scenario 1	Scenario 2	Scenario 3
CO (Kg)	1184,11	864,15	778,23
PM2.5 (Kg)	175,75	137,81	124,31
PM10 (Kg)	181,98	147,88	133,64
Nox (Kg)	5242,77	3100,17	2726,73
CO2 (ton)	542,66	389,24	352,23

Figure 57: Air pollution emissions outside city – Valencia - Scenario 1-3.

The tables show a clear advantage in the use of a CCC, in term of air pollution emissions, which monotonically decrease for all pollutants, both in the urban and non-urban area. In the next table, we present in detail the percentage decrease of pollutants from Scenario 1 (baseline) to Scenario 3 (one CCC, both echelons optimized).

	SC1 --> SC3		
Pollutant	Inside city	Outside city	Total
CO	-26%	-34%	-34%
PM2.5	-27%	-29%	-29%
PM10	-27%	-27%	-27%
NOx	-24%	-48%	-46%
CO2	-32%	-35%	-35%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The expected benefits for Valencia, are as follows:

Expected benefits	Indicators	Average quantified impacts in the pilot sites	Simulation results – inside city
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-42%**
Reduction of transport related pollutant emissions	CO_2 emissions NOx emissions PM10 emissions	-40%	**-35%** **-46%** **-27%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-39%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+30%**

3.4.3 Comparison of the scenarios with multiple sites

The comparison of the baseline (scenario 4) with the two scenarios using a CCC is as follows:

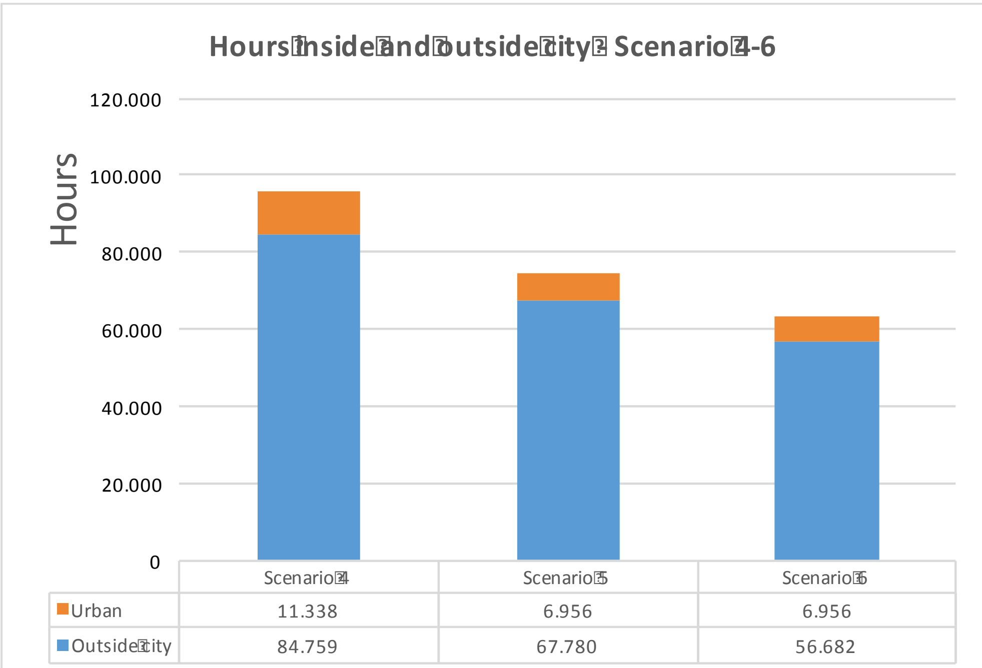


Figure 58: Comparison of traveling times - Valencia - Scenarios 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

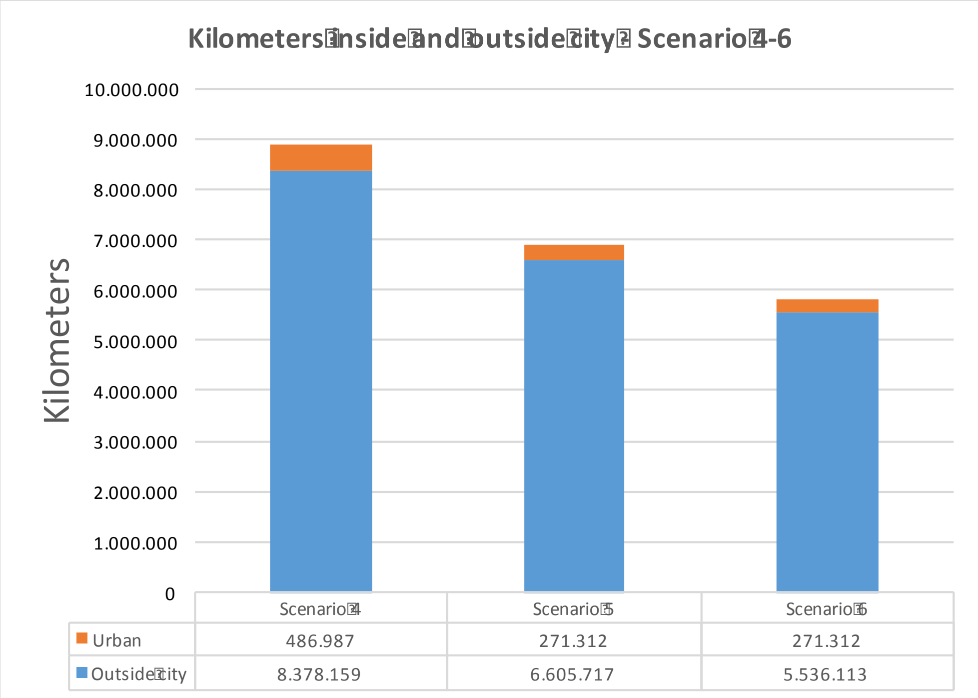


Figure 59: Comparison of distances travelled- Valencia - Scenarios 4-6.

The two above figures show that the deliveries can be optimized when a CCC is implemented. In scenario 5 the total number of kilometres and total duration of the deliveries decrease by more than 40%. In Scenario 6, where the optimization is on both echelons, there are further improvements.

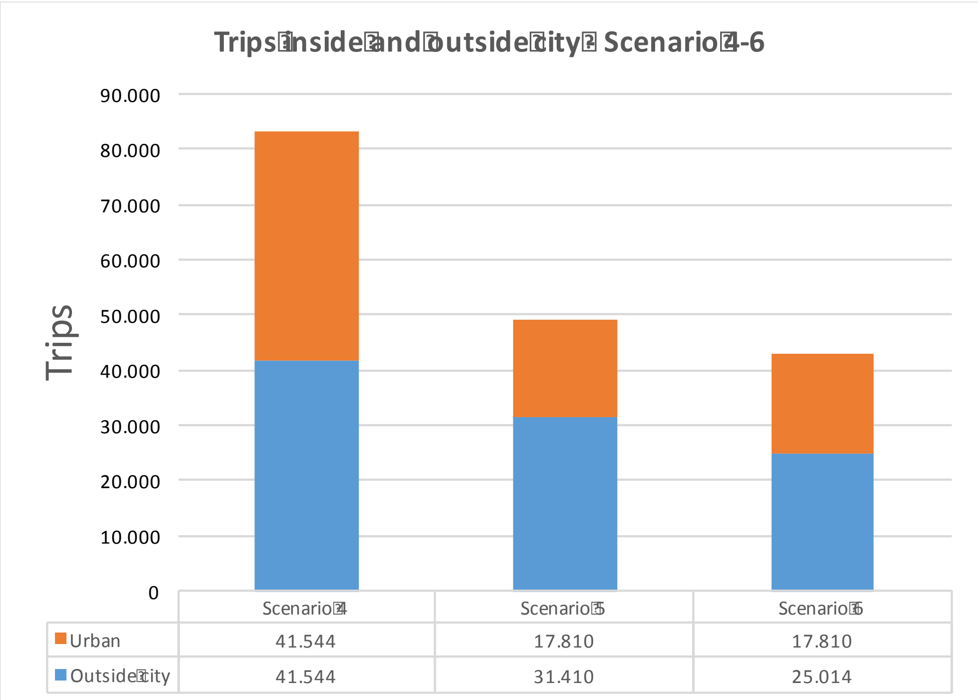


Figure 60: Comparison of number of trips - Valencia - Scenarios 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

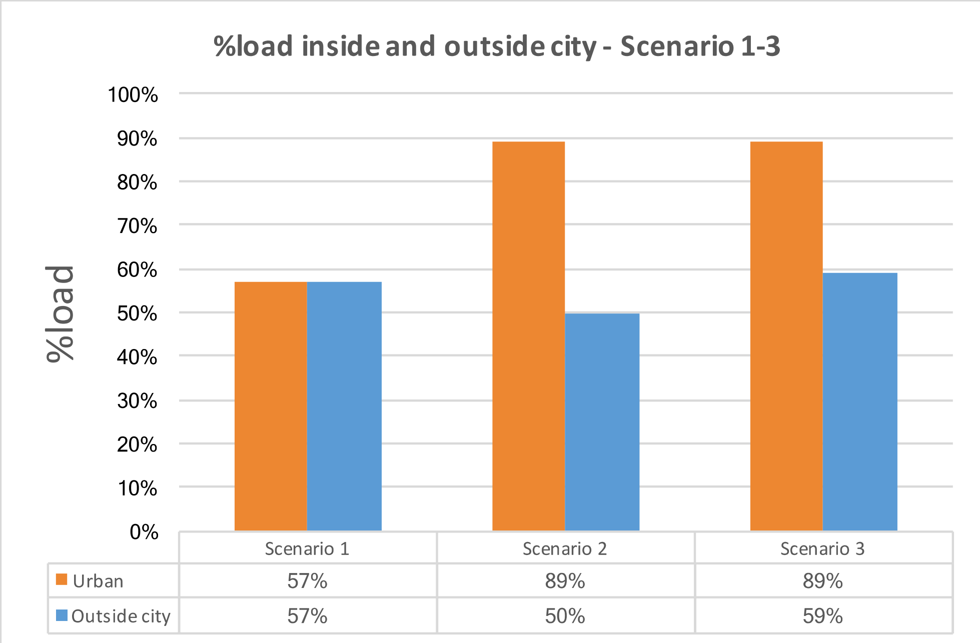


Figure 61: Comparison of % loads - Valencia - Scenario 4-6.

Again, the number of trips drastically reduces when a CCC is used. The indicators in the next table summarize the improvement of scenario 6 with respect to the baseline (scenario 4).

SC4 --> SC6			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-57%	-40%	-48%
Kilometres / day travelled by vehicles	-44%	-34%	-34%
% Increase load factor	87%	1%	44%
Travel time	-39%	-33%	-34%

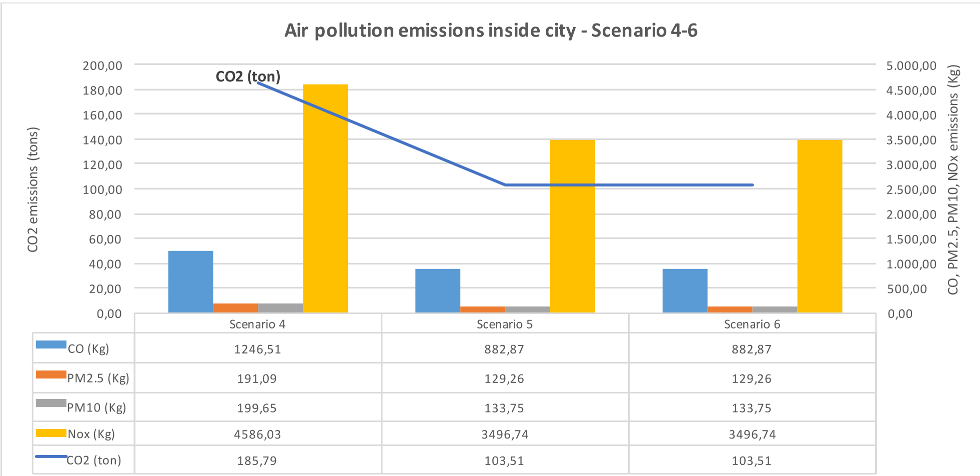


Figure 62: Air Pollution emissions in the urban area - Valencia - Scenario 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

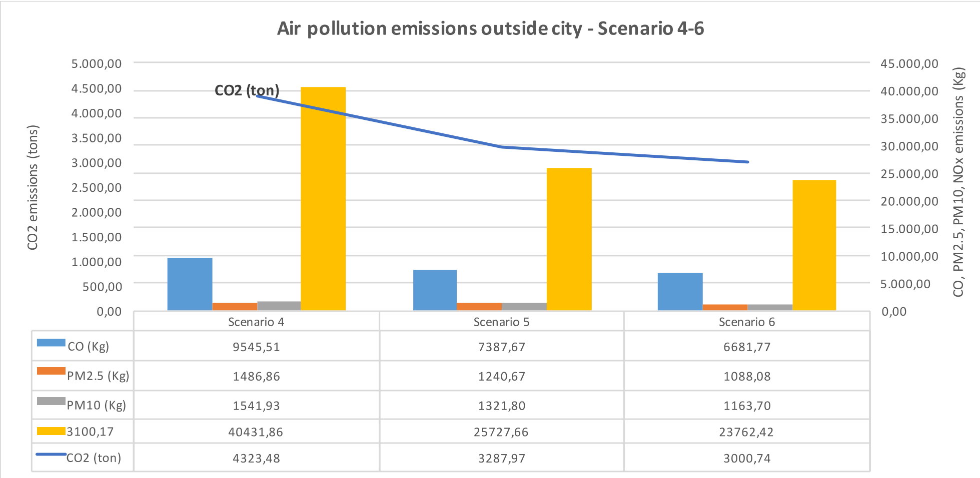


Figure 63: Air Pollution emissions outside the city - Valencia - Scenario 4-6.

The table below report the percentages improvements from scenario 4 to scenario 6, i.e., without CCC and with CCC and optimization on both echelons.

There is an overall improvement about 30%. The gains are similar inside and outside the city.

SC4 -->SC6			
Polluttant	**Inside city**	**Outside city**	**Total**
CO	-29%	-30%	-30%
PM2.5	-32%	-27%	-27%
PM10	-33%	0%	-26%
NOx	-24%	-41%	-39%
CO2	-44%	-31%	-31%

The expected benefits for Valencia, are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results – inside city**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-48%**
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%	**-31%** **-39%** **-26%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-34%**
	Small deliveries (fewer than 4 pallets)	-50%	**-100%**
Maximise load factor	% Increase load factor	30%	**+44%**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

3.4.4 Cost-Benefit-Analysis

3.4.4.1 *Business Model 1: CCC managed by a Construction Company*

Input data

The input data required from the Valencia pilot of the business model of a CCC implementation that is managed by a construction company is listed below:

Parameter	Value	Unit
Average yearly Budget of all the Construction Projects	71,767,864.56	€
Average number of ongoing Construction Sites	7.7	sites
Daily Average Deliveries per Construction Site	3.14	Deliveries
Average Weekly Storage Capacity needed [m3]	1,226.78	m3
Maximum Weekly Storage Capacity needed [m3]	1,632.08	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	533	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	914	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	990	km
Number of 3 Axes Truck <25t	6	Units
Annual km of 3 Axes Truck <25t	14,562	km

The input data was obtained from the simulations of the Scenarios 6 in the Valencia pilot. The average yearly budget of the construction sites was estimated considering only the construction sites of the typology "apartments", which corresponds to the pilot from Luxembourg.

Results

The results of the facility and operations dimensioning based on the simulation outputs and the set of assumptions previously explained (section 2.2) were as follows:

CCC Dimensioning

CCC Facility Dimensioning		
Storage Area Needed in the CCC [m2]	703	m2
Final Facility Dimensioning [m2]	1.737	m2

CCC Labor Force and Machinery Dimensioning	
Manager	1
Other Personnel	2
Operators	5
Drivers	9
Forklifts	3
Other Machinery	3

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For the facility dimensioning and considering 4 levels of shelves for the storage, the facility needs 1,773m² to store the average weekly material flows (1,227m³ per week) including the area dedicated to corridors, loading and unloading operations and common areas.

For the delivery operations, the outputs of the simulation resulted in 9 trucks to cover all the daily deliveries. For the drivers, as in the other cases, it was assumed one driver per truck needed.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that there are needed 5 operator plus 3 forklifts and 3 pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities (e.g. technical maintenance).

In reference to the Cost Benefit Analysis carried out for a period of five years, the results obtained for the Valencia case were as follows:

Year	ALTERNATIVE 2 CCC	ALTERNATIVE 2. Using CCC											TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
		Additional Cost of CCC					Savings			CCC Summary			
	INVESTMENTS (EUROS)	Facility Rent Costs (€)	Workforce Costs (€)	General expenses CCC (€)	Transport Costs (€)	Maintenance Costs (€)	Labor Force Savings [€/year]	Material Savings [€/year]	Unsorted Bins [€/year]	TOTAL ANNUAL COSTS	TOTAL ANNUAL SAVINGS	BENEFITS	
1	**141.000**	83.397	585.864	8.340	252.536	4.170	1.076.518 €	1.004.750 €	53.395 €	**934.306 €**	**2.134.663 €**	**1.200.357 €**	**1.059.357**
2	**0**	84.773	595.531	8.477	256.703	4.239	1.094.281 €	1.021.328 €	54.276 €	**949.722 €**	**2.169.885 €**	**1.220.163 €**	**1.220.163**
3	**0**	86.171	605.357	8.617	260.939	4.309	1.112.336 €	1.038.180 €	55.172 €	**965.393 €**	**2.205.688 €**	**1.240.296 €**	**1.240.296**
4	**0**	87.593	615.345	8.759	265.244	4.380	1.130.690 €	1.055.310 €	56.082 €	**981.322 €**	**2.242.082 €**	**1.260.761 €**	**1.260.761**
5	**-6.600**	89.039	625.499	8.904	269.621	4.452	1.149.346 €	1.072.723 €	57.008 €	**997.514 €**	**2.279.077 €**	**1.281.563 €**	**1.288.163**
												NPV	**5.233.590 €**

Year	Percentage of benefits compared to the annual budget of all the projects served via the CCC
1	**1.48%**
2	**1.70%**
3	**1.73%**
4	**1.76%**
5	**1.79%**

In this case, the CBA for the implementation of a CCC managed by a construction company in Valencia that serves several construction sites, shows positive effects with an NPV>5M€ after 5 years of operations. In addition, the CCC also shows potential between 1.48-1.79% of the annual budget of the ongoing construction projects.

It is important to remember that this positive effect is explained due to the assumptions of performance improvement on site, thus is recommended a more detailed study case by case about on these potential improvements in order to get a tailored result per construction site.

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3.4.4.2 Business Model 2: CCC managed by a Logistics Operator

Input data

The input data from the Valencia pilot of the business model for a CCC implementation that is managed by a logistics operator is listed below:

Parameter	Value	Unit
Average Distance from CCC to Construction Sites [km]	7.29	km
Number of Construction Sites	14	sites
Daily Average Deliveries per Construction Site	3.14	Deliveries
Average Weekly Storage Capacity needed [m3]	2,963.00	m3
Maximum Weekly Storage Capacity needed [m3]	3,941.90	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	533	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	914	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	990	km
Number of 3 Axes Truck <25t	6	Units
Annual km of 3 Axes Truck <25t	14,562	km

The input data was obtained from the simulations of the Scenarios 6 in the Valencia pilot.

Results

Firstly, the CBA results provide the dimensioning of the CCC facility based on the simulation outputs and a set of assumptions explained in section 2.2. The CCC dimensioning include an estimation of the size of the facility, the labour force and machinery needed. Following figure shows a table with the main results:

CCC Dimensioning		
CCC Facility Dimensioning		
Storage Area Needed [m2]	1.728	m2
Facility Dimensioning - Total Area Needed [m2]	4.423	
Final Facility Dimensionng [m2]	5.528	m2
CCC Labor Force and Machinery Dimensioning		
Manager	1	
Other Personnel	2	
Operators	10	
Drivers	9	
Forklifts	6	
Other Machinery	6	

In total and considering 4 stacking levels in the storage, the facility needs slightly more than 5.500m^2 to be able to store the average weekly material flows

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(2.963m³), including the area dedicated to corridors, loading and unloading operations and common areas.

For the delivery operations, the outputs of the simulation resulted in 9 trucks of different sizes needed to cover all the daily deliveries. For the drivers, it was assumed that one driver is needed per truck.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that are needed 10 operators and 6 forklifts and 6 pallet trucks for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities. It is important to remark that in the analysis 8h working day shifts and 12h of CCC open hours are considered in the analysis. The results show an approximation of the staff needed based on constant assumptions (see section 2.2 and annex 1 and 2), so working shifts and schedule management could lead to more adjusted figures regarding staff dimensioning.

Secondly, the CBA analysis also estimates the potential feasibility of the CCC implementation. In one side, the analysis considers the total costs (facility dimensioning, staff, trucks, etc.) and in the other side, the potential incomes due to the services provided by the CCC (see section 2.2 and annexes).

In this regard, in the case of the scenario 6 for the city of Valencia (two echelons optimization and one single CCC operated by a logistics operator and serving several construction sites) is feasible in long-term basis (NPV>10M€). Following figure shows the main results for the scenario assessed:

Year	Alternative 1: Current Situation Without CCC	Alternative 2: CCC Implementation										TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	Investments	Investments		Vehicles Operational Costs (Euros)	CCC General Expenses (Euros)	CCC Rental Cost (Euros)	CCC Personnel Costs (Euros)	Total Revenues (Euros)	TOTAL ANNUAL COSTS	TOTAL ANNUAL REVENUES	BENEFITS	
1	0	741.447		159.014	39.804	265.359	734.184	2.541.473	1.198.360 €	2.541.473 €	1.343.113 €	601.666
2	0	0		162.194	40.600	270.666	748.868	2.592.303	1.222.328 €	2.592.303 €	1.369.975 €	1.369.975
3	0	0		165.438	41.412	276.079	763.845	2.644.149	1.246.774 €	2.644.149 €	1.397.374 €	1.397.374
4	0	0		168.747	42.240	281.601	779.122	2.697.032	1.271.710 €	2.697.032 €	1.425.322 €	1.425.322
5	0	0		172.122	43.085	287.233	794.704	2.750.972	1.297.144 €	2.750.972 €	1.453.828 €	1.453.828
6	0	22.653		175.564	43.947	292.978	810.598	2.805.992	1.323.087 €	2.805.992 €	1.482.905 €	1.460.252
7	0	0		179.075	44.826	298.837	826.810	2.862.111	1.349.549 €	2.862.111 €	1.512.563 €	1.512.563
8	0	0		182.657	45.722	304.814	843.347	2.919.354	1.376.540 €	2.919.354 €	1.542.814 €	1.542.814
9	0	0		186.310	46.637	310.910	860.214	2.977.741	1.404.070 €	2.977.741 €	1.573.670 €	1.573.670
10	0	-47.200		190.036	47.569	317.128	877.418	3.037.296	1.432.152 €	3.037.296 €	1.605.144 €	1.652.344

NPV	10.572.103,26 €

However, it is important to remark that the case of the CBA of Valencia has the lowest costs (transport, rental, labour, etc.) meanwhile the basic income of this business model (i.e. price per pallet moved) was constant for the four pilots in order to be able to compare the results. Thus, as the NPV is much higher than the

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rest of the analysis, seems that there is margin to reduce the price per pallet in this specific scenario. The sensitivity analysis done for this business model (see Annex 3) shows the importance of the pallet price for the feasibility of the CBA.

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3.5 Verona site

The main figures of the Verona simulation are as follows

Number of construction sites	49
Number of suppliers	46
Number of potential CCC locations	5
Total budget for the construction sites	Euro 219,948,000

Pilot Site

Total budget	Euro 126,000,000
Total tons delivered	3,742
Total cubic meters delivered	5,497
Average tons delivered per week	40.24
Average m3 delivered per week	59,11

All construction sites

Total budget	Euro 219,948,000
Total tons delivered	79,537
Total cubic meters delivered	70,997
Average tons delivered per week	509.85
Average m3 delivered per week	455.11

In the following figure, the possible CCC locations are indicated by yellow icons, while the green icons indicate the positions of the construction sites.

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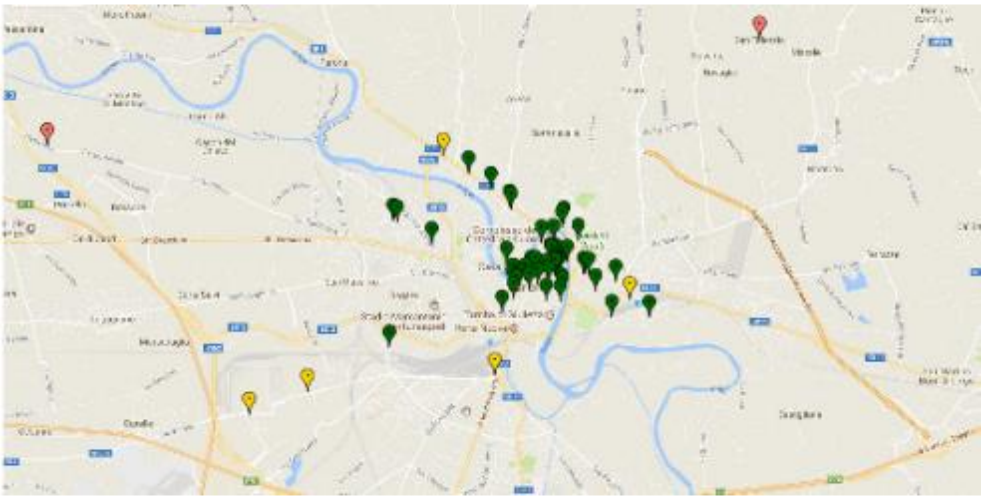

Figure 64: Verona CCCs and construction sites.

The positions of the suppliers are indicated in the next figure, by the red icons. Most of them are a few kilometres from the city and a few ones are about thousand kilometres far.

Figure 65: Suppliers of the Verona simulation site.

3.5.1 CCC location

The stochastic model has been used to determine the best CCC location among the 5 potential locations. The expected values of the locations, expressed in kilometres x cubic meters are the following:

Location	Expected objective value
Prossimità Quadrante Europa	5.29576e+06
Area Ferroviaria Porta Vescoso	6.39377e+06
Scalo Ferroviario	5.26058e+06
Ex Autogerma	5.24046e+06
Area via Ca di Cozzi	4.88364e+06

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The best choice is the fifth location, highlighted in the following figure.

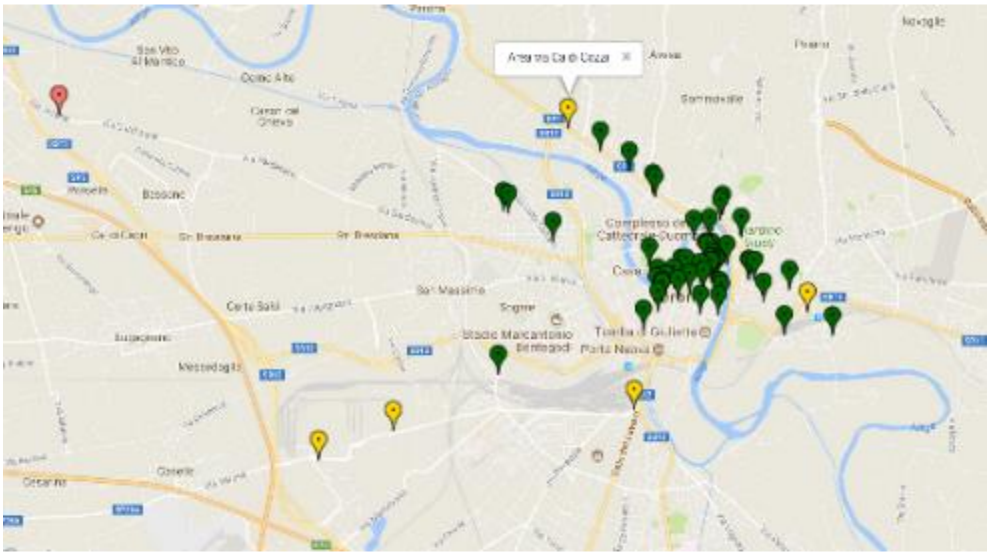

Figure 66: Best CCC location for Verona.

3.5.2 Comparison of the scenarios with a single big site

The following figures will be dedicated to the comparison of the baseline, described in Scenario 1, with the two scenarios using a CCC described in scenario 2 and 3.

The following two figures will show that, when a CCC is used, the deliveries improve.

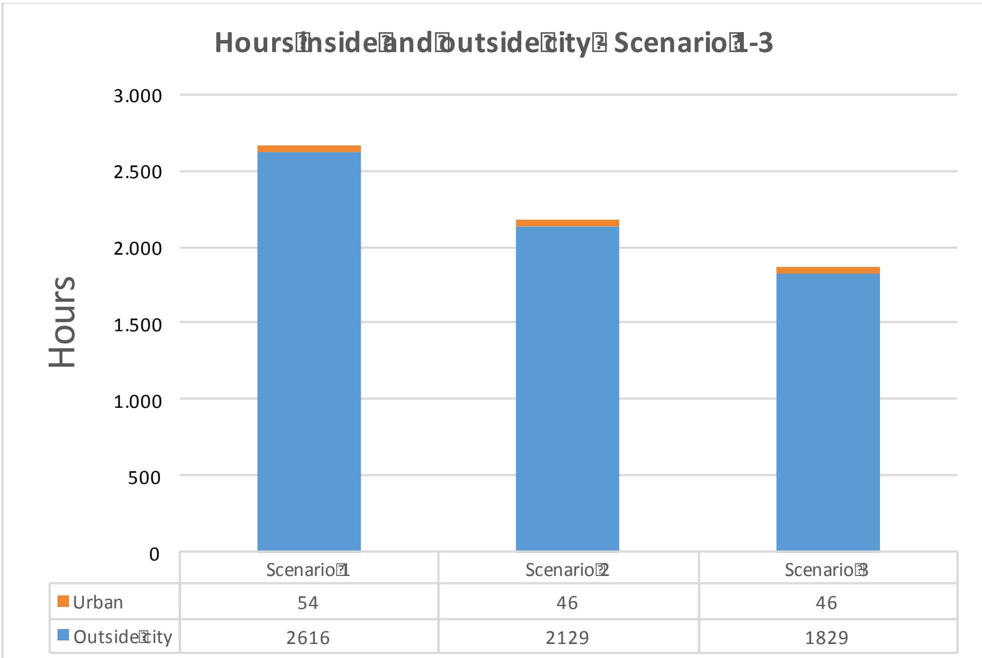

Figure 67: Comparison of traveling times – Verona - Scenario 1-3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

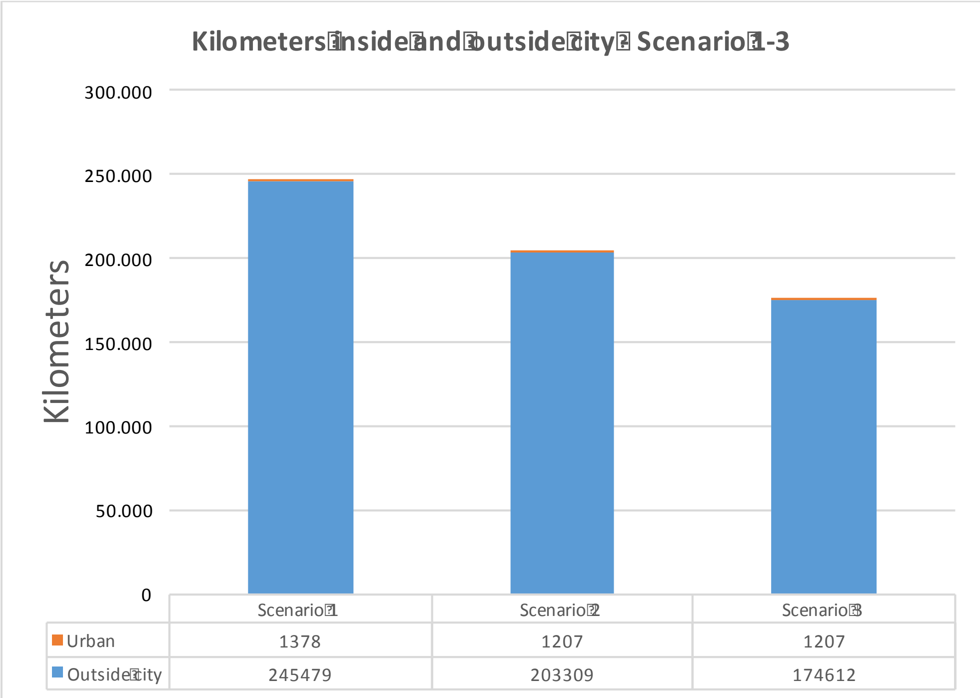

Figure 68: Comparison of distance travelled – Verona - Scenario 1-3.

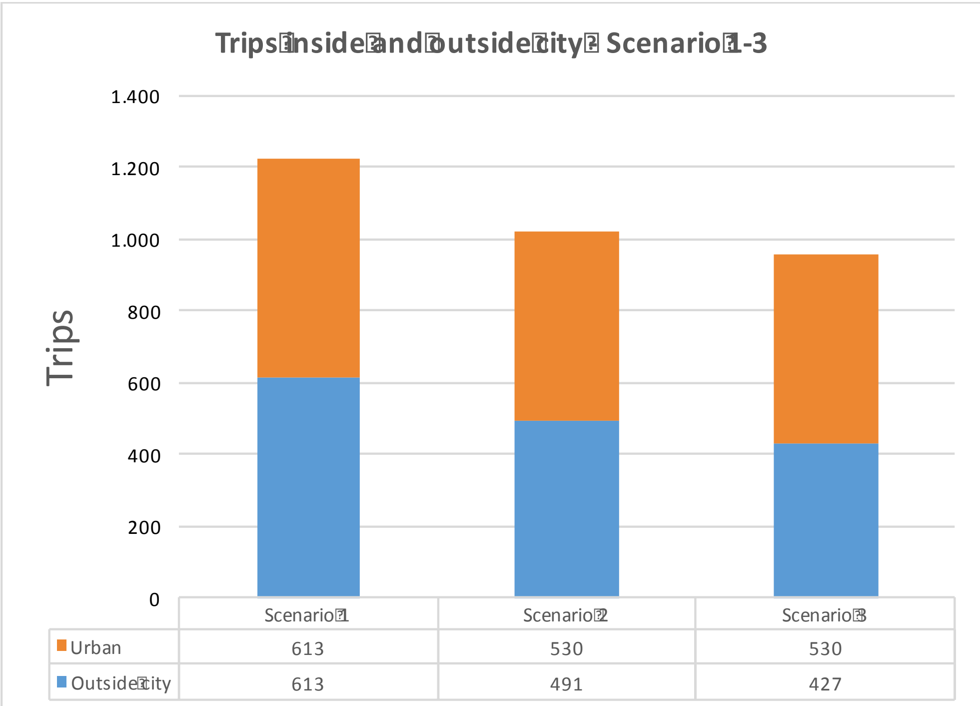

Figure 69: Comparison of number of trips – Verona - Scenario 1-3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

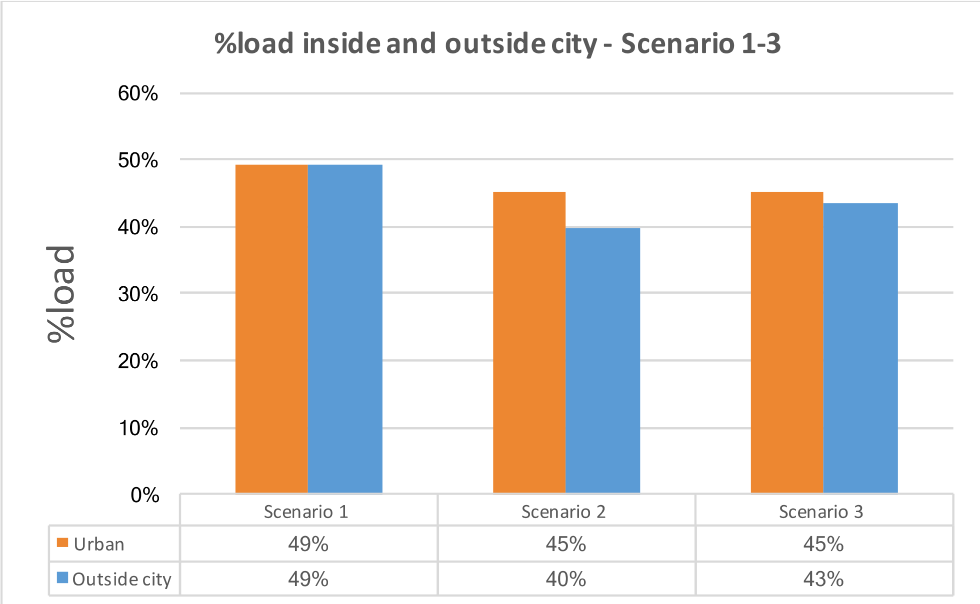

Figure 70: Comparison of % loads - Verona - Scenarios 1-3.

As it can be noticed from the above figure and by the summarizing table below, the traveling time, kilometres and number of trips reduce when a CCC is used.

SC1 --> SC3			
Indicator	**Inside city**	**Outside city**	**Total**
Daily number of freight vehicles	-14%	-30%	-22%
Kilometres / day travelled by vehicles	-12%	-29%	-29%
% Increase load factor	8%	12%	10%
Travel time	-15%	-30%	-30%

There is a good improvement in terms of number of deliveries, kilometres travelled and travel time, with largest gains outside the city. Instead, the loading shows a small improvement. This is mainly due to the mix of use of larger trucks to reduce the number of trips and to the limited material flows. Indeed, one can observe that the Verona pilot is much smaller of the other pilots, in terms of budget, hence of foreseen construction site sizes, and so of total materials to be delivered.

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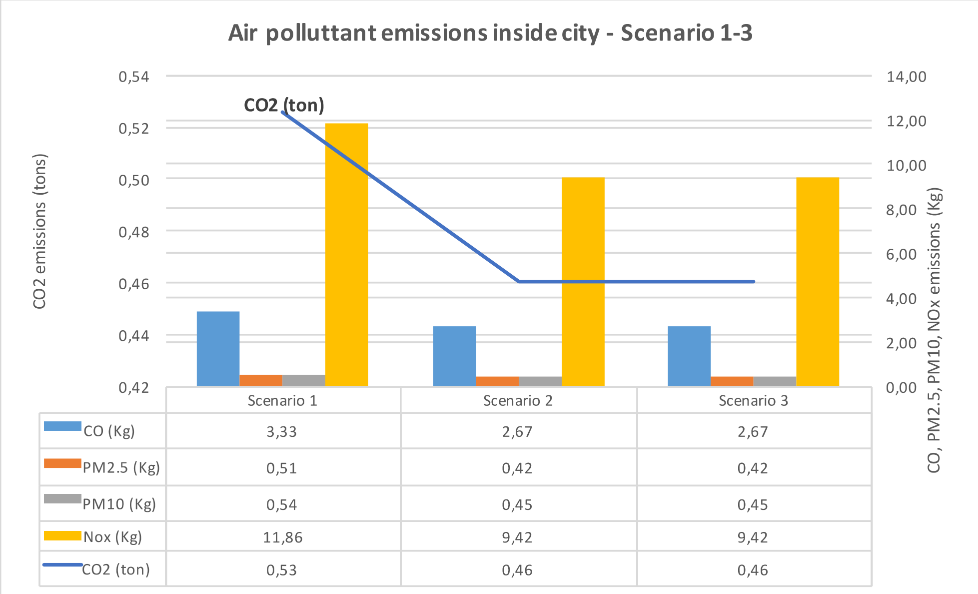


Figure 71: Air pollution emissions in the urban area – Verona – Scenarios 1-3.

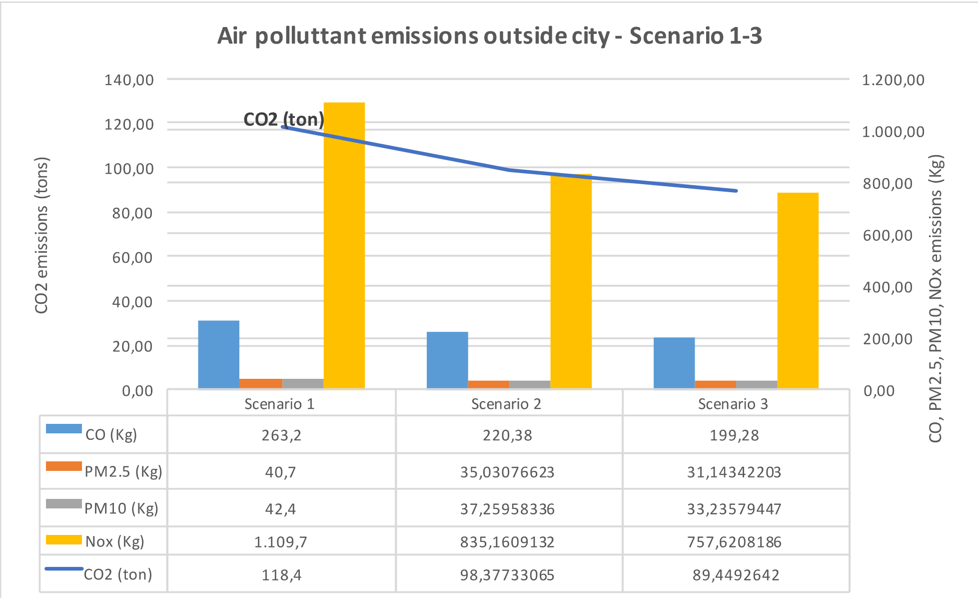


Figure 72: Air pollution emissions outside the city - Verona - Scenarios 1-3.

The results are summarized in the next table:

	SC1 --> SC3		
Pollutant	Inside city	Outside city	Total
CO	-20%	-24%	-24%
PM2.5	-17%	-23%	-23%
PM10	-16%	-22%	-21%
NOx	-21%	-32%	-32%
CO2	-12%	-24%	-24%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

There is an improvement for all pollutant emissions with a similar behaviour inside and outside the city. The reductions ranges from 20% to 30%.

The expected benefits for Verona, are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**-22%**
Reduction of transport related pollutant emissions	CO_2 emissions NOx emissions PM10 emissions	-40%	**-24%** **-32%** **-21%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**-29%**
	Small deliveries (fewer than 4 pallets)	-50%	**100%**
Maximise load factor	% Increase load factor	30%	**+ 10%**

3.5.3 Comparison of the scenarios with multiple sites

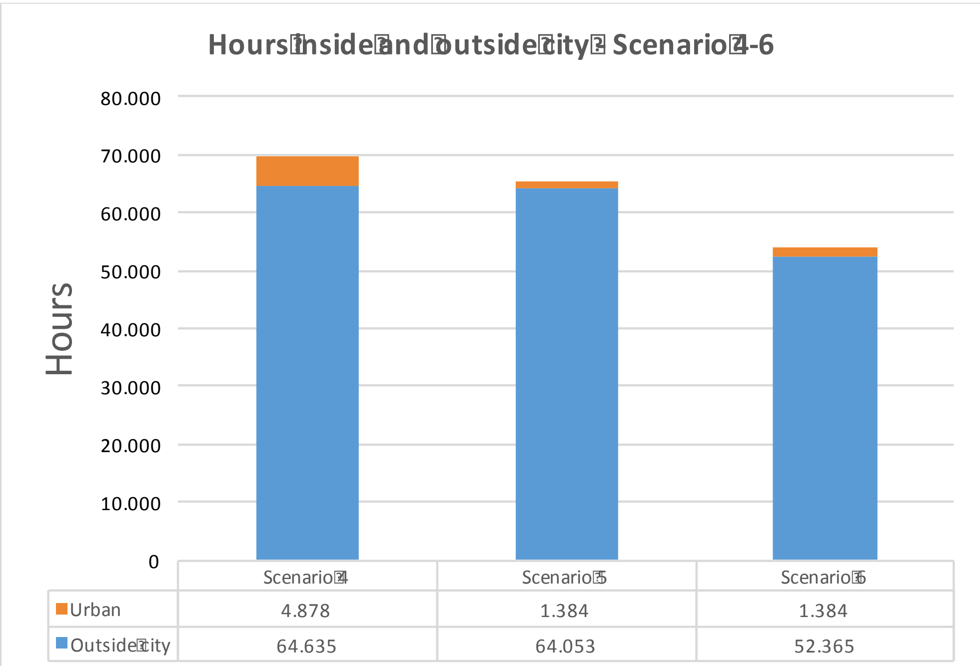
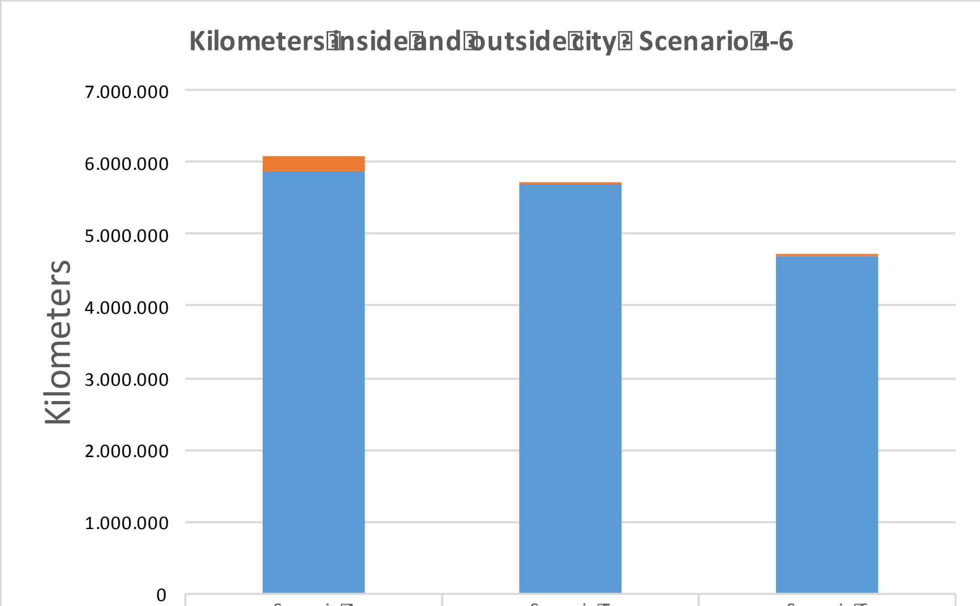


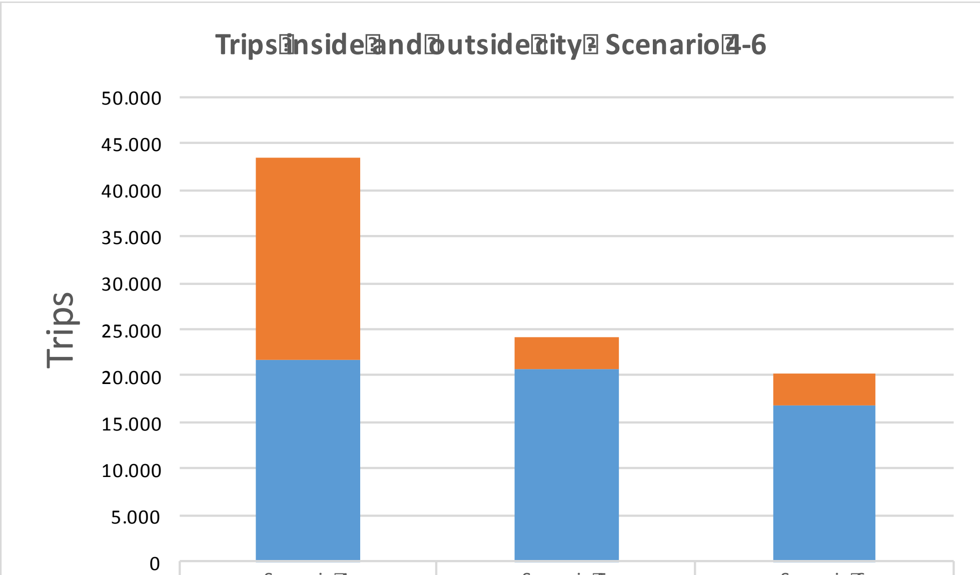
Figure 73: Comparison of traveling times – Verona - Scenario 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Scenario 4	Scenario 5	Scenario 6
Urban	205.408	29.601	29.601
Outside city	5.886.477	5.685.172	4.686.482

Figure 74: Comparison of distance travelled – Verona - Scenario 4-6.



	Scenario 4	Scenario 5	Scenario 6
Urban	21.714	3.360	3.360
Outside city	21.714	20.842	16.773

Figure 75: Comparison of number of trips – Verona - Scenario 4-6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

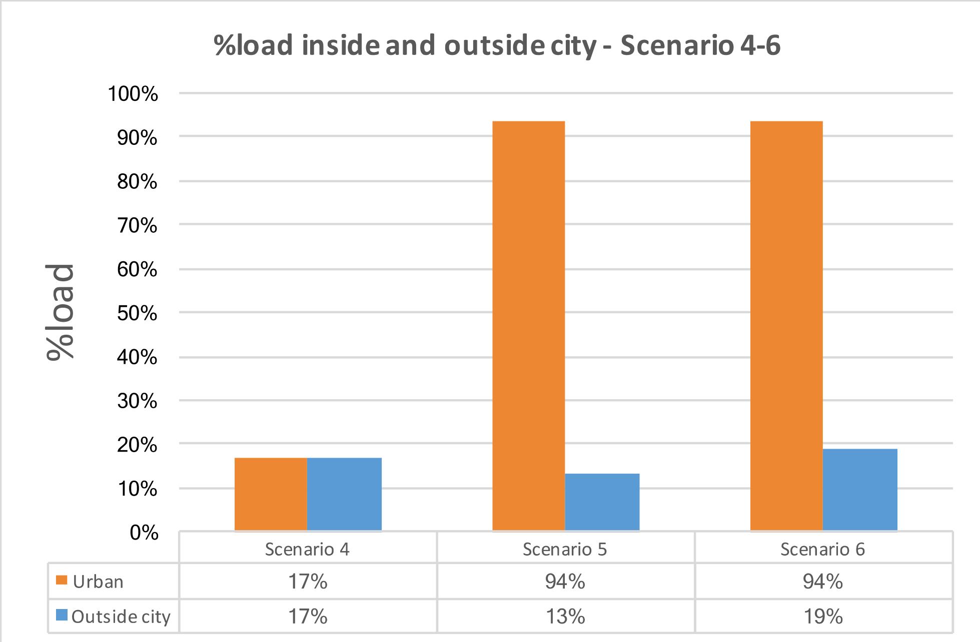


Figure 76: Comparison of % loads - Verona - Scenarios 4-6.

	SC4 --> SC6		
Indicator	Inside city	Outside city	Total
Daily number of freight vehicles	-85%	-23%	-54%
Kilometres / day travelled by vehicles	-86%	-20%	-23%
% Increase load factor	452%	12%	232%
Travel time	-72%	-19%	-23%

There is a very good improvement in terms of number of deliveries, kilometres travelled and travel time, especially inside the city. Concerning the loading factor, we have a drastic improvement inside the city, since we can consolidate the deliveries and use almost all the truck capacity, but outside the city we have a small improvement. This is due to the combined effect of use or largest trucks, to reduce the number of deliveries, within the low quantities required in each week. Indeed, one can observe that the Verona pilot is much smaller of the other pilots, in terms of foreseen construction site sizes, and so of total materials to be delivered.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

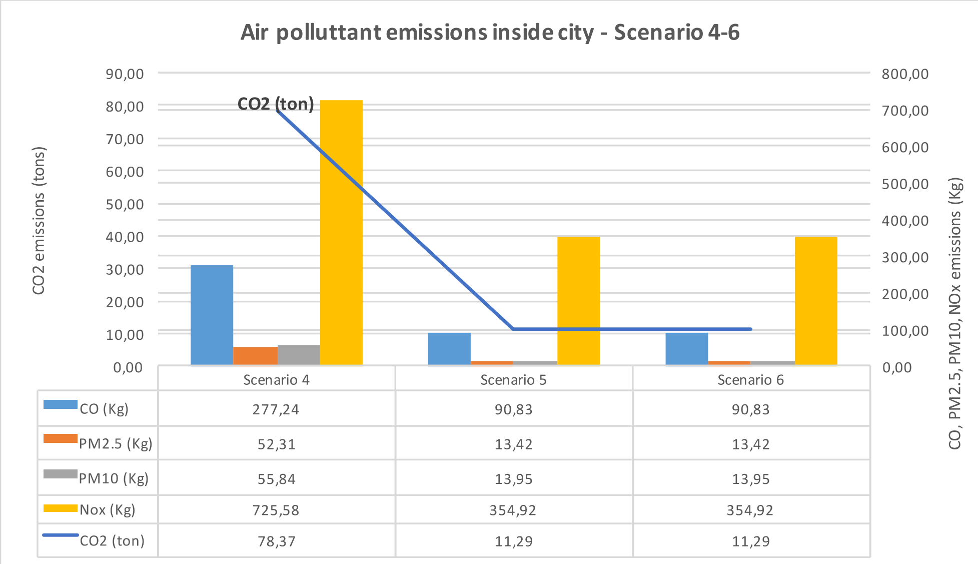


Figure 77: Air pollution emissions in the urban area – Verona - Scenario 4-6.

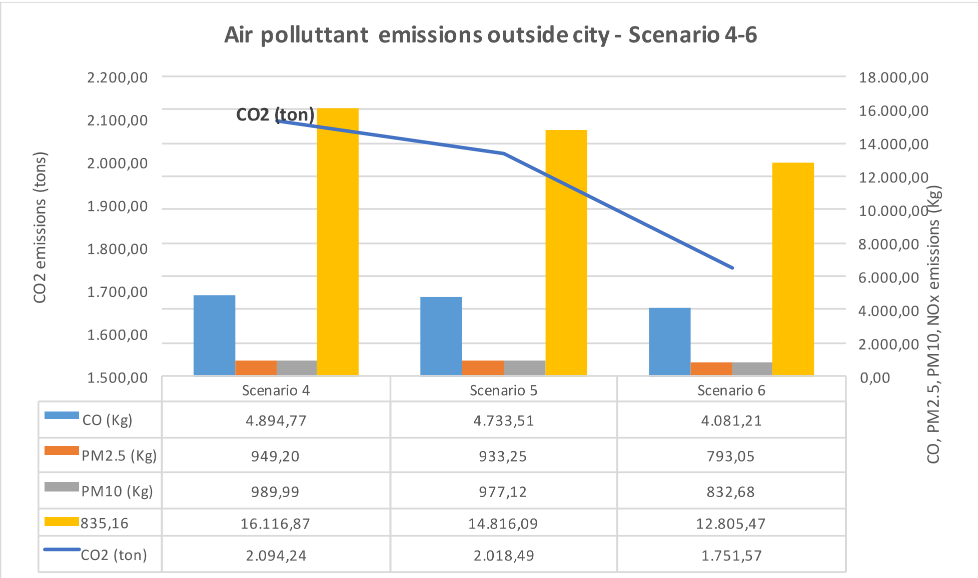


Figure 78: Air pollution emissions outside the city – Verona - Scenario 4-6.

The table below report the percentages improvements from scenario 4 to scenario 6, i.e., without CCC and with CCC and optimization on both echelons.

There is an improvement close to 20% overall and improvements from 50% to 86% inside the city.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Polluttant	SC4 -->SC6 Inside city	Outside city	Total
CO	-67%	-17%	-19%
PM2.5	-74%	-16%	-19%
PM10	-75%	0%	-19%
NOx	-51%	-21%	-22%
CO2	-86%	-16%	-19%

There are clear improvements inside the city and improvements outside the city. The CO2 reduction inside the city is really large, but all the figures are over 50%.

The expected benefits for Verona, scenario 6, are as follows:

Expected benefits	**Indicators**	**Average quantified impacts in the pilot sites**	**Simulation results**
Reduction of congestion	Daily number of freight vehicles both for direct and reverse logistics	-40%	**- 54%**
Reduction of transport related pollutant emissions	CO2 emissions NOx emissions PM10 emissions	-40%	**- 19%** **- 22%** **- 19%**
Vehicle use & route optimisation	Kilometres / day travelled by vehicles	-20%	**- 23%**
	Small deliveries (fewer than 4 pallets)	-50%	**100%**
Maximise load factor	% Increase load factor	30%	**232%**

3.5.4 Cost-Benefit-Analysis

3.5.4.1 Business Model 1: CCC managed by a Construction Company

Input data

The input data from the Verona pilot of the business model of a CCC implementation that is managed by a construction company is listed below:

Parameter	Value	Unit
Average yearly Budget of all the Construction Projects	17,608,000	€
Number of Construction Sites	24.3	sites
Daily Average Deliveries per Construction Site	0.248	Deliveries
Average Weekly Storage Capacity needed [m3]	109.3	m3
Maximum Weekly Storage Capacity needed [m3]	166.84	m3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	323	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	293	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	866	km
Number of 3 Axes Truck <25t	6	Units
Annual km of 3 Axes Truck <25t	8,384	km

The input data was obtained from the simulations of the Scenarios 6 in the Verona pilot. The average yearly budget of the construction sites was estimated considering only the construction sites of the typology "apartments", which correspond to the pilot from Luxembourg.

Results

The CBA results provide an approximate dimensioning of the CCC facility based on the simulation outputs and a set of assumptions previously considered. The results of the facility and operations dimensioning based on the simulation results of the scenario 6 (CCC managed by a construction serving several construction sites) were:

CCC Dimensioning		
CCC Facility Dimensioning		
Storage Area Needed in the CCC [m2]	63	m2
Final Facility Dimensioning [m2]	155	m2
CCC Labor Force and Machinery Dimensioning		
Manager	1	
Other Personnel	1	
Operators	2	
Drivers	4	
Forklifts	1	
Other Machinery	1	

For the facility dimensioning and considering 4 levels of shelves in the storage, the facility needs a very small surface, only 155m^2 to store the average weekly material flows (109m^3 per week) including the area dedicated to corridors, loading and unloading operations and common areas. This means that the CCC manages less than 22m^3 of material per day, which do not seem a big quantity that could justify the implementation of a CCC (approximately one 2 Axis truck per day).

For the delivery operations, the outputs of the simulation resulted in 4 trucks needed to cover all the daily deliveries. However, number of daily deliveries per site is 0.2, which means that there is only needed one delivery per site and week.

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For the drivers, as in the other cases, it was assumed one driver per truck needed. Thus, in this specific case, even though the CCC serves 24 sites simultaneously, the material requirements of them seem that are not enough to justify the implementation of the CCC, especially from the construction company point of view, because it seems that managing 1 or 2 deliveries per week do not justifies the extra cost of the CCC.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that would be needed 2 operators plus a forklift and a pallet truck for loading, unloading and housekeeping operations in the CCC. In addition, other staff was considered for the management and horizontal activities, although they could be neglected due to the low rate of activity.

In regards to the Cost Benefit Analysis carried out for a period of five years, the results obtained for the Verona case were:

Year	ALTERNATIVE 2 CCC	ALTERNATIVE 2. Using CCC											TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	INVESTMENTS (EUROS)	Additional Cost of CCC					Savings			CCC Summary			
		Facility Rent Costs (€)	Workforce Costs (€)	General expenses CCC (€)	Transport Costs (€)	Maintenance Costs (€)	Labor Force Savings [€/year]	Material Savings [€/year]	Unsorted Bins [€/year]	TOTAL ANNUAL COSTS	TOTAL ANNUAL SAVINGS	BENEFITS	
1	**97.000**	9.845	403.000	984	90.749	492	264.120 €	246.512 €	13.100 €	**505.071 €**	**523.732 €**	**18.661 €**	**-78.339**
2	**0**	10.007	409.650	1.001	92.247	500	268.478 €	250.579 €	13.317 €	**513.405 €**	**532.374 €**	**18.969 €**	**18.969**
3	**0**	10.173	416.409	1.017	93.769	509	272.908 €	254.714 €	13.536 €	**521.876 €**	**541.158 €**	**19.282 €**	**19.282**
4	**0**	10.340	423.279	1.034	95.316	517	277.411 €	258.917 €	13.760 €	**530.487 €**	**550.087 €**	**19.600 €**	**19.600**
5	**-2.200**	10.511	430.264	1.051	96.889	526	281.988 €	263.189 €	13.987 €	**539.240 €**	**559.164 €**	**19.924 €**	**22.124**
												NPV	-7.286 €

Year	Percentage of benefits compared to the annual budget of all the projects served via the CCC
1	**-0.44%**
2	**0.11%**
3	**0.11%**
4	**0.11%**
5	**0.13%**

In this specific case the CBA results shows negative results due to extra cost that requires the CCC implementation (NPV<0) compared to the potential benefits that it could bring. Thus, the investment in the facility is not recommended from the economic point of view.

Moreover, a more detailed study about this specific scenario in which the flows from each of the construction sites are very low is recommended, aiming to find a reasonable explanation of the low materials flows of the construction sites that this CCC would served.

3.5.4.2 *Business Model 2: CCC managed by a Logistics Operator*

Input data

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The input data from the Verona pilot of the business model for a CCC implementation that is managed by a logistics operator is listed below:

Parameter	Value	Unit
Average Distance from CCC to Construction Sites [km]	4.31	km
Number of Construction Sites	32	sites
Daily Average Deliveries per Construction Site	0.248	Deliveries
Average Weekly Storage Capacity needed [m3]	455.1	m3
Maximum Weekly Storage Capacity needed [m3]	694.7	m3
Number of Vans/Light Trucks	1	Units
Annual km of Vans/Light Trucks	323	km
Number of 2 Axes Truck <7.5t	1	Units
Annual km of 2 Axes Truck <7.5t	293	km
Number of 2 Axes Truck <14t	1	Units
Annual km of 2 Axes Truck <14t	866	km
Number of 3 Axes Truck <25t	6	Units
Annual km of 3 Axes Truck <25t	8,348	km

The input data has been obtained from the simulations of the Scenarios 6 in the Verona pilot.

Results

The CBA of the Verona case in which a logistics operator manages the CCC, provides the dimensioning of the facility based on the simulation outputs and a set of assumptions previously explained in section 2.2. The CCC dimensioning includes an estimation of the size of the facility, the labour force and machinery needed that is summarized in the following table:

CCC Dimensioning		
CCC Facility Dimensioning		
Storage Area Needed [m2]	265	m2
Facility Dimensioning - Total Area Needed [m2]	806	
Final Facility Dimensionng [m2]	1.008	m2
CCC Labor Force and Machinery Dimensioning		
Manager	1	
Other Personnel	2	
Operators	2	
Drivers	4	
Forklifts	1	
Other Machinery	1	

In total, the facility needs around 1,000m^2 to be able to accommodate the average weekly material flows (455m^3), including the area dedicated to corridors, loading and unloading operations and common areas.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

For the delivery operations, the outputs of the simulation resulted in four trucks needed to cover all the daily deliveries and it was assumed one driver per truck for the estimation of the personnel cost. However, the number of daily deliveries per site is 0.25, which means slightly more than one delivery per site and week. Thus, even though the CCC serves 32 sites simultaneously, the material requirements of them are very low and seems that are not enough to justify the implementation of the CCC, especially from the construction company point of view, because it seems that managing 1 or 2 deliveries per week do not justifies the extra cost of the CCC.

In reference to the labour force and machinery dimensioning inside the CCC, the results based on the simulation outputs and the set of assumptions considered, showed that are needed 2 operators and one single forklifts and one single pallet trucks for loading, unloading and housekeeping operations in the CCC.

Secondly, the CBA analysis also estimates the potential feasibility of the CCC implementation. In one side, the analysis considers the total costs (facility dimensioning, staff, trucks, etc.) and in the other side, the potential incomes due to the services provided by the CCC (see section 2.2 and annexes).

In this regard, in the case of the scenario 6 for the city of Verona (one single CCC operated by a logistics operator and serving several construction sites) seems to be not feasible in long-term basis because it has a negative NPV (NPV<0.6M€). Following figure shows the main results for the scenario assessed:

Year	Alternative 1: Current Situation Without CCC	Alternative 2: CCC Implementation									TOTAL BENEFITS ALTERNATIVE 2 INSTEAD OF ALTERNATIVE 1 (EUROS)
	Investments	Investments	Vehicles Operational Costs (Euros)	CCC General Expenses (Euros)	CCC Rental Cost (Euros)	CCC Personnel Costs (Euros)	Total Revenues (Euros)	TOTAL ANNUAL COSTS	TOTAL ANNUAL REVENUES	BENEFITS	
1	0	281.556	19.641	9.615	64.097	455.500	503.336	548.853 €	503.336 €	-45.517 €	-327.073
2	0	0	19.965	9.773	65.155	463.016	511.641	557.909 €	511.641 €	-46.268 €	-46.268
3	0	0	20.295	9.934	66.230	470.656	520.083	567.115 €	520.083 €	-47.032 €	-47.032
4	0	0	20.630	10.098	67.323	478.421	528.664	576.472 €	528.664 €	-47.808 €	-47.808
5	0	0	20.970	10.265	68.433	486.315	537.387	585.984 €	537.387 €	-48.597 €	-48.597
6	0	2.670	21.316	10.434	69.563	494.339	546.254	595.652 €	546.254 €	-49.398 €	-52.069
7	0	0	21.668	10.607	70.710	502.496	555.267	605.481 €	555.267 €	-50.213 €	-50.213
8	0	0	22.025	10.782	71.877	510.787	564.429	615.471 €	564.429 €	-51.042 €	-51.042
9	0	0	22.389	10.959	73.063	519.215	573.742	625.626 €	573.742 €	-51.884 €	-51.884
10	0	-17.200	22.758	11.140	74.269	527.782	583.209	635.949 €	583.209 €	-52.740 €	-35.540

NPV -635.851,83 €

Again, in the case of the CBA of a CCC in the city of Verona, the results shows negative values of NPV. In this regard, the implementation and operational cost that requires the CCC compared to the revenues that it could get from the demand of the sites of Verona is not enough to cover them in long term basis.

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Thus, the investment in the facility is not recommended from the economic point of view.

Furthermore, a more detailed study about this specific scenario in which the flows from each of the construction sites are very low is recommended, aiming to find a reasonable explanation of the low materials flows of the construction sites that this CCC would served.

3.6 Outcomes from the simulation results

The above results show different behaviour in the simulated cities, but there is a clear common factor: the use of a CCC to consolidate materials and to perform efficient transports from the suppliers and to the construction sites, has a direct positive impact by reducing:

- Number of trips;
- Vehicle-kilometres;
- Travel time;
- Pollutants emissions.

These reductions have a positive impact on the following aspect, although the relation is not directly computable:

- Congestion (on the roads and near the construction site);
- Accidents;
- Noise.

The implementation of a CCC can highly help to reduce those impacts by reducing the number of deliveries on the construction site and the number of km travelled in the urban area (as shown in the results of the simulations) -> less emissions, less congestion, less accidents and less noise.

In the next table, we report the average emissions gains in the four pilot cities: Luxembourg, Paris, Valencia and Verona. We have gains about 15% outside the city and about 25% inside the cities, with a 34% reduction of CO2 and a 32% reduction of PMx in the cities.

Polluttant	Inside city	Outside city	Total
CO	-27%	-26%	-26%
PM2.5	-31%	-24%	-24%
PM10	-32%	-3%	-22%
NOx	-18%	-37%	-34%
CO2	-34%	-27%	-26%

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Using more environmental friendly vehicles we could further optimize in term of pollutants emissions when delivering from the CCC to the construction sites.

In the urban area of the same cities, the percentage reduction of kilometres travelled, time and trips are as follows:

Kilometers	-44%
Hours	-36%
Deliveries	-60%
Load	166%

In particular, the great reduction in the number of trips (deliveries) has a strong impact on the congestion and safety.

For the city of Paris, the situation changes when we impose to use two CCCs. We have observed that there is a deterioration inside the city (while the global supply chain has an improvement). This aspect must be considered carefully when evaluating the opportunity to use two smaller CCCs instead of a big CCC. Of course, there are other business and side constraints that must be considered, but that are outside the scope of this document, devoted to present the quantitative simulation results.

Due to these social advantages, economical and business issues have to be considered to define the viability of a CCC implementation.

The cost-benefit-analysis has showed, in most of the cases, a **positive return over the total budget of the construction sites**, so we have proven also an economic advantage. The economic benefits of the CCCs are mainly obtained when there are enough material flows to reach economies of scale. These economies of scale can be achieved with major urban developments or from several sites simultaneously serve by the CCC, which allows distributing the fixed cost of the facility among more construction projects.

The agreements between the companies and the will to cooperate are then the key points to be addressed. The implementation of a CCC will request a new type of collaboration between all the partners of a construction project and a new way to manage contracts between stakeholders. Nowadays, in most of the contracts signed the subcontractors are fully responsible of the materials deliveries from the suppliers to the working area on the construction site. It means that the subcontractors take into account in their price all the transport and handling costs generated by the logistics flows from the suppliers to the working area. Also, insurances contract for the materials must be modified when introducing a CCC.

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The public authorities may have an important role with specific rules to enter the city and congestion charge.

Cities policies could implement incentives in order that operators choosing to invest in a "low emissions" fleet (new vehicles (euro 6), electrical etc.) are not disadvantaged with regard to the operators that do not invest at all in new vehicles. Examples of incentives that can be implemented are: limited access zones with access forbidden to pollutants vehicles (euro 0, euro 1 etc.), higher taxes for pollutants vehicles, subsidies for low-emission vehicles purchase etc.

4 Conclusions

We have presented the activities done to simulate the optimization of the distribution to the construction sites, accordingly to the scenarios defined in D2.2.

The simulation involves three main aspects:

1. Trips (including number of trips, kilometres travelled and travel time);
2. Emissions (including 5 air pollutant elements: CO, PM2.5, PM10. NOx and CO2);
3. Economic sustainability of a CCC.

We used the tools developed in previous WP and tasks to optimize the solutions in the scenarios. In particular, we used:

- C++ programs to define the stochastic demand, based on the real data from the pilot sites;
- Mathematical models to implement the stochastic optimization;
- XPRESS tool to solve the stochastic optimization;
- C++ programs to simulate the trips in the optimized and non-optimized scenarios;
- And COPERT to compute the emissions in the pilot cities.

All the activities have been done in close relation with WP5 and several iterations following the AGILE method have been implemented to refine the solutions, based on the findings of previous choices.

The final results show that **there is a clear advantage to introduce a CCC**, in quantitative terms with respect to number of deliveries, kilometres travelled and driving time, thus implying a reduction of the congestion, improvement of the safety, reduction of the emissions.

The Cost-Benefit-Analysis showed that the implementation of CCCs can be **economically sustainable**. However, the analysis carried out is based on simulations and the adoption of general assumptions, so a tailored study case by case is recommended.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Discussions with the stakeholders have shown that the main possible **barriers** arise from the change in the habits and usual management of the supply chain. The introduction of a CCC will imply change in ordering processes. With a CCC, the construction companies should better anticipate activities and increase their order sizes to generate financial savings. Agreements should be found between the construction companies et the CCC to transfer responsibility of goods from the suppliers to the CCC operators (in case of damage, loss…).

Some suggestions, also involving possible actions by the municipalities have been collected, and will be detailed and discussed in the validation (WP5).

Another scenario is related with the possibility to use more than one CCC. In this case we have shown that it is necessary to have a very careful evaluation and planning, since two small CCCs may produce larger emissions inside the city.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

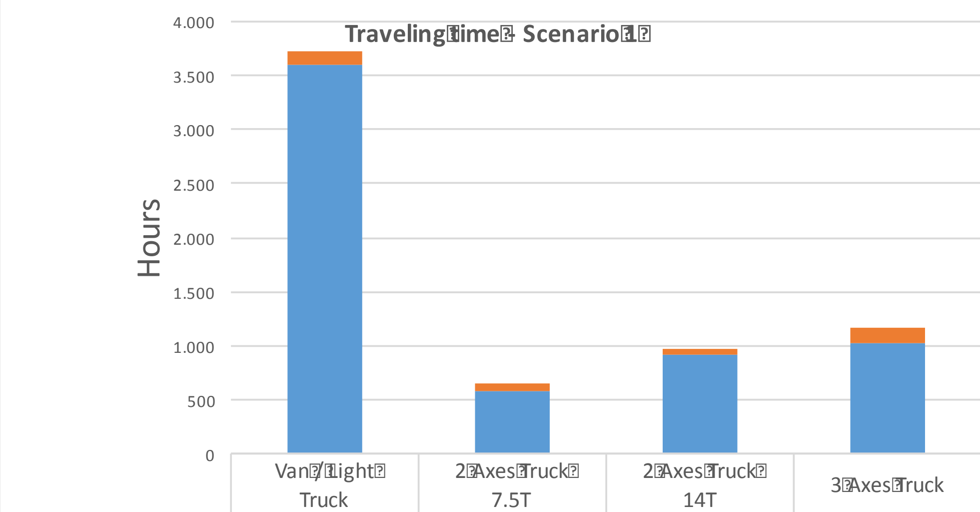
5 Annex I: material flows details

We report in this appendix the full tables of the simulation results for each pilot and each scenario.

5.1 Luxembourg

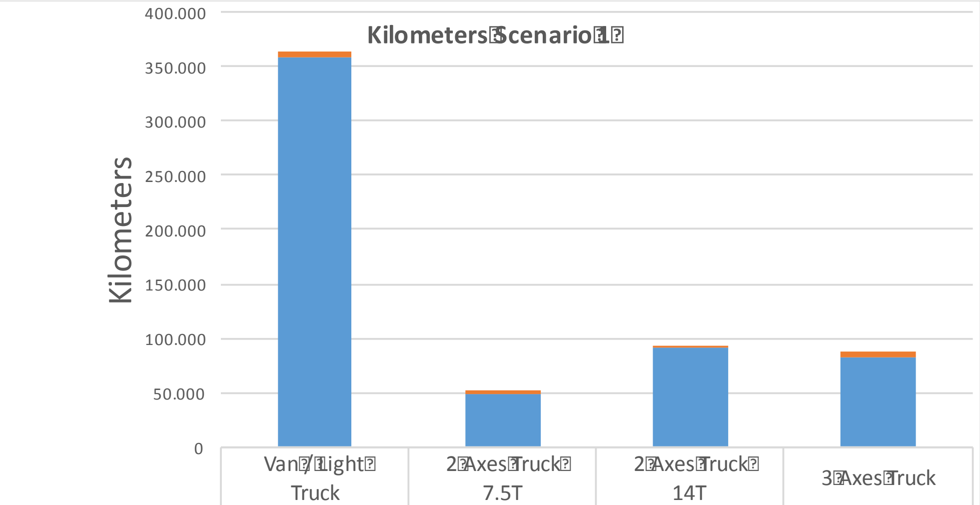
5.1.1 Scenario with a single big site

5.1.2 Scenario 1 - no CCC - 1 site – baseline



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Hours Urban	112	67	40	143
Hours Outside	3.608	586	926	1.026

Figure 79: Traveling time - Luxembourg - Scenario 1.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Km Urban	5.071	2.405	1.275	5.150
Km Outside	358.967	49.105	91.374	82.436

Figure 80: Kilometres travelled - Luxembourg - Scenario 1.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

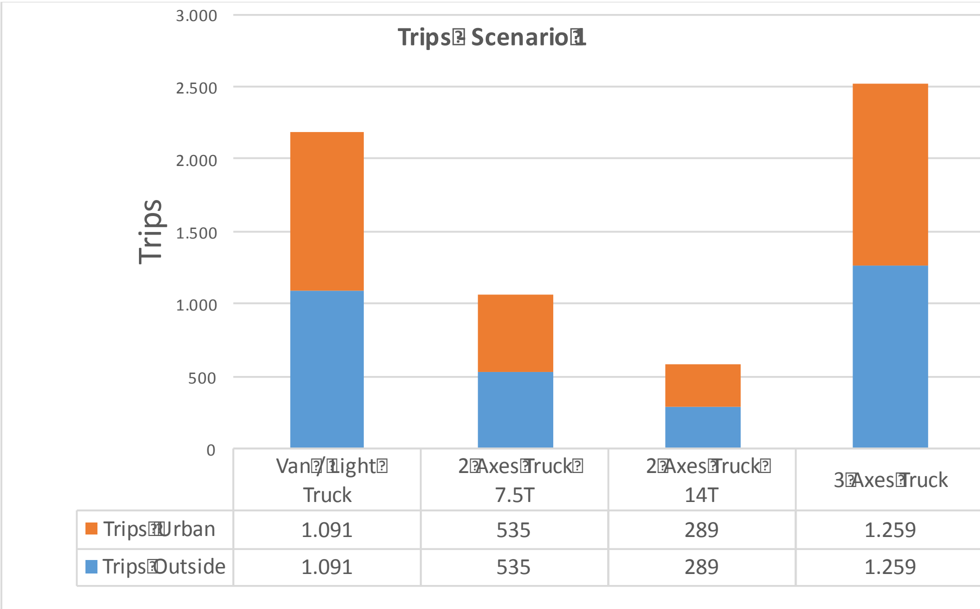


Figure 81: Number of trips - Luxembourg - Scenario 1.

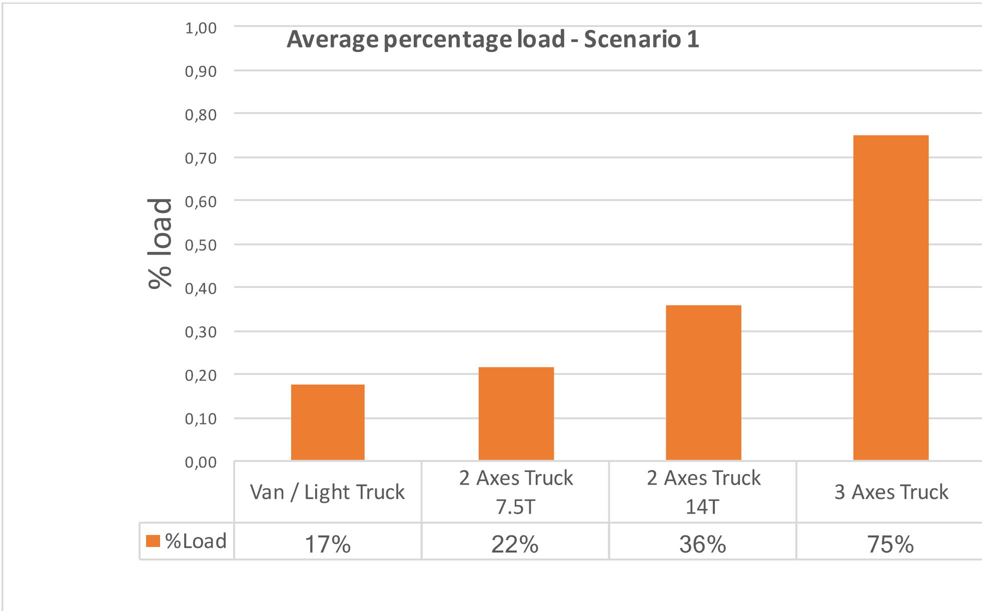


Figure 82: Percentage loads - Luxembourg - Scenario 1.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

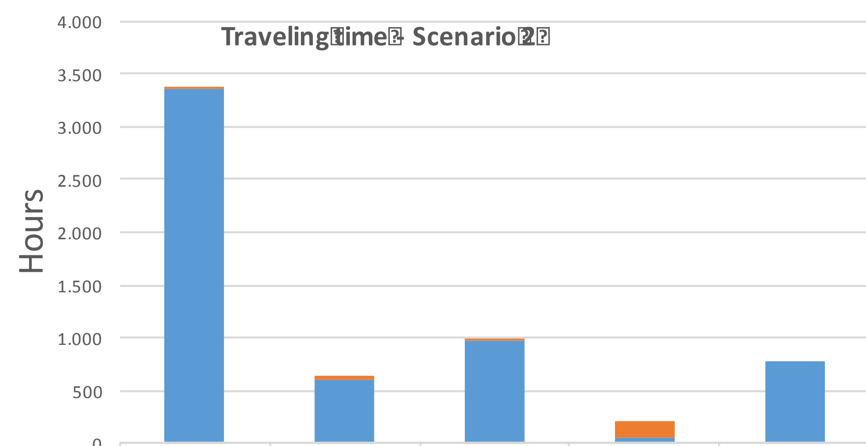
	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	5,03	1,12	1,20	9,75	1,93
2 Axes Truck 7.5T	4,12	0,62	0,66	10,12	1,09
2 Axes Truck 14T	2,67	0,42	0,47	9,69	0,94
3 Axes Truck	16,98	2,48	2,57	67,49	6,88
Tot	**28,80**	**4,64**	**4,89**	**97,04**	**10,85**

Table 7: Pollutant emissions caused by transport inside the city - Luxembourg - Scenario 1.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	234,6	61,7	63,9	411,0	93,2
2 Axes Truck 7.5T	39,3	5,8	6,0	154,5	16,9
2 Axes Truck 14T	91,6	12,3	13,5	444,2	41,6
3 Axes Truck	115,8	16,4	16,9	534,2	53,8
Tot	**481,26**	**96,18**	**100,39**	**1.543,86**	**205,49**

Table 8: Pollutant emissions caused by transport outside the city - Luxembourg - Scenario 1.

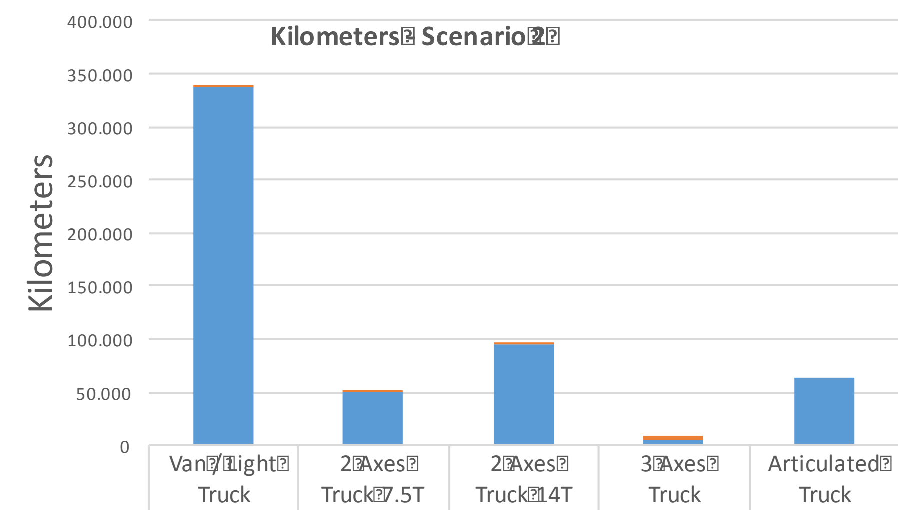
5.2 Scenario 2 - CCC-1 site – optimization on the second echelon



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	13	40	18	154	0
Hours Outside	3.365	598	979	59	768

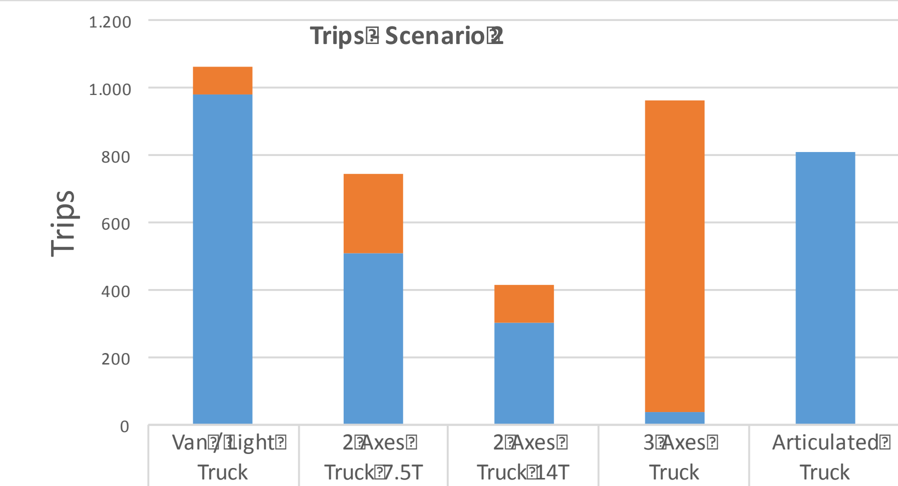
Figure 83: Traveling times - Luxembourg - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	390	1.169	536	4.505	0
Km Outside	338.289	50.118	95.839	5.170	63.166

Figure 84: Kilometres travelled - Luxembourg - Scenario 2.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	80	240	110	925	0
Outside city	981	507	304	36	810

Figure 85: Number of trips - Luxembourg - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

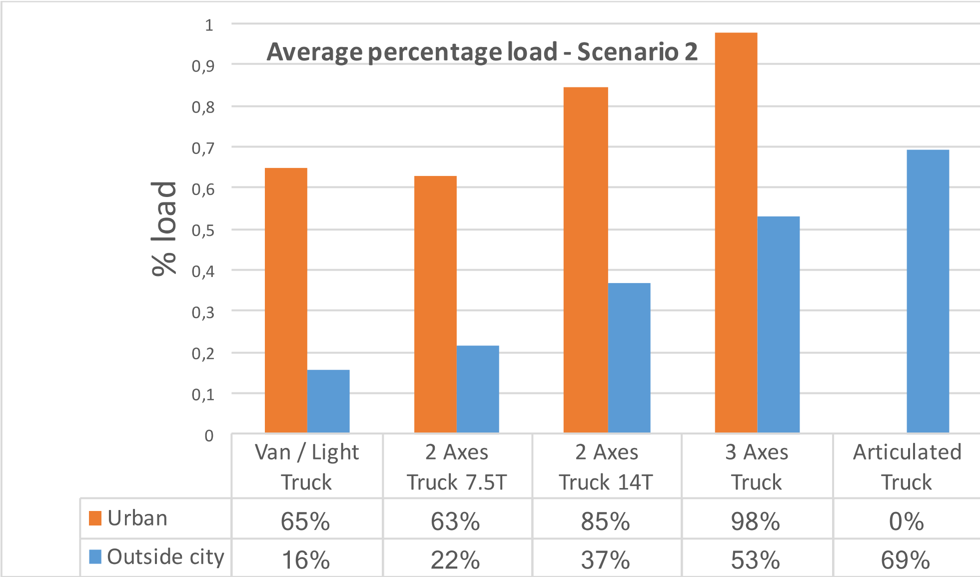


Figure 86: Percentage loads – Luxembourg - Scenario 2.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	0,39	0,09	0,09	0,75	0,15
2 Axes Truck 7.5T	2,00	0,30	0,32	4,92	0,53
2 Axes Truck 14T	1,12	0,18	0,20	4,07	0,40
3 Axes Truck	14,85	2,17	2,24	59,04	6,02
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**18,37**	**2,74**	**2,85**	**68,77**	**7,10**

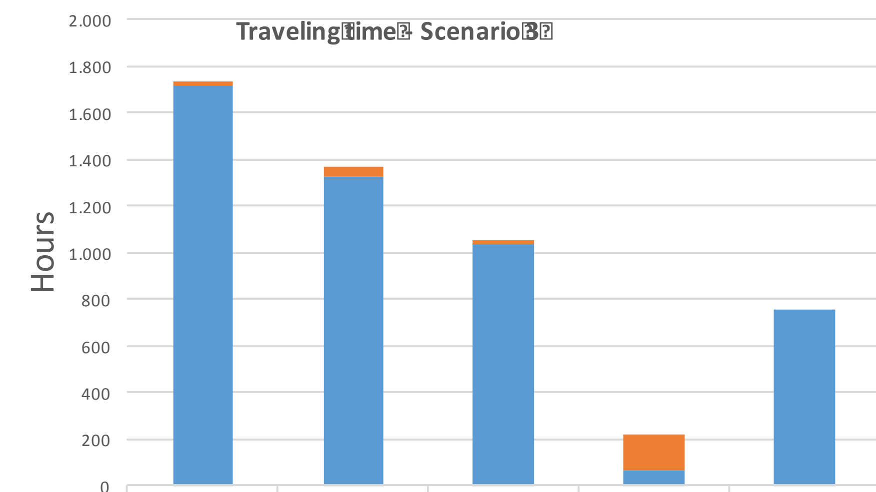
Table 9: Pollutants emissions caused by transport inside the city – Luxembourg - Scenario 2.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	221,1	58,1	60,2	387,3	87,9
2 Axes Truck 7.5T	40,1	5,9	6,1	157,7	17,2
2 Axes Truck 14T	96,1	12,9	14,2	465,9	43,6
3 Axes Truck	7,3	1,0	1,1	33,5	3,4
Articulated Truck	93,1	14,7	15,9	319,6	42,4
Tot	**457,65**	**92,69**	**97,57**	**1.363,98**	**194,47**

Table 10: Pollutants emissions caused by transport outside the city – Luxembourg - Scenario 2.

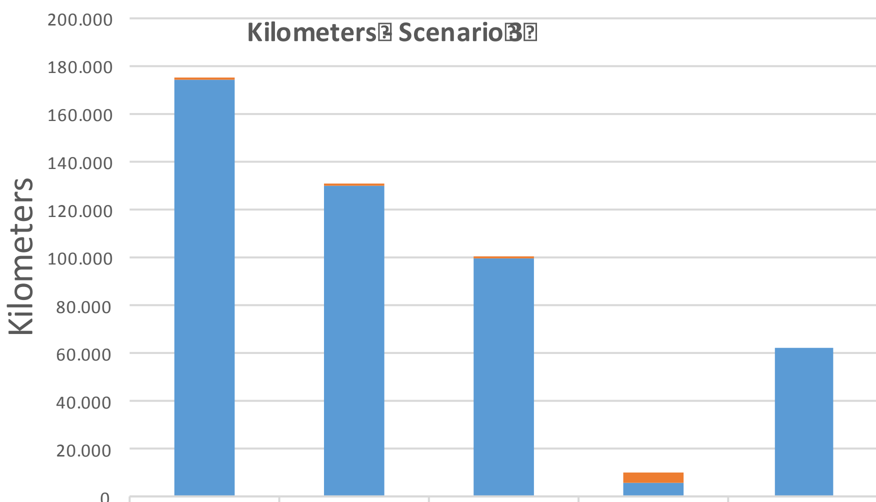
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.2.1 Scenario 3 – 1 CCC, 1 site, optimization on both echelons



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	13	40	18	154	0
Hours Outside	1.720	1.330	1.037	67	760

Figure 87: Traveling times - Luxembourg - Scenario 3.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	390	1.169	536	4.505	0
Km Outside	174.340	129.741	99.589	5.675	62.661

Figure 88: Kilometres travelled - Luxembourg - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

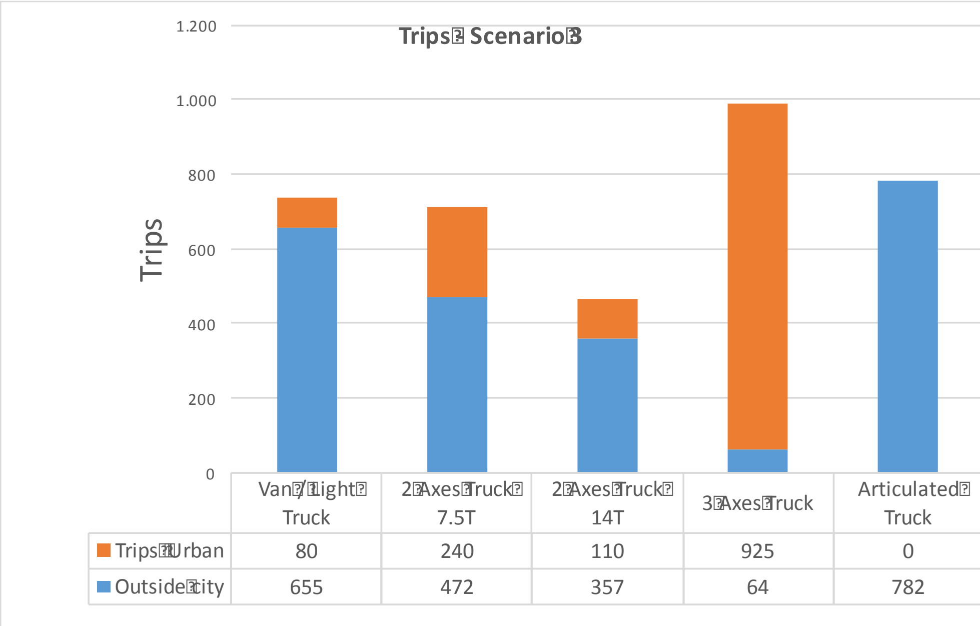


Figure 89: Number of trips - Luxembourg - Scenario 3.

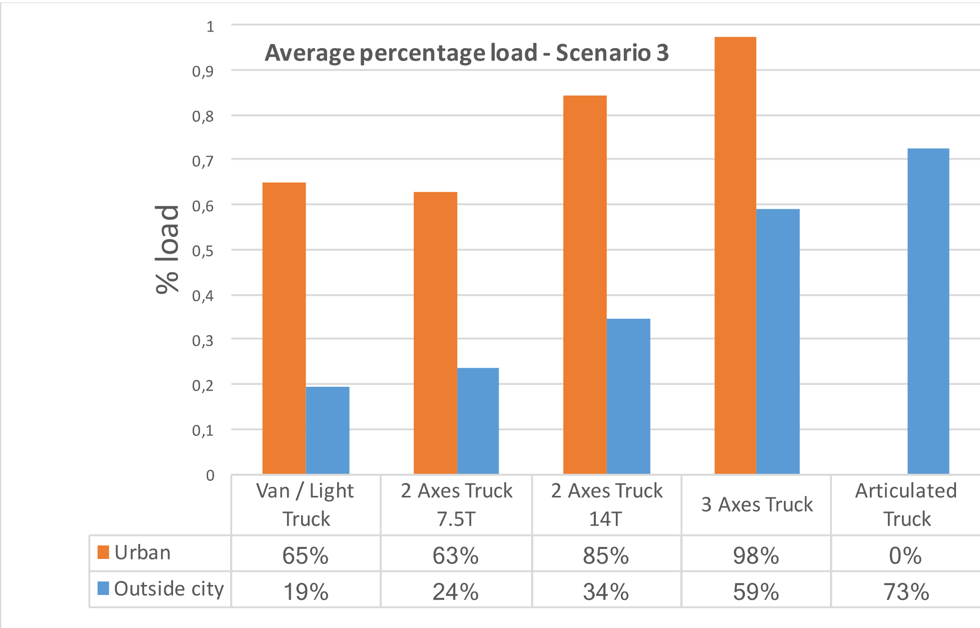


Figure 90: Percentage loads – Luxembourg - Scenario 3.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	0,39	0,09	0,09	0,75	0,15
2 Axes Truck 7.5T	2,00	0,30	0,32	4,92	0,53
2 Axes Truck 14T	1,12	0,18	0,20	4,07	0,40
3 Axes Truck	14,85	2,17	2,24	59,04	6,02
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**18,37**	**2,74**	**2,85**	**68,77**	**7,10**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Table 11: Pollutants emissions caused by transport inside the city – Luxembourg - Scenario 3.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	113,9	29,9	31,0	199,6	45,3
2 Axes Truck 7.5T	103,9	15,2	15,9	408,2	44,6
2 Axes Truck 14T	99,8	13,4	14,8	484,1	45,3
3 Axes Truck	8,0	1,1	1,2	36,8	3,7
Articulated Truck	92,4	14,6	15,8	317,0	42,1
Tot	**417,99**	**74,35**	**78,67**	**1.445,77**	**180,98**

Table 12: Pollutants emissions caused by transport outside the city – Luxembourg - Scenario 3.

5.2.2 Scenario with multiple construction sites

The next scenarios consider all the construction sites and different optimizations.

5.2.3 Scenario 4 – no CCC, all construction sites optimization for each supplier/period/material

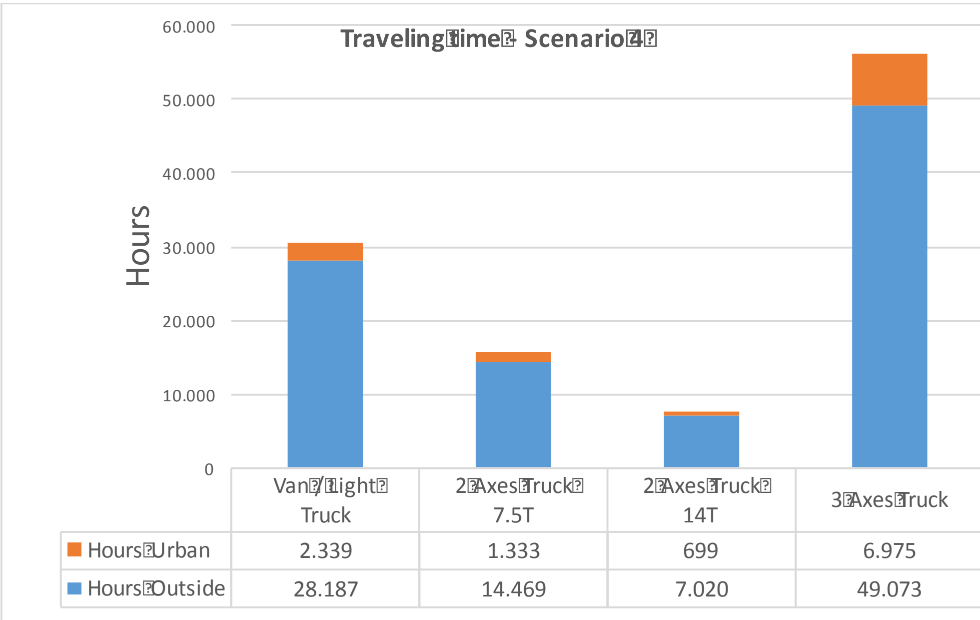
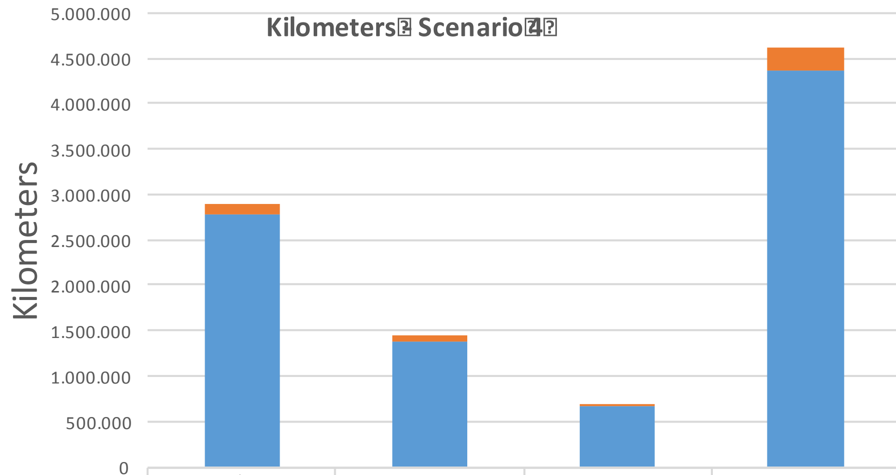


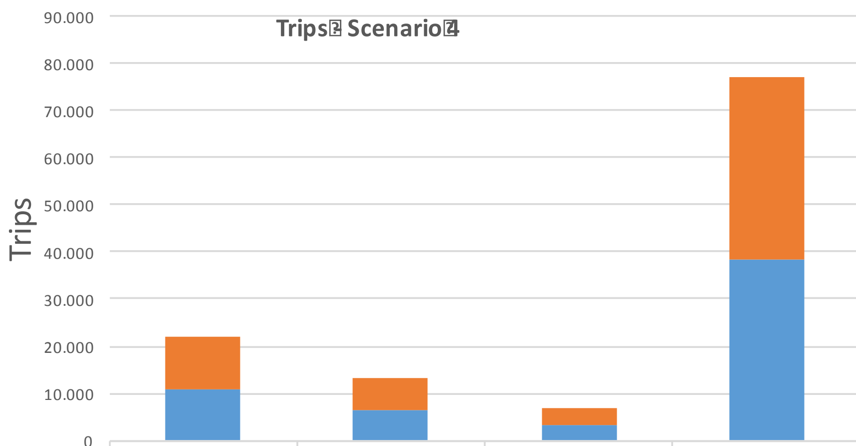
Figure 91: Traveling times - Luxembourg - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Km Urban	104.205	55.880	31.478	258.924
Km Outside	2.778.485	1.381.290	668.835	4.367.026

Figure 92: Kilometres travelled - Luxembourg - Scenario 4.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Trips Urban	10.925	6.561	3.353	38.472
Outside city	10.925	6.561	3.353	38.472

Figure 93: Number of trips - Luxembourg - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

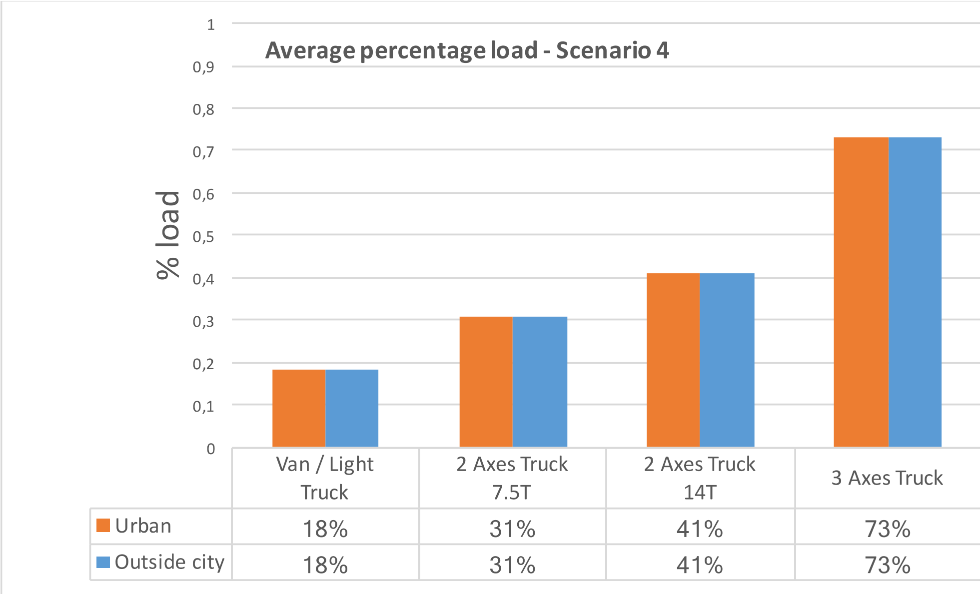


Figure 94: Percentage loads – Luxembourg - Scenario 4.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	103,46	22,95	24,60	200,28	39,76
2 Axes Truck 7.5T	95,79	14,51	15,36	235,04	25,37
2 Axes Truck 14T	65,89	10,35	11,54	239,14	23,21
3 Axes Truck	853,63	124,78	129,00	3.393,05	346,09
Tot	**1.118,76**	**172,58**	**180,49**	**4.067,51**	**434,43**

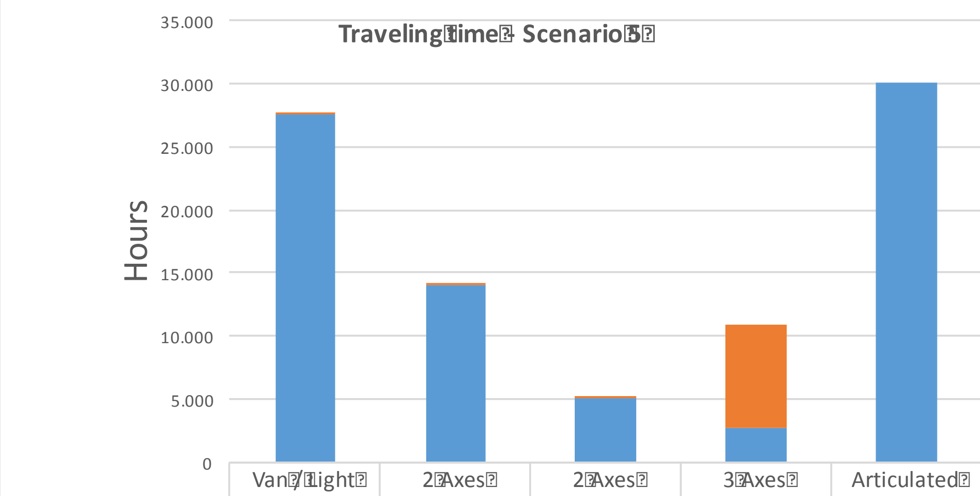
Table 13: Pollutants emissions caused by transport inside the city – Luxembourg - Scenario 4.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1.815,7	477,3	494,6	3.180,9	721,6
2 Axes Truck 7.5T	1.106,1	161,9	169,2	4.346,3	475,1
2 Axes Truck 14T	670,4	90,3	99,1	3.251,4	304,2
3 Axes Truck	6.132,4	870,0	896,5	28.299,4	2.850,7
Tot	**9.724,66**	**1.599,53**	**1.659,54**	**39.077,98**	**4.351,62**

Table 14: Pollutants emissions caused by transport outside the city – Luxembourg -Scenario 4.

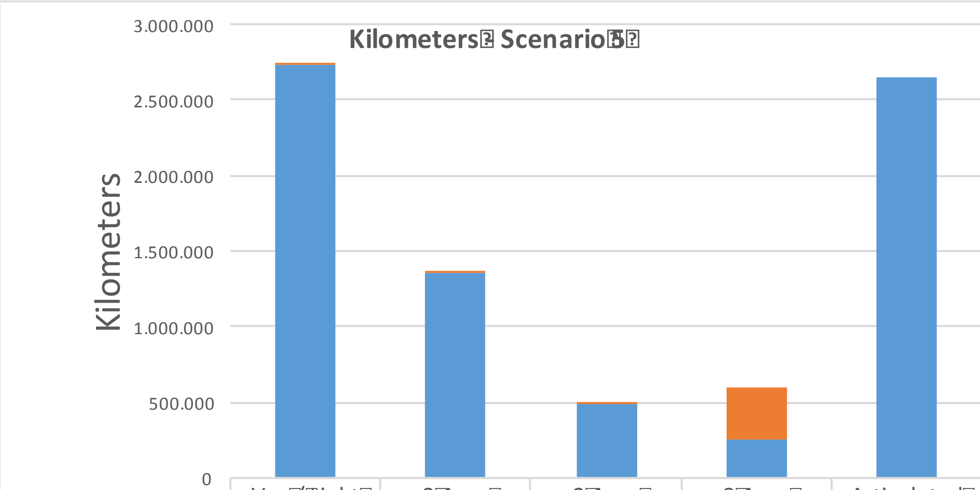
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.2.4 Scenario 5 – 1 CCC multiple sites, optimization on the second echelon



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	12	49	78	8.186	0
Hours Outside	27.589	14.067	5.161	2.774	30.056

Figure 95: Traveling times - Luxembourg - Scenario 5.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	510	2.042	3.254	339.299	0
Km Outside	2.734.401	1.360.514	492.605	256.824	2.656.099

Figure 96: Kilometres travelled - Luxembourg - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

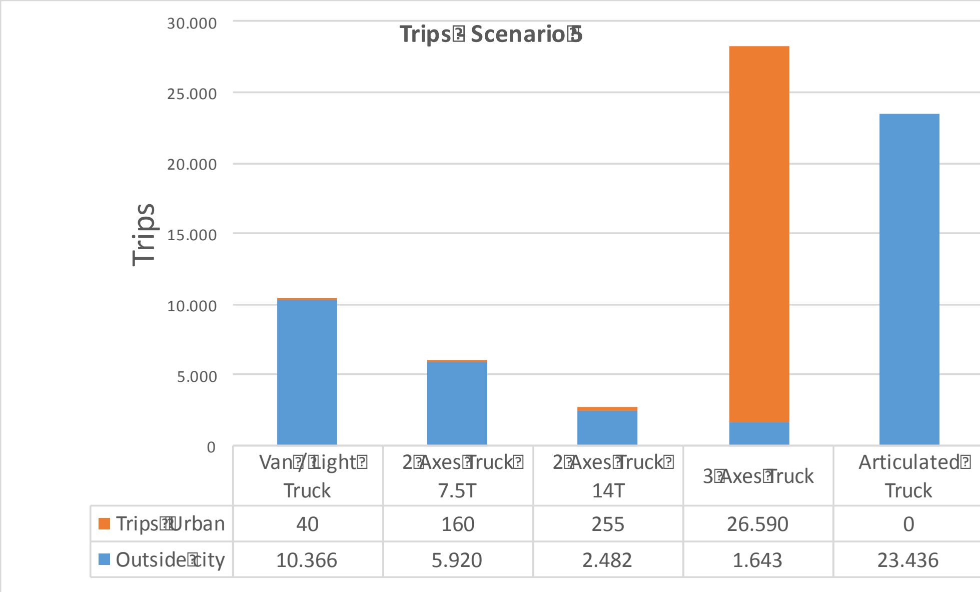


Figure 97: Number of trips - Luxembourg - Scenario 5.

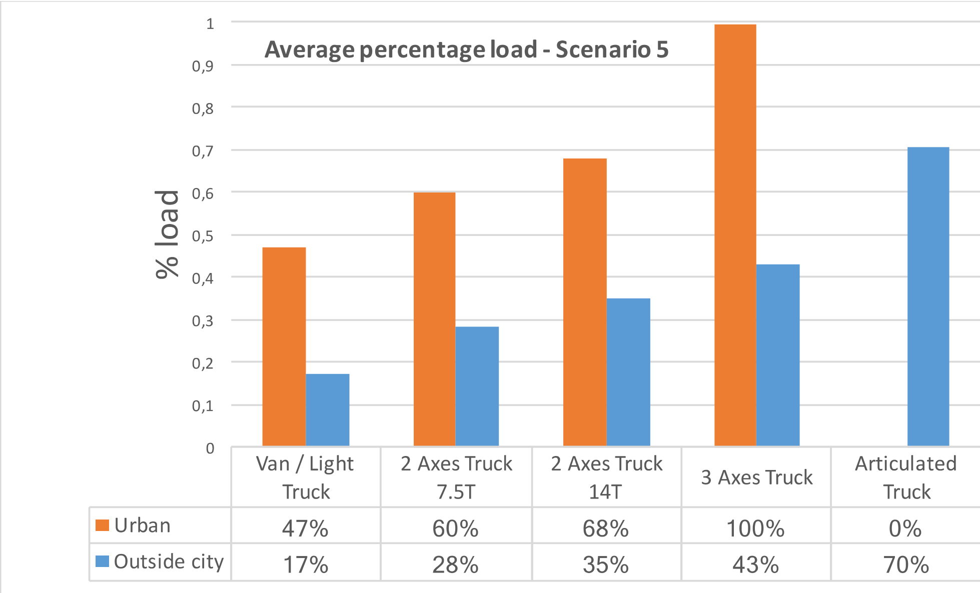


Figure 98: Percentage loads – Luxembourg - Scenario 5.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	0,51	0,11	0,12	0,98	0,19
2 Axes Truck 7.5T	3,50	0,53	0,56	8,59	0,93
2 Axes Truck 14T	6,81	1,07	1,19	24,72	2,40
3 Axes Truck	1.118,61	163,51	169,04	4.446,32	453,52
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**1.129,43**	**165,22**	**170,91**	**4.480,61**	**457,04**

Table 15: Pollutants emissions caused by transport inside the city – Luxembourg - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	1.786,9	469,7	486,8	3.130,4	710,2
2 Axes Truck 7.5T	1.089,5	159,5	166,7	4.281,0	468,0
2 Axes Truck 14T	493,8	66,5	73,0	2.394,7	224,0
3 Axes Truck	360,6	51,2	52,7	1.664,3	167,7
Articulated Truck	3.915,5	619,5	670,1	13.439,0	1.783,6
Tot	**7.646,31**	**1.366,40**	**1.449,32**	**24.909,33**	**3.353,43**

Table 16: Pollutants emissions caused by transport outside the city – Luxembourg - Scenario 5.

5.2.5 Scenario 6 – 1 CCC multiple sites, optimization on both echelons

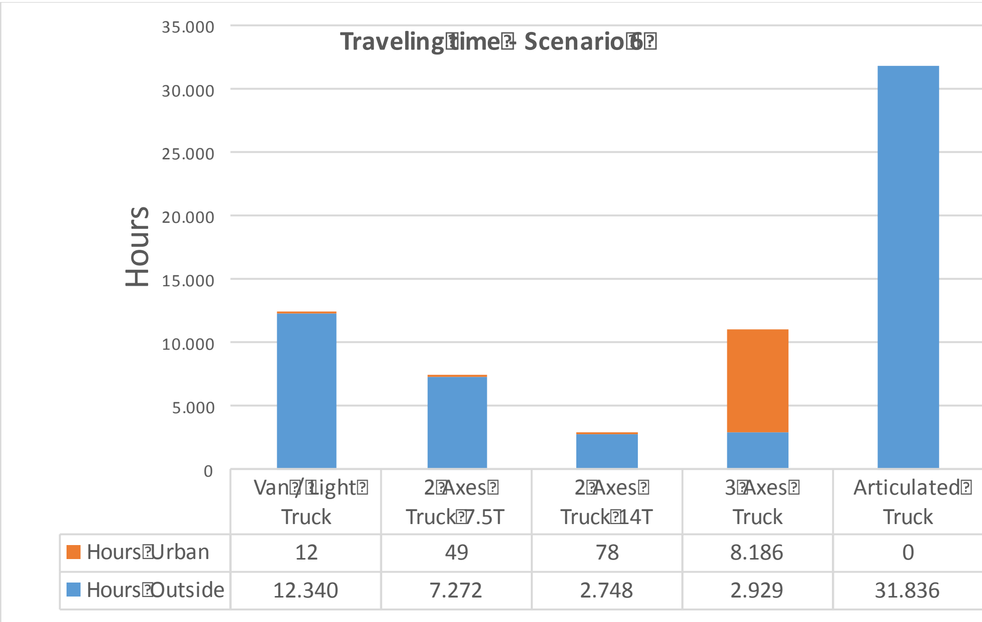
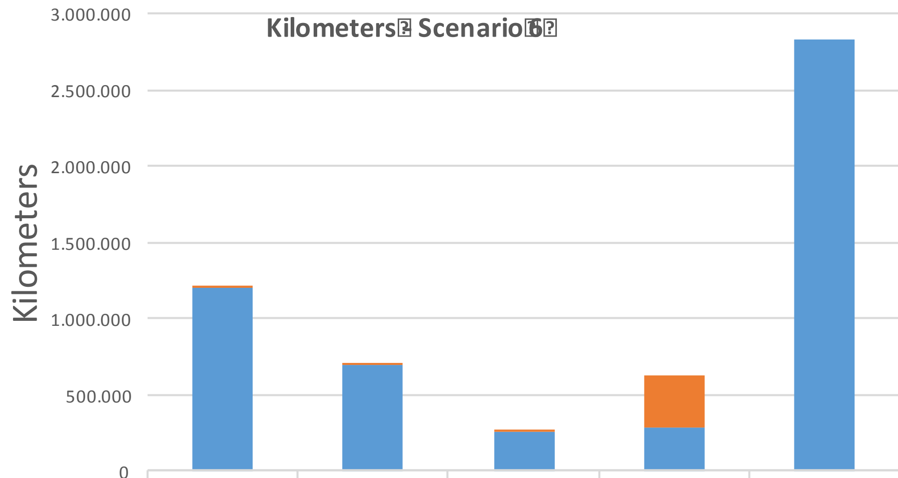


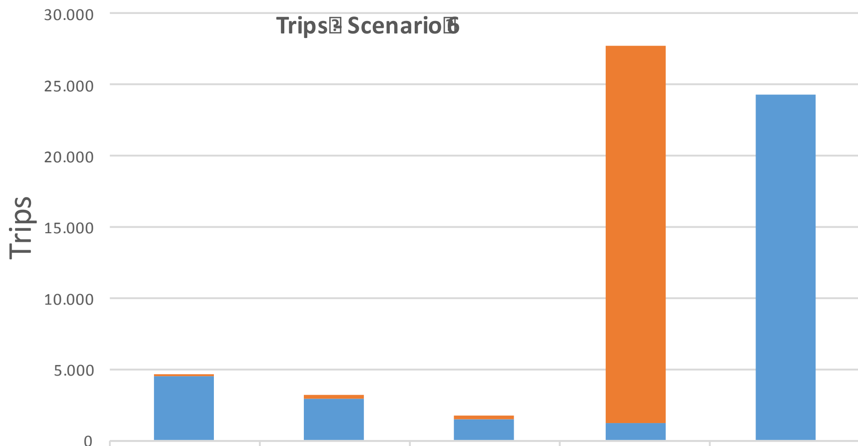
Figure 99: Traveling times - Luxembourg - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	510	2.042	3.254	339.299	0
Km Outside	1.207.253	702.331	254.439	284.532	2.827.882

Figure 100: Kilometres travelled - Luxembourg - Scenario 6.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	40	160	255	26.590	0
Outside city	4.525	2.974	1.508	1.148	24.346

Figure 101: Number of trips - Luxembourg - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

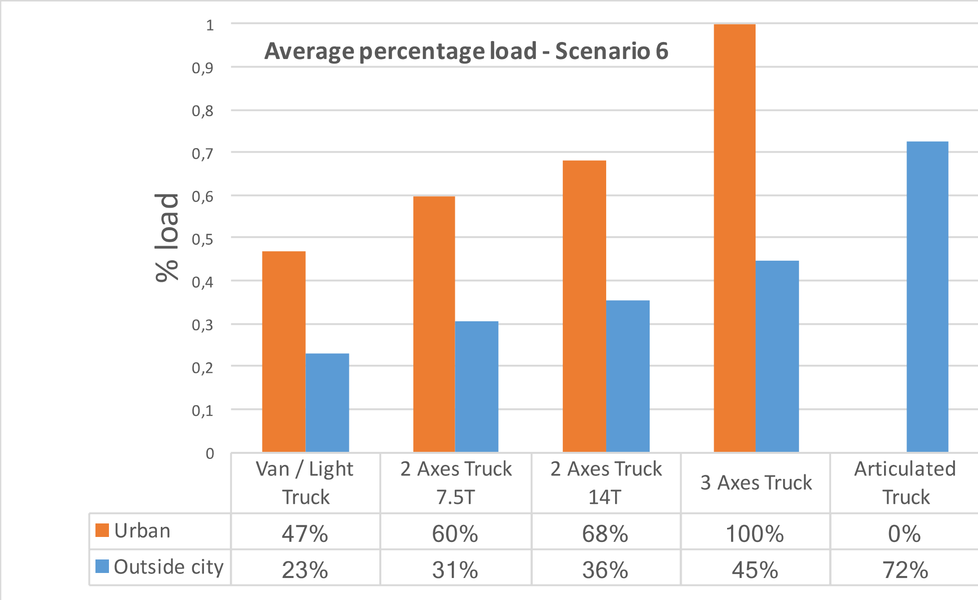


Figure 102: Percentage loads – Luxembourg - Scenario 6.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,51	0,11	0,12	0,98	0,19
2 Axes Truck 7.5T	3,50	0,53	0,56	8,59	0,93
2 Axes Truck 14T	6,81	1,07	1,19	24,72	2,40
3 Axes Truck	1.118,61	163,51	169,04	4.446,32	453,52
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**1.129,43**	**165,22**	**170,91**	**4.480,61**	**457,04**

Table 17: Pollutants emissions caused by transport inside the city – Luxembourg - Scenario 6.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	788,9	207,4	214,9	1.382,1	313,5
2 Axes Truck 7.5T	562,4	82,3	86,0	2.209,9	241,6
2 Axes Truck 14T	255,0	34,3	37,7	1.236,9	115,7
3 Axes Truck	399,6	56,7	58,4	1.843,8	185,7
Articulated Truck	4.168,7	659,6	713,5	14.308,2	1.899,0
Tot	**6.174,68**	**1.040,36**	**1.110,54**	**20.980,95**	**2.755,56**

Table 18: Pollutants emissions caused by transport outside the city – Luxembourg - Scenario 6.

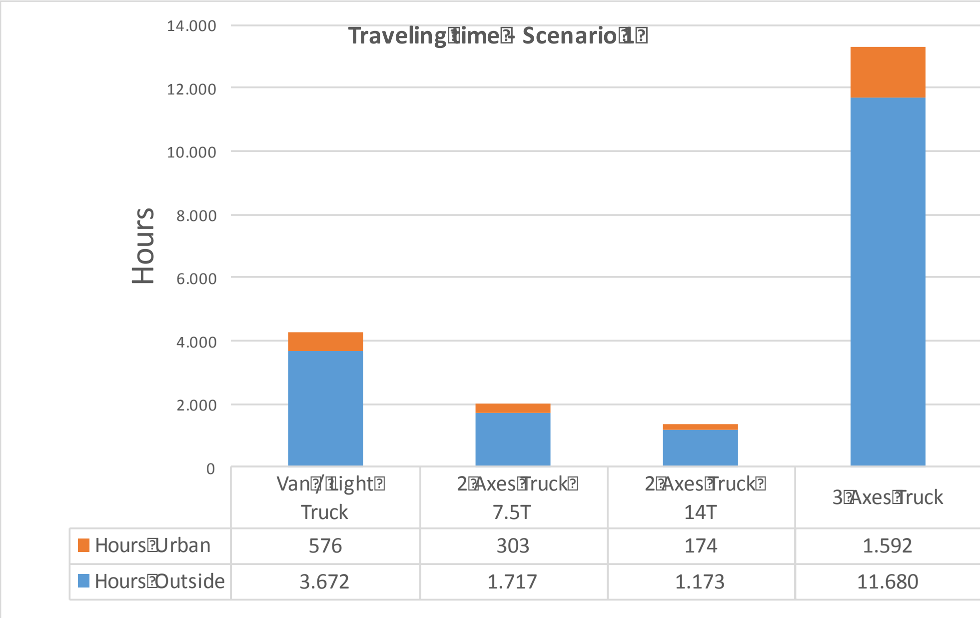
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.3 Paris

5.3.1 Scenario with a single big site

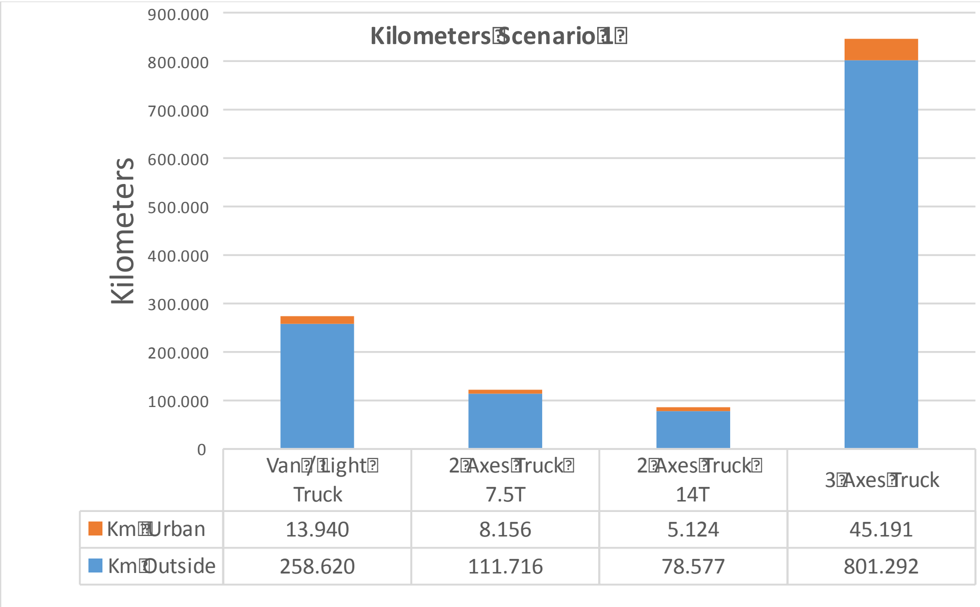
5.3.2 Scenario 1 - no CCC - 1 site – baseline

In the next figures, we report the Total time for traveling outside and inside the inner city, the Total Km travelled outside and inside the inner city, and the percentage loads for each type of truck.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Hours Urban	576	303	174	1.592
Hours Outside	3.672	1.717	1.173	11.680

Figure 103: Traveling times - Paris - Scenario 1.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Km Urban	13.940	8.156	5.124	45.191
Km Outside	258.620	111.716	78.577	801.292

Figure 104: Kilometres travelled - Paris - Scenario 1.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

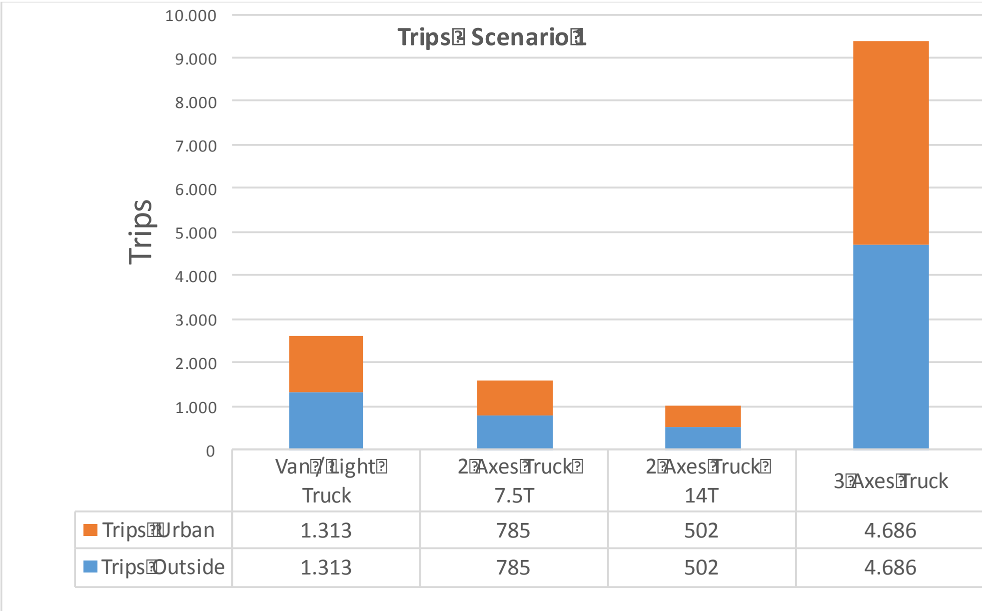


Figure 105: Number of trips - Paris - Scenario 1.

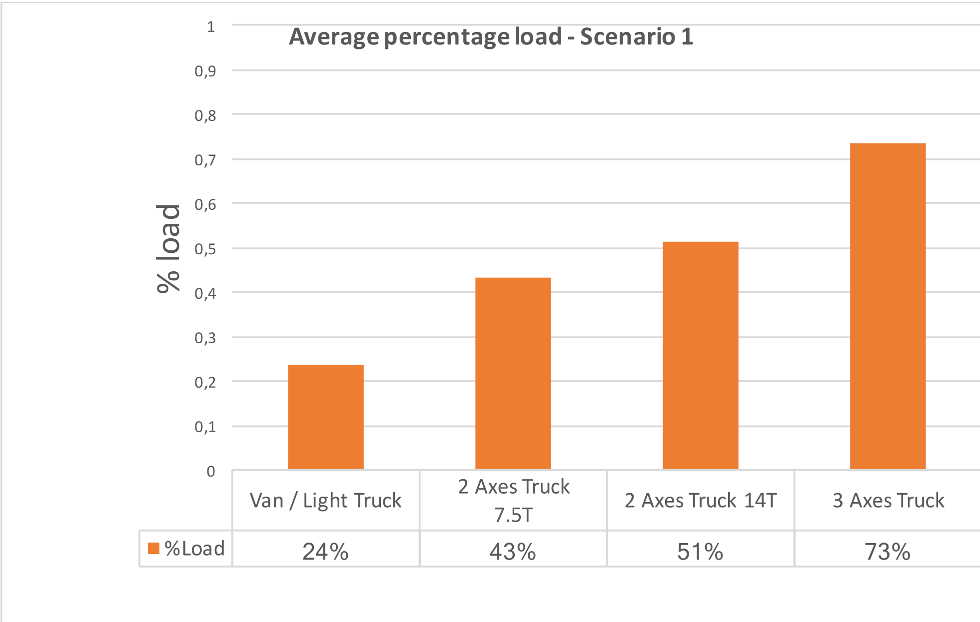


Figure 106: Percentage loads - Paris - Scenario 1.

The next tables report the emissions inside and outside the inner city.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	13,84	3,07	3,29	26,79	5,32
2 Axes Truck 7.5T	13,98	2,12	2,24	34,31	3,70
2 Axes Truck 14T	10,72	1,68	1,88	38,93	3,78
3 Axes Truck	148,99	21,78	22,51	592,20	60,40
Tot	**187,53**	**28,65**	**29,92**	**692,23**	**73,20**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Table 19: Pollutants emissions caused by transport inside the city – Paris - Scenario 1.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	169,01	44,42	46,04	296,07	67,17
2 Axes Truck 7.5T	89,46	13,10	13,69	351,52	38,43
2 Axes Truck 14T	78,76	10,61	11,65	381,98	35,73
3 Axes Truck	1.125,22	159,64	164,50	5.192,58	523,07
Tot	**1.462,45**	**227,77**	**235,88**	**6.222,15**	**664,40**

Table 20: Pollutants emissions caused by transport outside the city – Paris - Scenario 1.

5.3.3 Scenario 2 - CCC-1 site – optimization on the second echelon

We give the same figures and tables of scenario 1. We will do the same for scenario 3 and then we will present a comparison of the three cases.

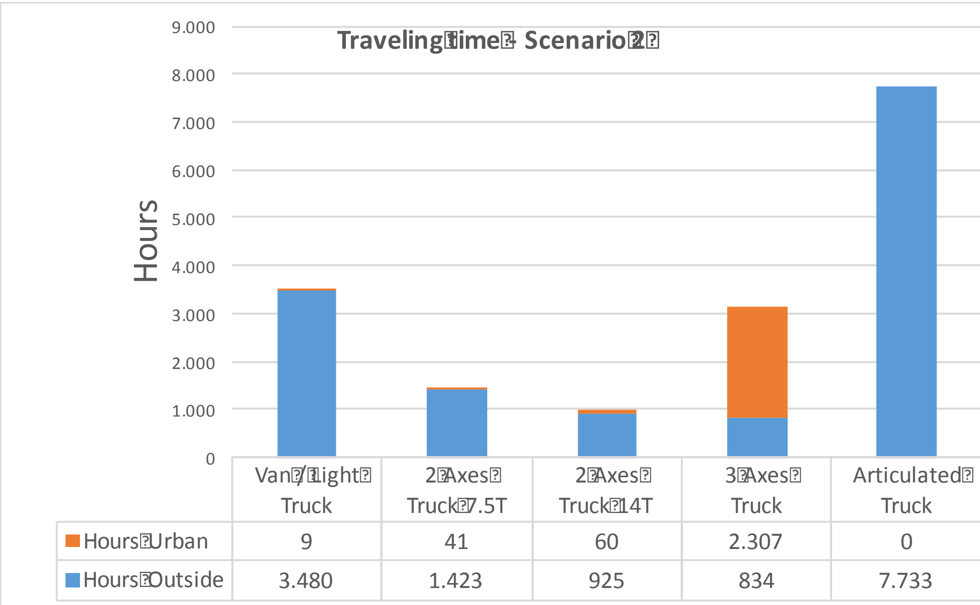
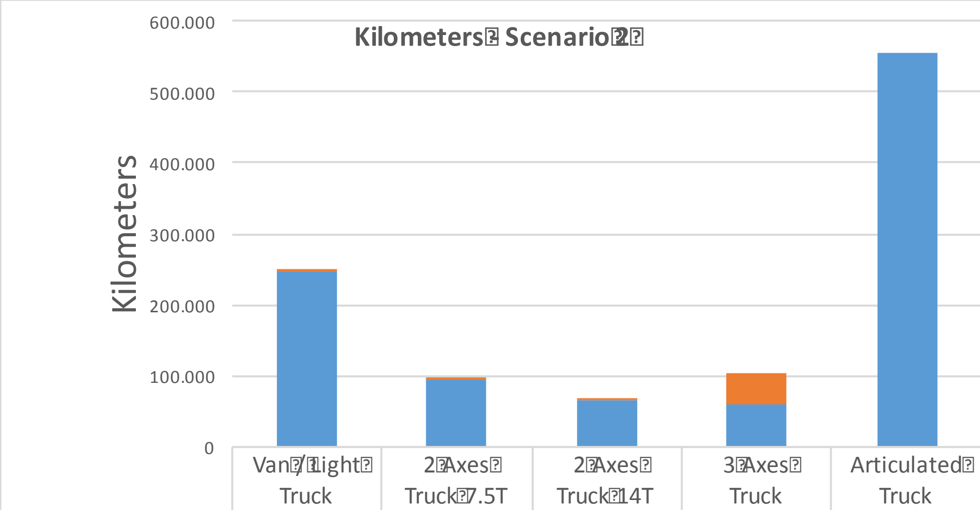


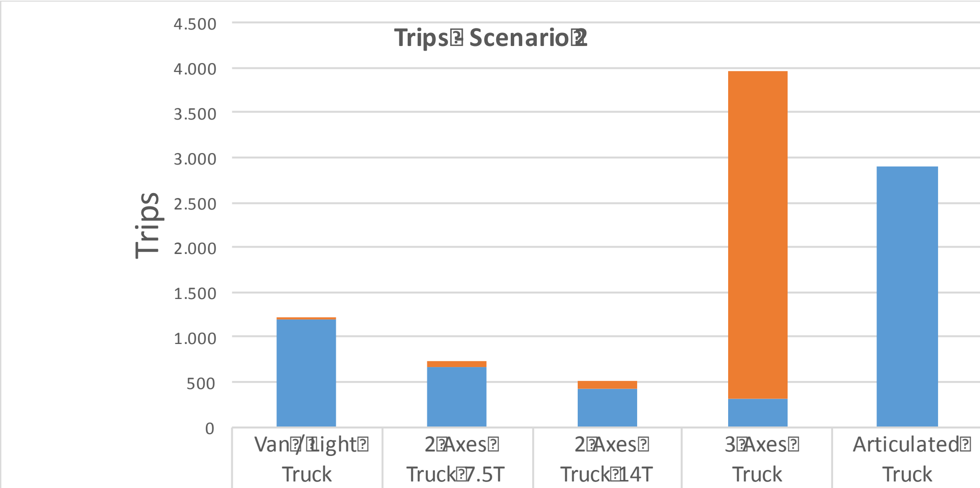
Figure 107: Traveling times - Paris - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	176	763	1.115	42.822	0
Km Outside	247.752	95.566	65.189	59.332	554.616

Figure 108: Kilometres travelled - Paris - Scenario 2.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	15	65	95	3.650	0
Outside city	1.195	662	419	309	2.898

Figure 109: Number of trips - Paris - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

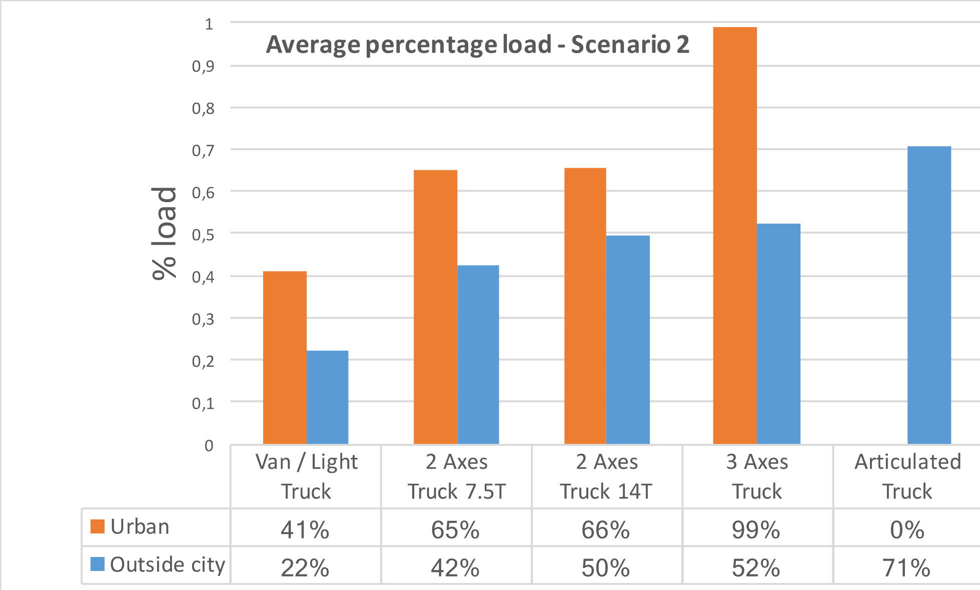


Figure 110: Percentage loads - Paris - Scenario 2.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,17	0,04	0,04	0,34	0,07
2 Axes Truck 7.5T	1,31	0,20	0,21	3,21	0,35
2 Axes Truck 14T	2,33	0,37	0,41	8,47	0,82
3 Axes Truck	141,18	20,64	21,33	561,16	57,24
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**144,99**	**21,24**	**21,99**	**573,18**	**58,47**

Table 21: Pollutants emissions caused by transport inside the city – Paris - Scenario 2.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	161,90	42,56	44,11	283,63	64,34
2 Axes Truck 7.5T	76,53	11,20	11,71	300,71	32,87
2 Axes Truck 14T	65,34	8,80	9,66	316,90	29,65
3 Axes Truck	83,32	11,82	12,18	384,49	38,73
Articulated Truck	817,59	129,37	139,93	2.806,18	372,44
Tot	**1.204,68**	**203,75**	**217,58**	**4.091,91**	**538,03**

Table 22: Pollutants emissions caused by transport outside the city - Paris -Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.3.4 Scenario 3 – 1 CCC, 1 site, optimization on both echelons

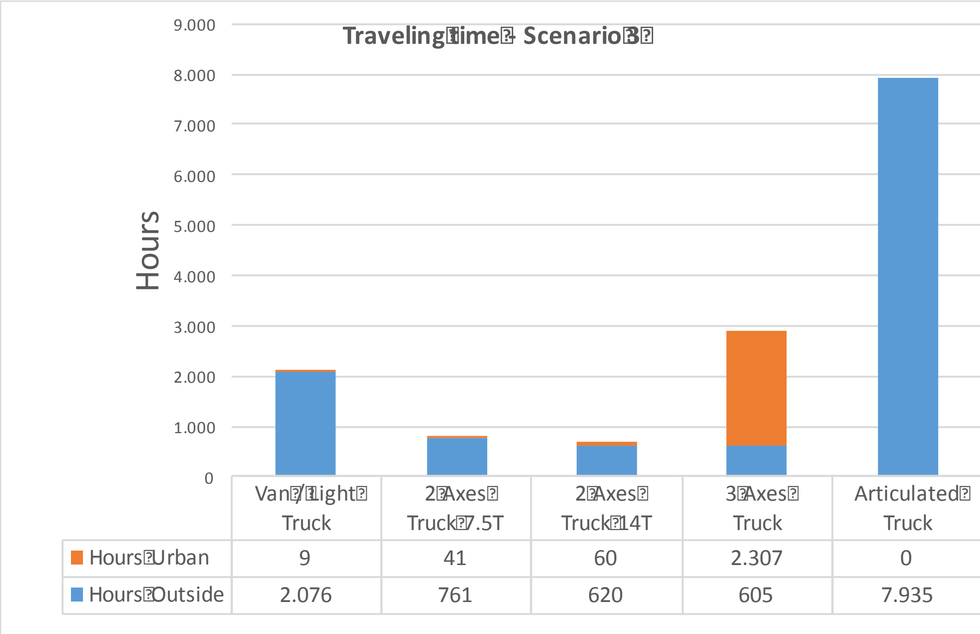


Figure 111: Traveling times - Paris - Scenario 3.

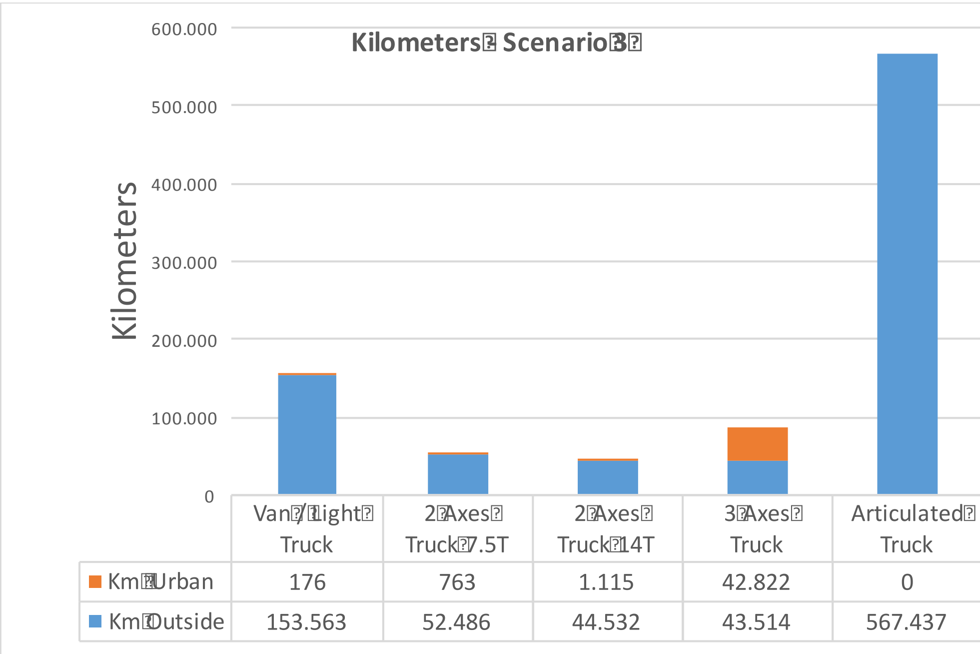
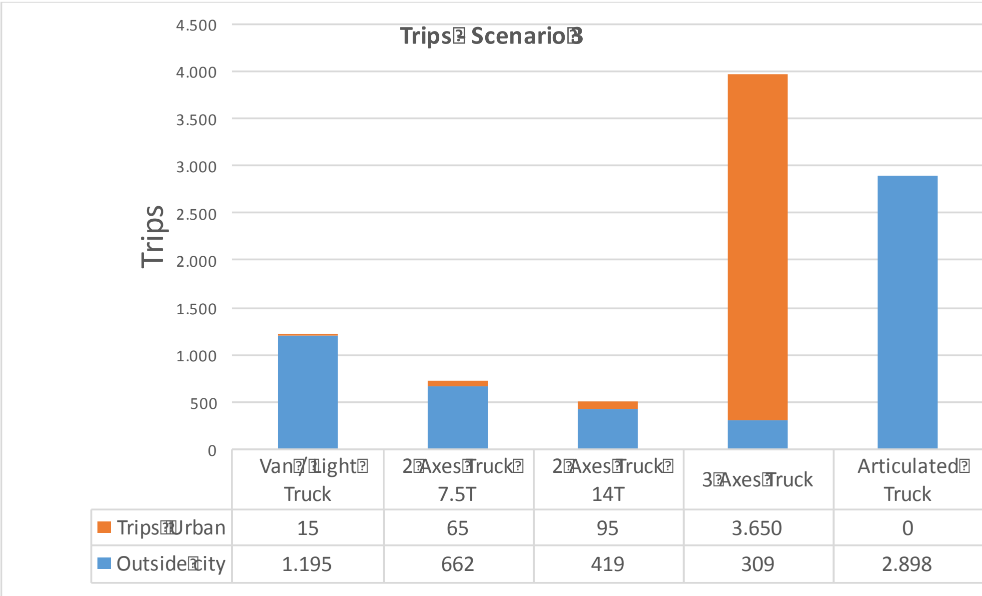


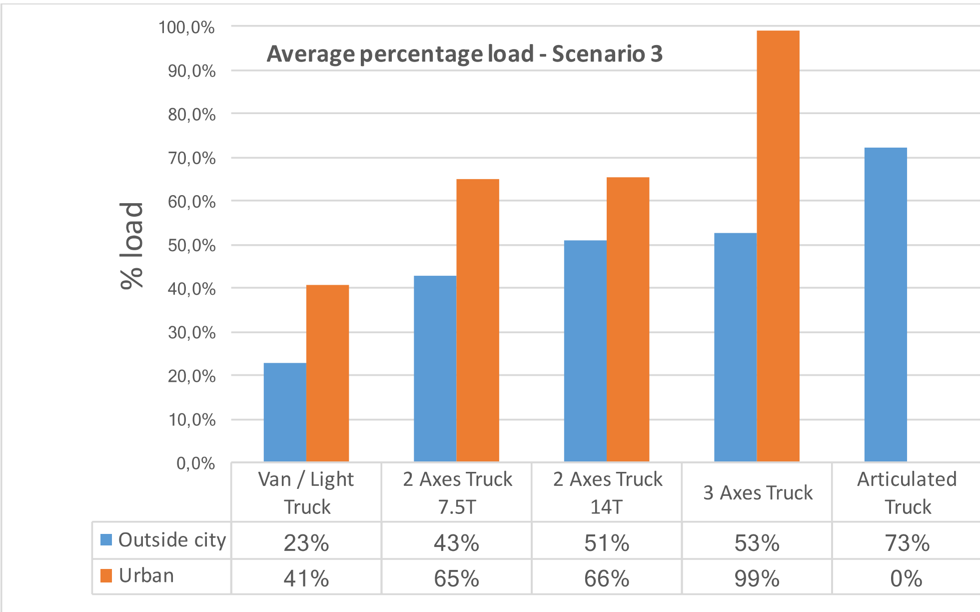
Figure 112: Kilometres travelled - Paris - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	15	65	95	3.650	0
Outside city	1.195	662	419	309	2.898

Figure 113: Number of trips - Paris - Scenario 3.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Outside city	23%	43%	51%	53%	73%
Urban	41%	65%	66%	99%	0%

Figure 114: Percentage loads - Paris - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,17	0,04	0,04	0,34	0,07
2 Axes Truck 7.5T	1,31	0,20	0,21	3,21	0,35
2 Axes Truck 14T	2,33	0,37	0,41	8,47	0,82
3 Axes Truck	141,18	20,64	21,33	561,16	57,24
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**144,99**	**21,24**	**21,99**	**573,18**	**58,47**

Table 23: Pollutants emissions caused by transport inside the city - Paris - Scenario 3.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	100,35	26,38	27,34	175,80	39,88
2 Axes Truck 7.5T	42,03	6,15	6,43	165,15	18,05
2 Axes Truck 14T	44,64	6,01	6,60	216,48	20,25
3 Axes Truck	61,10	8,67	8,93	281,98	28,41
Articulated Truck	836,49	132,36	143,16	2.871,05	381,05
Tot	**1.084,62**	**179,57**	**192,46**	**3.710,47**	**487,64**

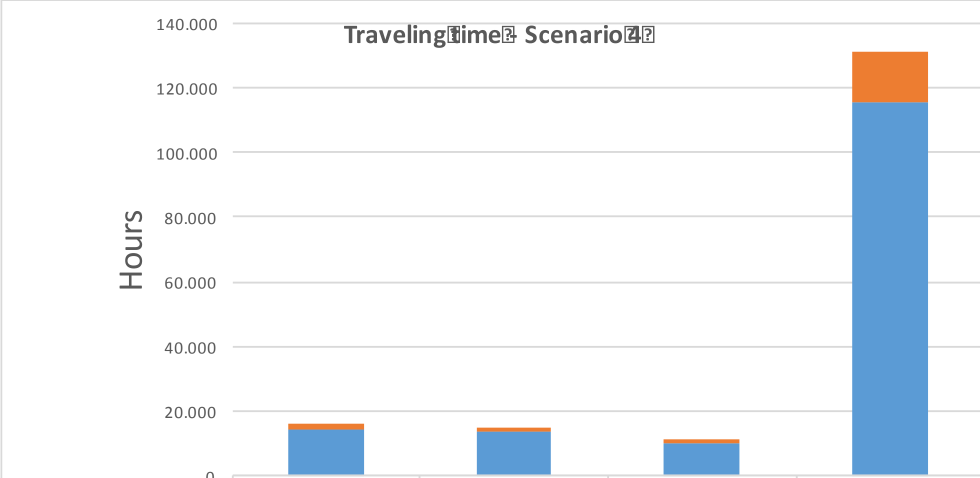
Table 24: Pollutants emissions caused by transport outside the city - Paris - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.3.5 Scenario with multiple construction sites

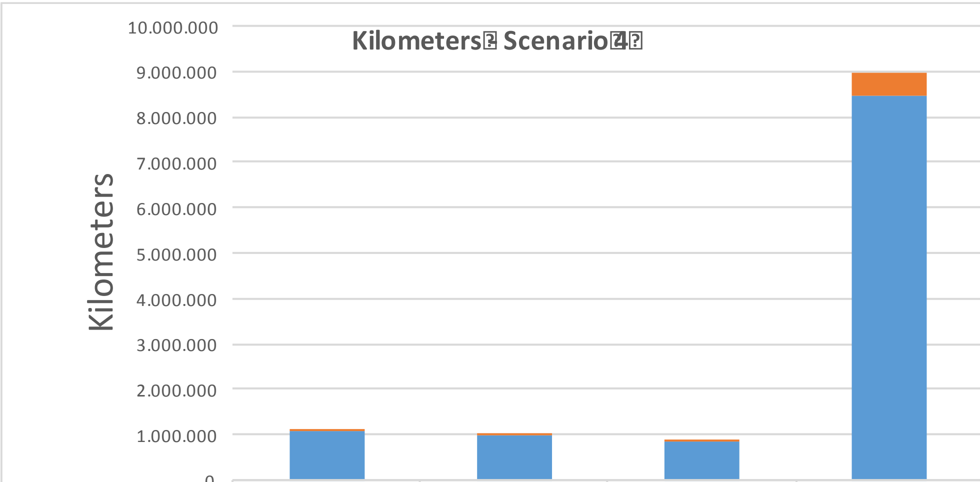
The next sections give the results of the simulation with all construction sites.

5.3.6 Scenario 4 – no CCC, all construction sites optimization for each supplier/period/material



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Hours Urban	1.848	1.215	727	15.554
Hours Outside	14.491	13.892	10.326	115.443

Figure 115: Traveling times - Paris - Scenario 4.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Km Urban	58.150	43.368	28.048	489.301
Km Outside	1.063.039	1.009.745	842.678	8.473.817

Figure 116: Kilometres travelled - Paris - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

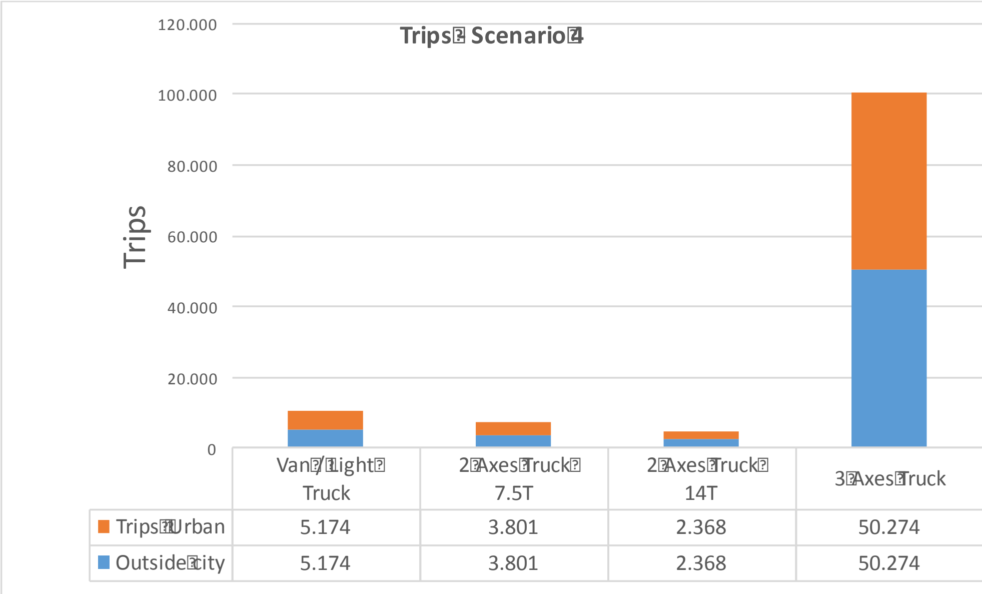


Figure 117: Number of trips - Paris - Scenario 4.

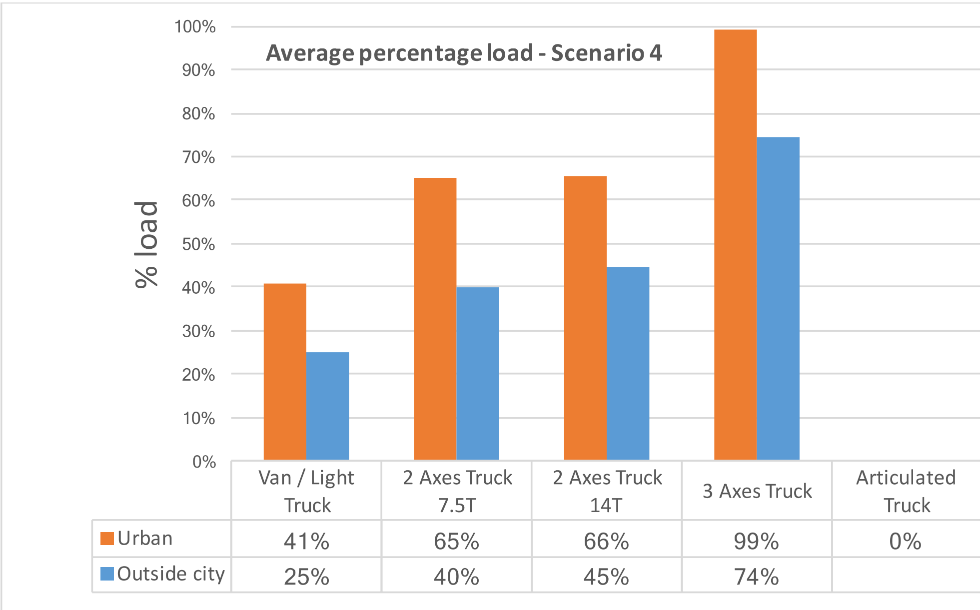


Figure 118: Percentage loads - Paris - Scenario 4.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	57,74	12,81	13,73	111,76	22,18
2 Axes Truck 7.5T	74,34	11,26	11,92	182,41	19,69
2 Axes Truck 14T	58,71	9,22	10,28	213,08	20,68
3 Axes Truck	1.613,14	235,79	243,77	6.412,01	654,02
Tot	**1.803,93**	**269,08**	**279,70**	**6.919,27**	**716,57**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Table 25: Pollutants emissions caused by transport inside the city - Paris - Scenario 4.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	694,69	182,60	189,25	1.216,99	276,09
2 Axes Truck 7.5T	808,58	118,36	123,70	3.177,24	347,31
2 Axes Truck 14T	844,69	113,76	124,89	4.096,45	383,21
3 Axes Truck	11.899,38	1.688,24	1.739,66	54.912,48	5.531,62
Tot	**14.247,33**	**2.102,97**	**2.177,50**	**63.403,15**	**6.538,22**

Table 26: Pollutants emissions caused by transport outside the city - Paris - Scenario 4.

5.3.7 Scenario 5 – 1 CCC multiple sites, optimization on the second echelon

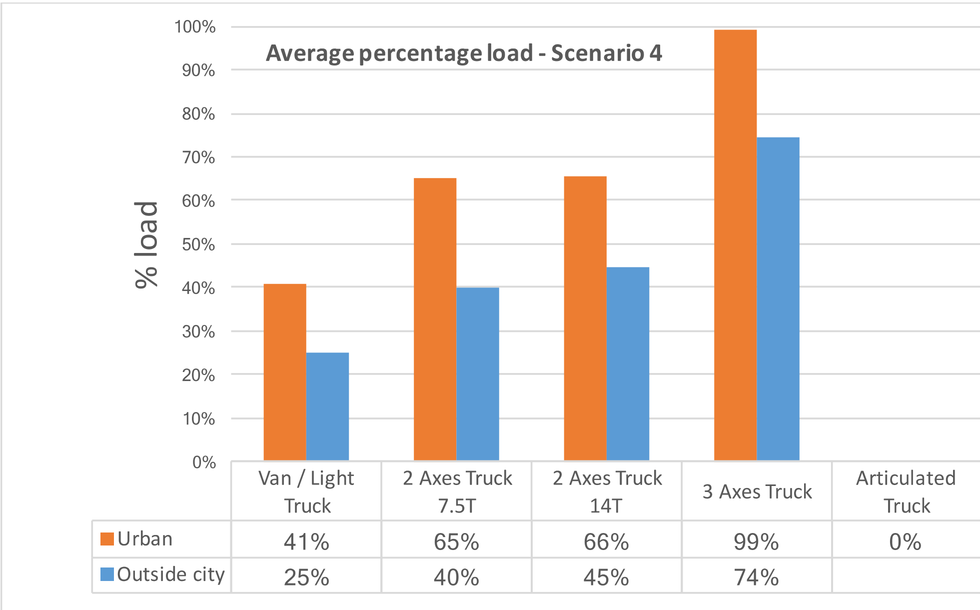


Figure 119: Traveling times - Paris - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

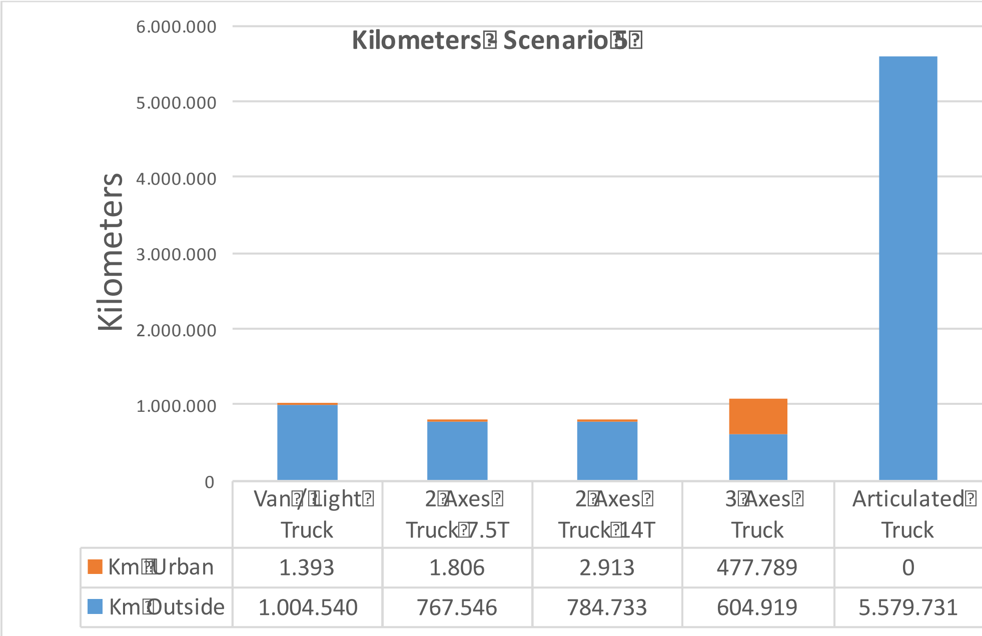


Figure 120: Kilometres travelled - Paris - Scenario 5.

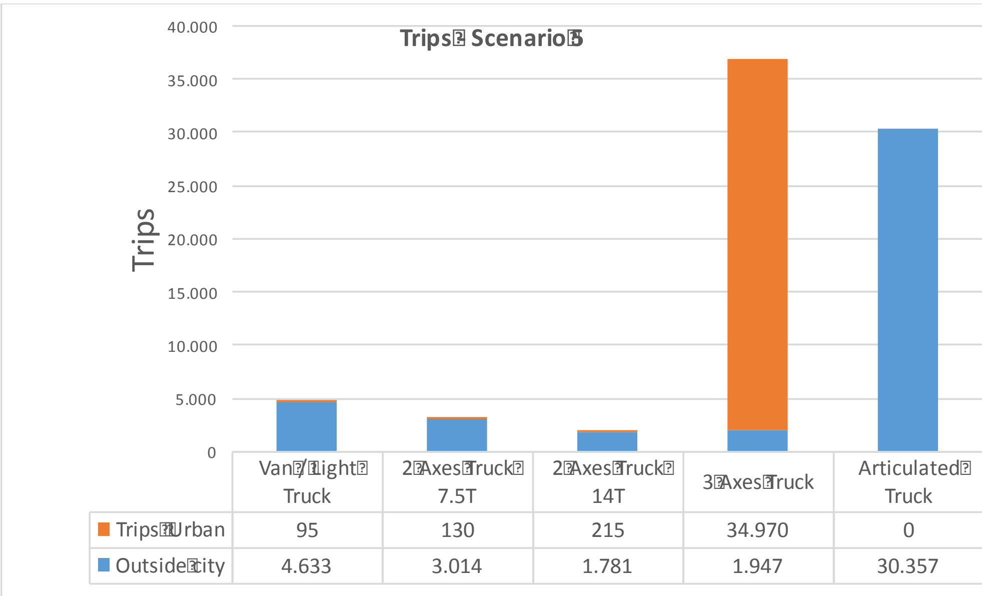


Figure 121: Number of trips - Paris - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

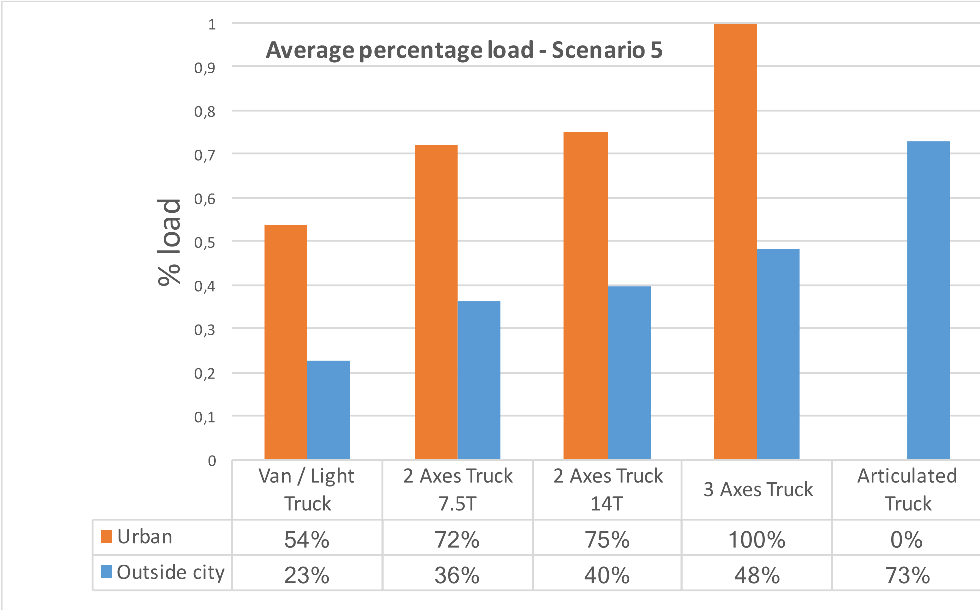


Figure 122: Percentage loads - Paris - Scenario 5.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1,38	0,31	0,33	2,68	0,53
2 Axes Truck 7.5T	3,10	0,47	0,50	7,60	0,82
2 Axes Truck 14T	6,10	0,96	1,07	22,13	2,15
3 Axes Truck	1.575,19	230,25	238,04	6.261,15	638,63
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**1.585,77**	**231,98**	**239,93**	**6.293,56**	**642,13**

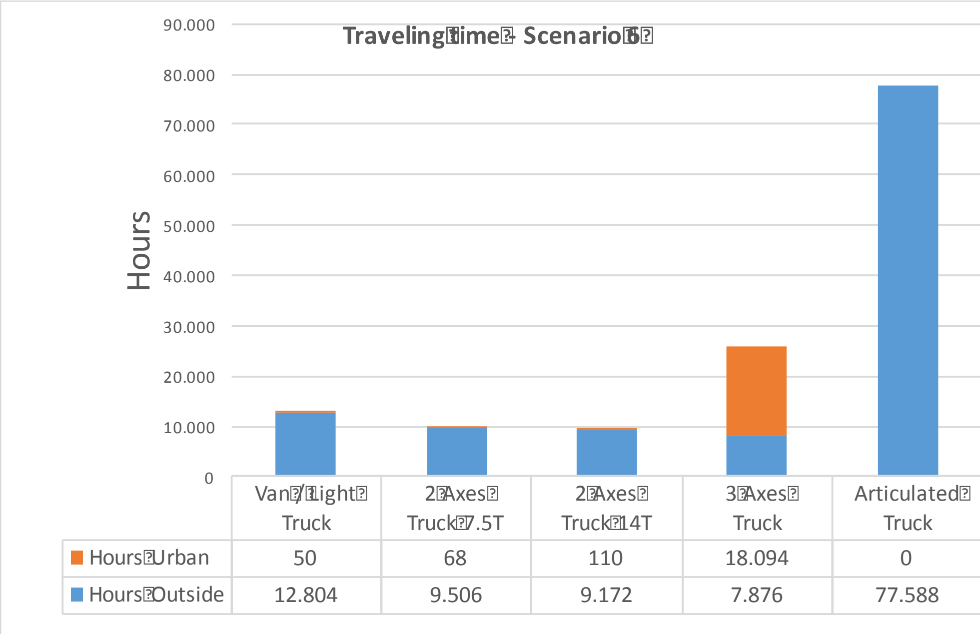
Table 27: Pollutants emissions caused by transport inside the city - Paris - Scenario 5.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	656,46	172,56	178,84	1.150,02	260,89
2 Axes Truck 7.5T	614,63	89,97	94,03	2.415,14	264,00
2 Axes Truck 14T	786,61	105,94	116,30	3.814,76	356,86
3 Axes Truck	849,46	120,52	124,19	3.920,03	394,88
Articulated Truck	8.225,40	1.301,49	1.407,72	28.231,70	3.746,94
Tot	**11.132,56**	**1.790,48**	**1.921,08**	**39.531,65**	**5.023,59**

Table 28: Pollutants emissions caused by transport outside the city - Paris - Scenario 5.

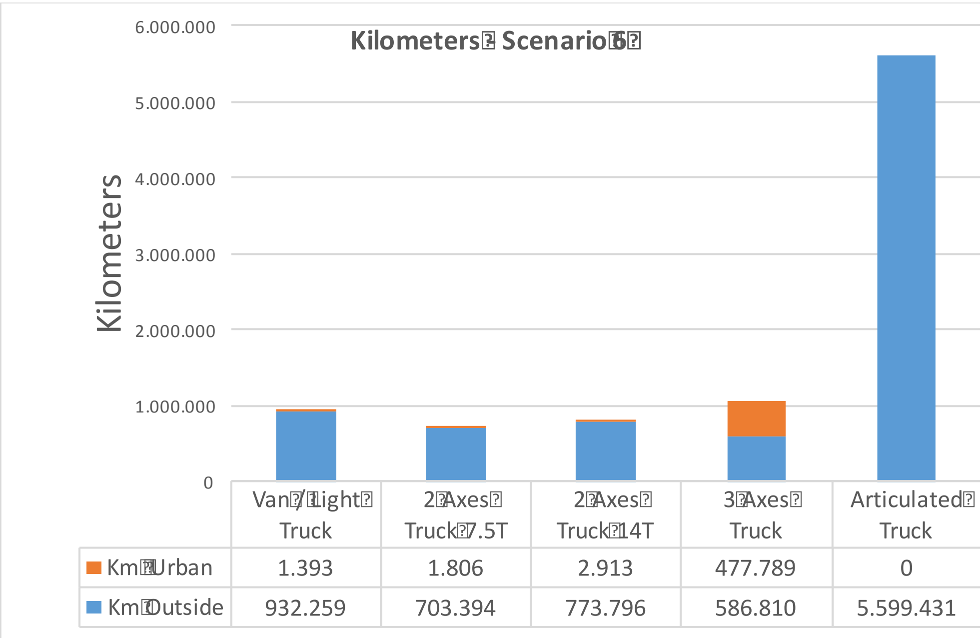
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.3.8 Scenario 6 – 1 CCC multiple sites, optimization on both echelons



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	50	68	110	18.094	0
Hours Outside	12.804	9.506	9.172	7.876	77.588

Figure 123: Traveling times - Paris - Scenario 6.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	1.393	1.806	2.913	477.789	0
Km Outside	932.259	703.394	773.796	586.810	5.599.431

Figure 124: Kilometres travelled - Paris - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

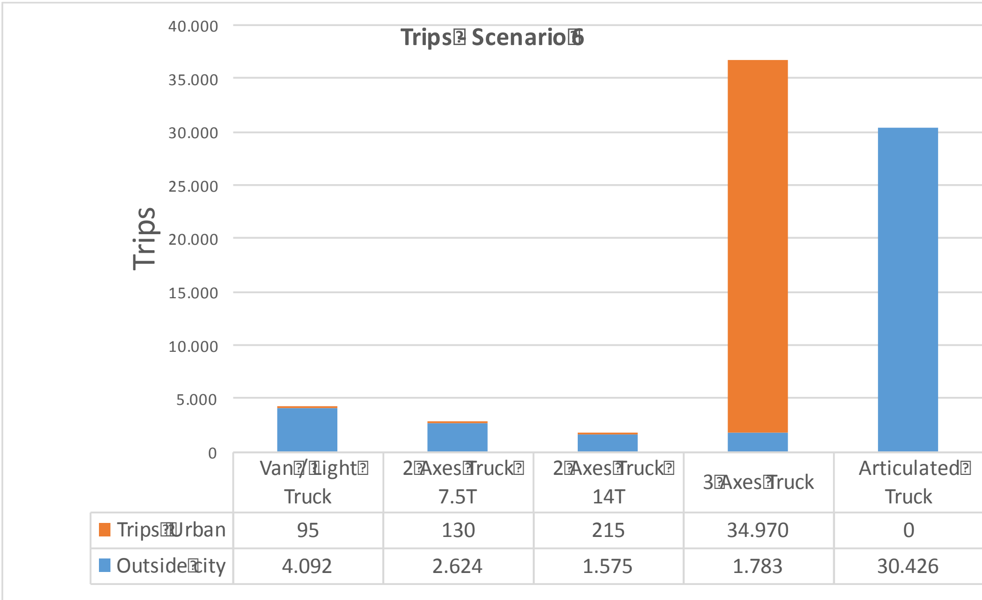


Figure 125: Number of trips - Paris - Scenario 6.

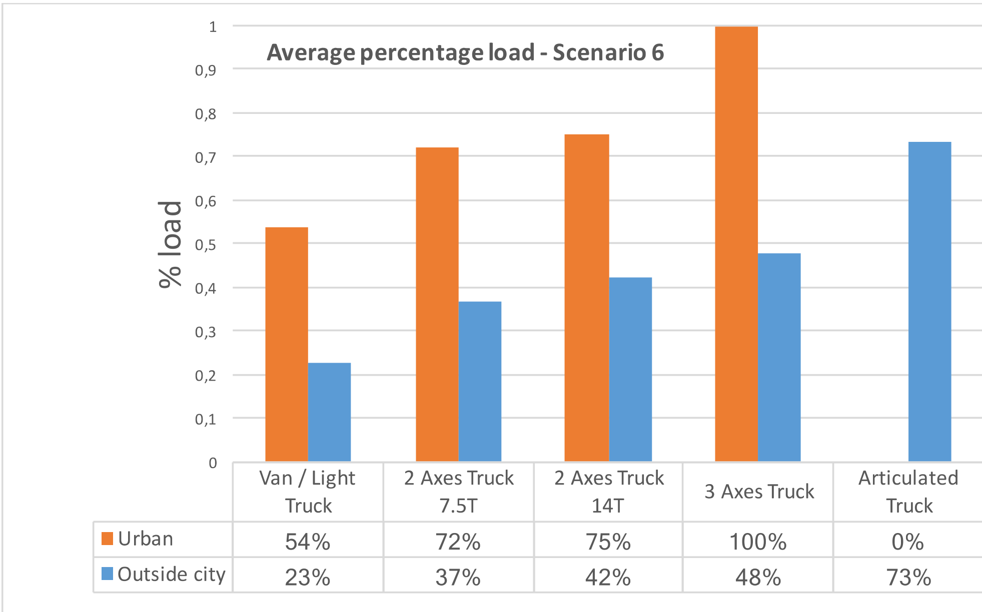


Figure 126: Percentage loads - Paris - Scenario 6.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1,38	0,31	0,33	2,68	0,53
2 Axes Truck 7.5T	3,10	0,47	0,50	7,60	0,82
2 Axes Truck 14T	6,10	0,96	1,07	22,13	2,15
3 Axes Truck	1.575,19	230,25	238,04	6.261,15	638,63
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**1.585,77**	**231,98**	**239,93**	**6.293,56**	**642,13**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Table 29: Pollutants emissions caused by transport inside the city - Paris - Scenario 6.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	609,22	160,14	165,97	1.067,27	242,12
2 Axes Truck 7.5T	563,26	82,45	86,17	2.213,28	241,94
2 Axes Truck 14T	775,64	104,46	114,68	3.761,59	351,89
3 Axes Truck	824,03	116,91	120,47	3.802,68	383,06
Articulated Truck	8.254,44	1.306,09	1.412,69	28.331,38	3.760,17
Tot	**11.026,60**	**1.770,05**	**1.899,98**	**39.176,20**	**4.979,18**

Table 30: Pollutants emissions caused by transport outside the city – Paris - Scenario 6.

5.3.9 Scenario 7 – 2 CCC multiple sites, optimization on the second echelons

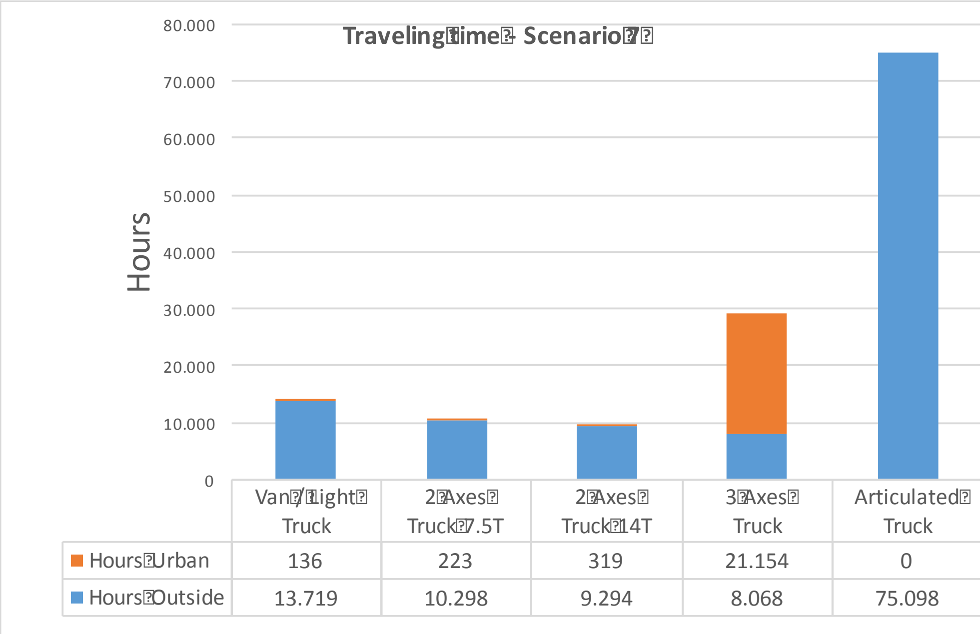


Figure 127: Traveling times - Paris - Scenario 7.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

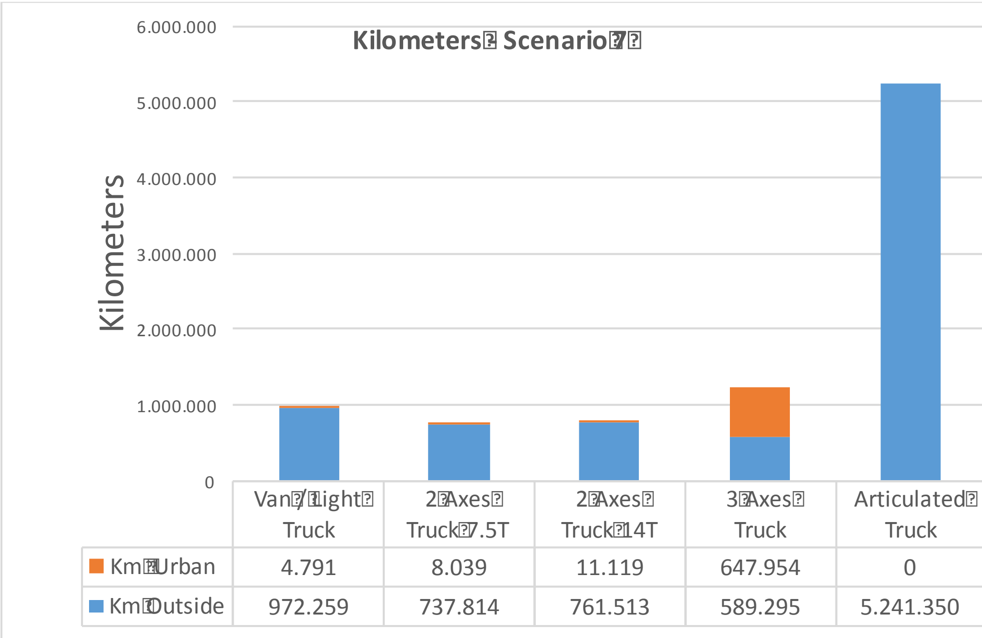


Figure 128: Kilometres travelled - Paris - Scenario 7.

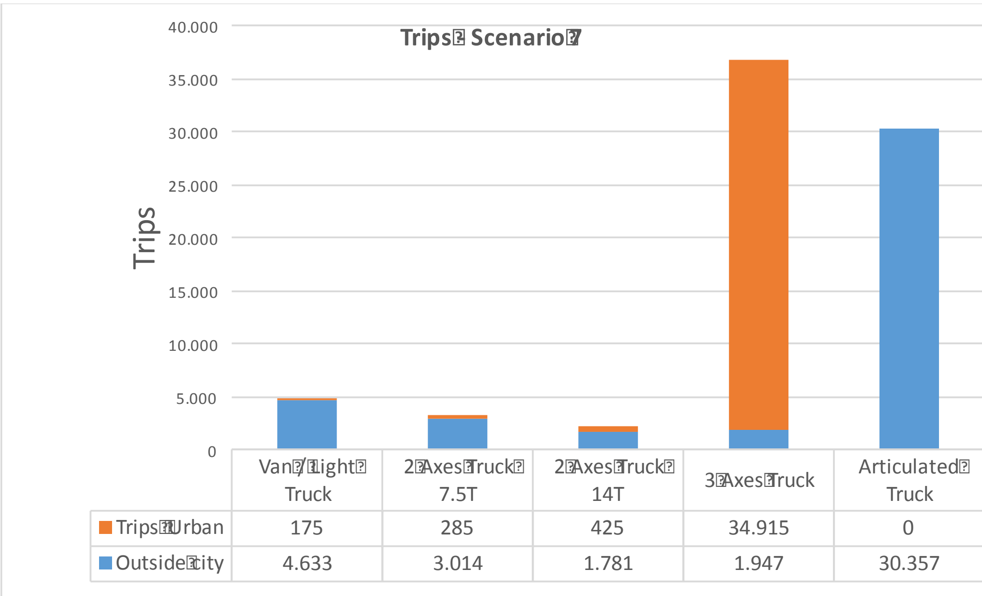


Figure 129: Number of trips - Paris - Scenario 7.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

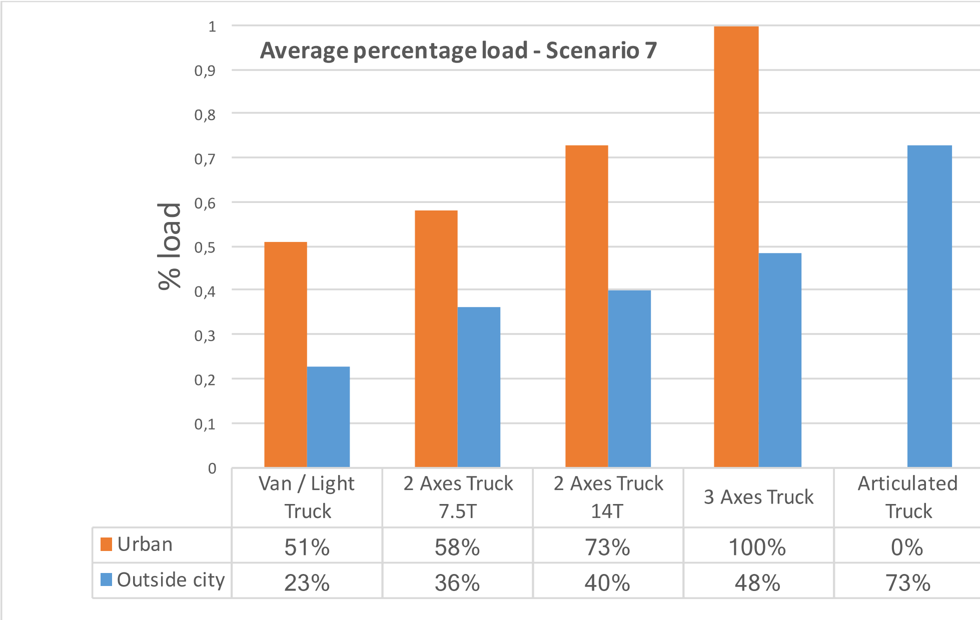


Figure 130: Percentage loads – Paris - Scenario 7.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	4,76	1,06	1,13	9,21	1,83
2 Axes Truck 7.5T	13,78	2,09	2,21	33,81	3,65
2 Axes Truck 14T	23,27	3,65	4,08	84,47	8,20
3 Axes Truck	2.136,20	312,25	322,81	8.491,07	866,08
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**2.178,01**	**319,05**	**330,23**	**8.618,56**	**879,75**

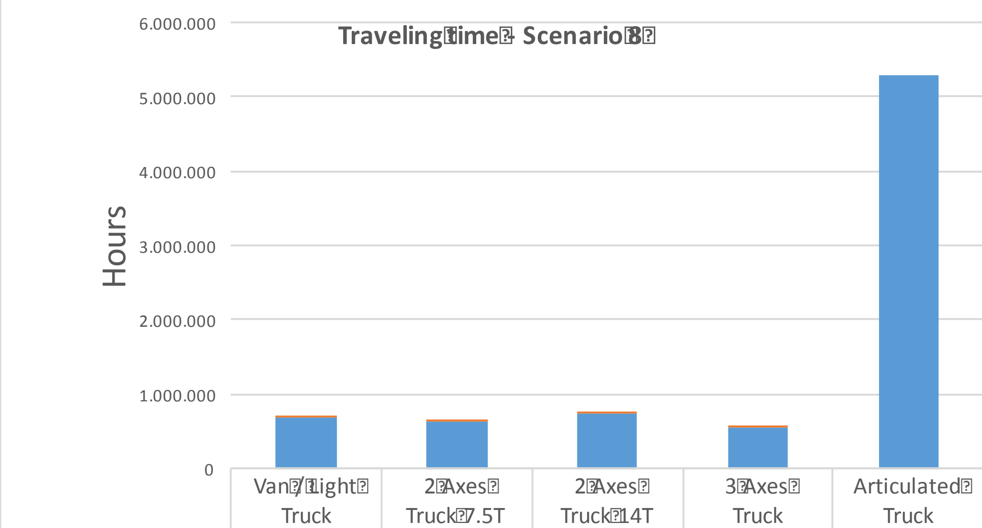
Table 31: Pollutants emissions caused by transport inside the city -Paris - Scenario 7.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	635,36	167,01	173,09	1.113,06	252,51
2 Axes Truck 7.5T	590,82	86,49	90,39	2.321,58	253,77
2 Axes Truck 14T	763,33	102,80	112,86	3.701,88	346,30
3 Axes Truck	827,52	117,41	120,98	3.818,78	384,69
Articulated Truck	7.726,57	1.222,56	1.322,35	26.519,60	3.519,71
Tot	**10.543,61**	**1.696,27**	**1.819,67**	**37.474,91**	**4.756,99**

Table 32: Pollutants emissions caused by transport outside the city -Paris - Scenario 7.

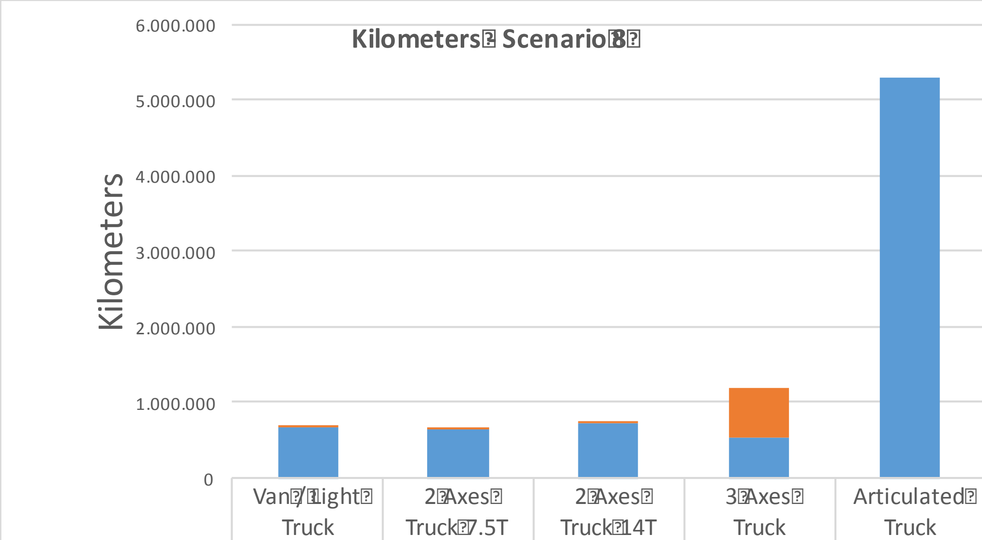
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.3.10 Scenario 8 – 2 CCC multiple sites, optimization on both echelons



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	136	223	319	21.154	0
Hours Outside	682.793	640.509	727.815	543.390	5.281.511

Figure 131: Traveling times - Paris - Scenario 8.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	4.791	8.039	11.119	647.954	0
Km Outside	682.793	640.509	727.815	543.390	5.281.511

Figure 132: Kilometres travelled - Paris - Scenario 8.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

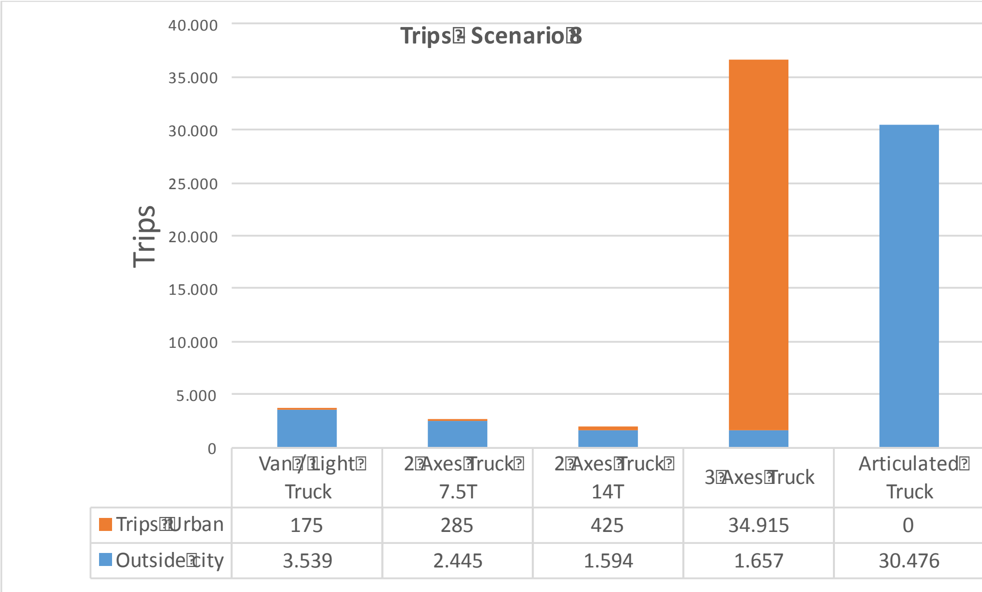


Figure 133: Number of trips - Paris - Scenario 8.

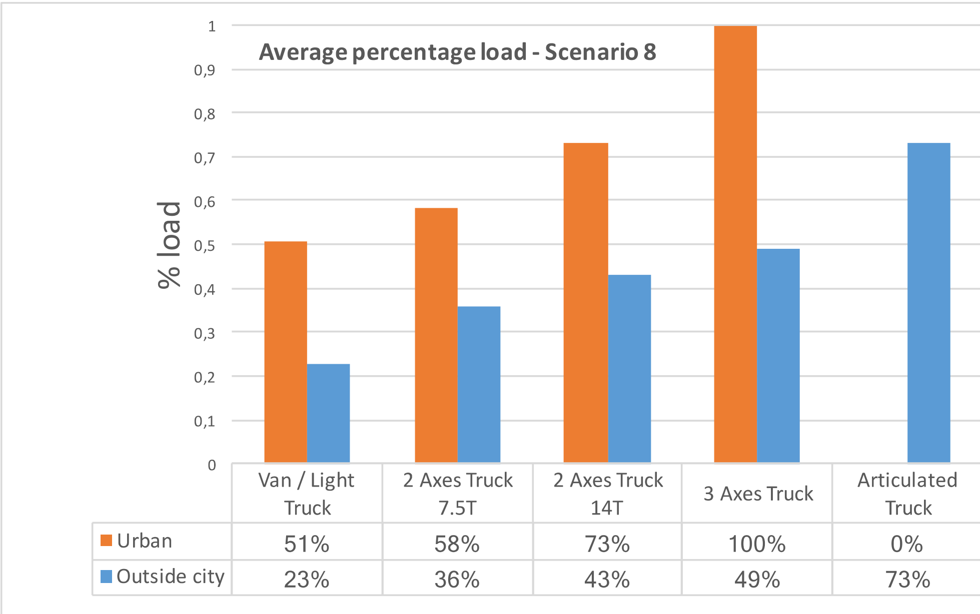


Figure 134: Percentage loads - Paris - Scenario 8.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	4,76	1,06	1,13	9,21	1,83
2 Axes Truck 7.5T	13,78	2,09	2,21	33,81	3,65
2 Axes Truck 14T	23,27	3,65	4,08	84,47	8,20
3 Axes Truck	2.136,20	312,25	322,81	8.491,07	866,08
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**2.178,01**	**319,05**	**330,23**	**8.618,56**	**879,75**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Table 33: Pollutants emissions caused by transport inside the city – Paris - Scenario 8.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	446,20	117,29	121,56	781,67	177,33
2 Axes Truck 7.5T	512,90	75,08	78,47	2.015,41	220,31
2 Axes Truck 14T	729,55	98,25	107,86	3.538,07	330,98
3 Axes Truck	763,06	108,26	111,56	3.521,31	354,72
Articulated Truck	7.785,78	1.231,93	1.332,48	26.722,80	3.546,68
Tot	**10.237,49**	**1.630,81**	**1.751,93**	**36.579,26**	**4.630,02**

Table 34: Pollutants emissions caused by transport outside the city - Paris- Scenario 8.

5.4 Valencia

5.4.1 Scenario with a single big site

We consider the simulations with the pilot site and no or one CCC.

5.4.2 Scenario 1 - no CCC - 1 site – baseline

In the next two figures, we report respectively, the time and the kilometres for the deliveries in the Valencia simulation. We consider 4 types of trucks, since the articulated trucks are not allowed to enter the city, and in the baseline (scenario 1) the materials are delivered directly to the construction site.

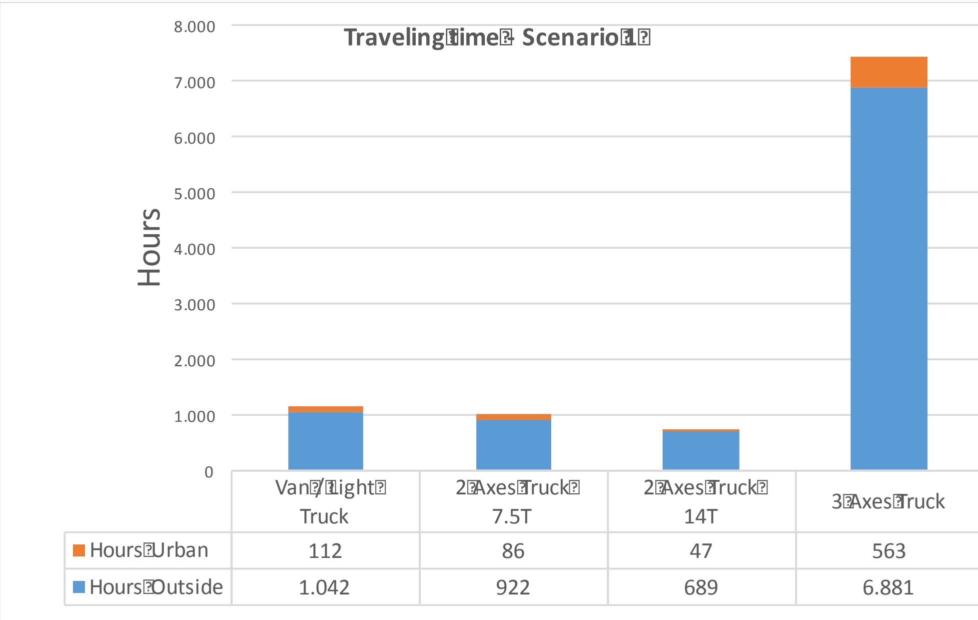


Figure 135: Traveling times - Valencia - Scenario 1.

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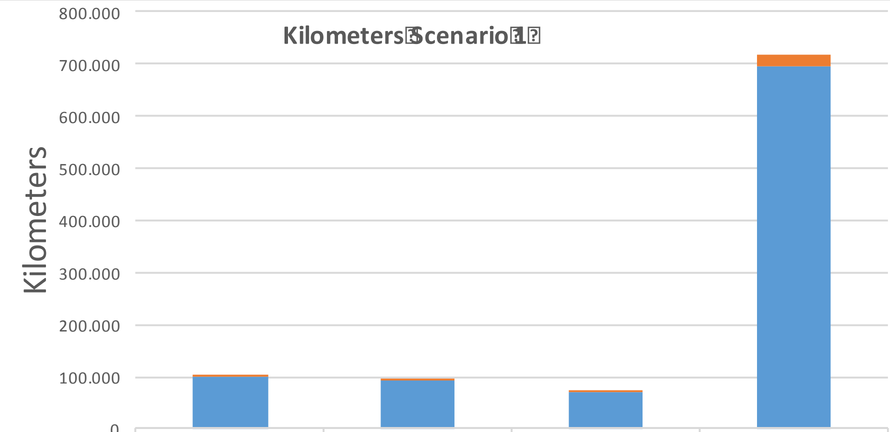

	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck
Km Urban	4.773	4.295	2.226	24.738
Km Outside	100.090	92.076	68.830	695.013

Figure 136: Kilometres travelled - Valencia - Scenario 1.

It can be noticed that the kilometres and the minutes for traveling outside the city are one order of magnitude larger than that inside the city. This is normal due to the fact that the supplier is several kilometres, to thousands of kilometres far from the city border.

We also observe that there is a prevalence of transports using the 3 axes trucks, which minimizes the number of deliveries. The deliveries with the other kind of trucks are one order of magnitude smaller.

In regards to the numbers of trips, it is the same outside and inside the city, since in this scenario we consider deliveries going directly from the supplier to the site. The use of the trucks is that already observed, i.e., there is a large prevalence of trips using the 3 axes truck (one order of magnitude). The number of trips with the 3 axes truck is more than double than the number of trips with all the other trucks.

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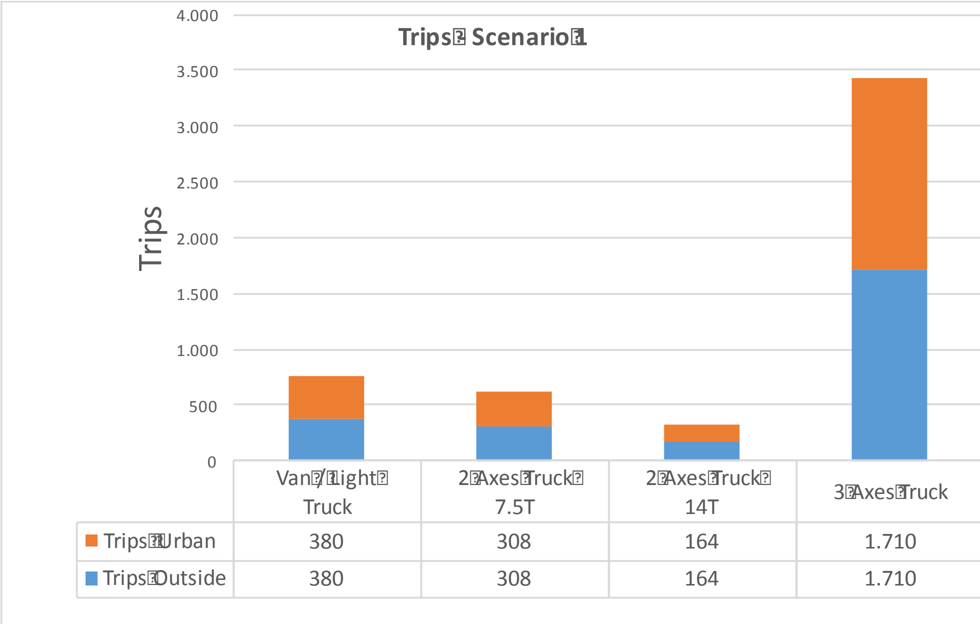

Figure 137: Number of trips - Valencia - Scenario 1.

The following figure reports on the average truck loads.

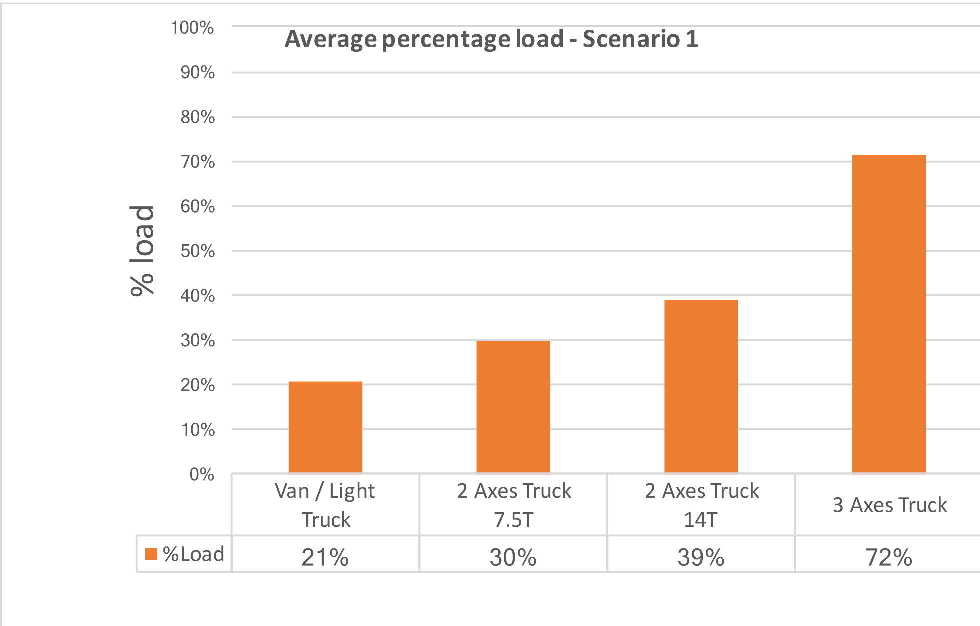

Figure 138: Percentage loads - Valencia- Scenario 2.

The biggest trucks have the largest loads. The 3 axes trucks have a load close to the maximum realistic load when we start from the suppliers (fixed to 75% of the nominal capacity). The smaller vehicles have lower load percentage, since they are used only when some residual material quantity cannot be delivered efficiently through the largest vehicles.

The next tables give the total tons of pollutants emissions: CO, PM2.5, PM10. NOx and CO2:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	4,74	1,05	1,13	9,17	1,82
2 Axes Truck 7.5T	7,36	1,12	1,18	18,07	1,64
2 Axes Truck 14T	4,66	0,73	0,82	16,91	0,85
3 Axes Truck	81,56	11,92	12,32	324,18	9,44
Tot	0,12	0,02	0,02	0,49	49,16

Table 35: Pollutants emissions caused by transport inside the city - Valencia- scenario 1.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	65,4	17,2	17,8	114,6	26,0
2 Axes Truck 7.5T	73,7	10,8	11,3	289,7	31,7
2 Axes Truck 14T	69,0	9,3	10,2	334,6	31,3
3 Axes Truck	976,0	138,5	142,7	4.503,9	453,7
Tot	**1.184,1**	**175,7**	**182,0**	**5.242,8**	**542,7**

Table 36: Pollutants emissions caused by transport outside the city - Valencia- Scenario 1.

5.4.3 Scenario 2 - CCC-1 site – optimization on the second echelon

Scenario 2 considers the introduction of the CCC identified by the stochastic facility location optimization.

I would add here more information about the CCC identified by the stochastic model with at least a map showing the location of the CCC and a short explanation about the reasons why this CCC is the best one (it might be obvious while having a look at the map that this CCC is well located considering where the site and the suppliers are located).

In the next two figures we report respectively, the time and the kilometres for the deliveries in the Valencia simulation, in scenario 2. The types of trucks are 5, since we can use “big” articulated trucks to deliver the materials to the CCC.

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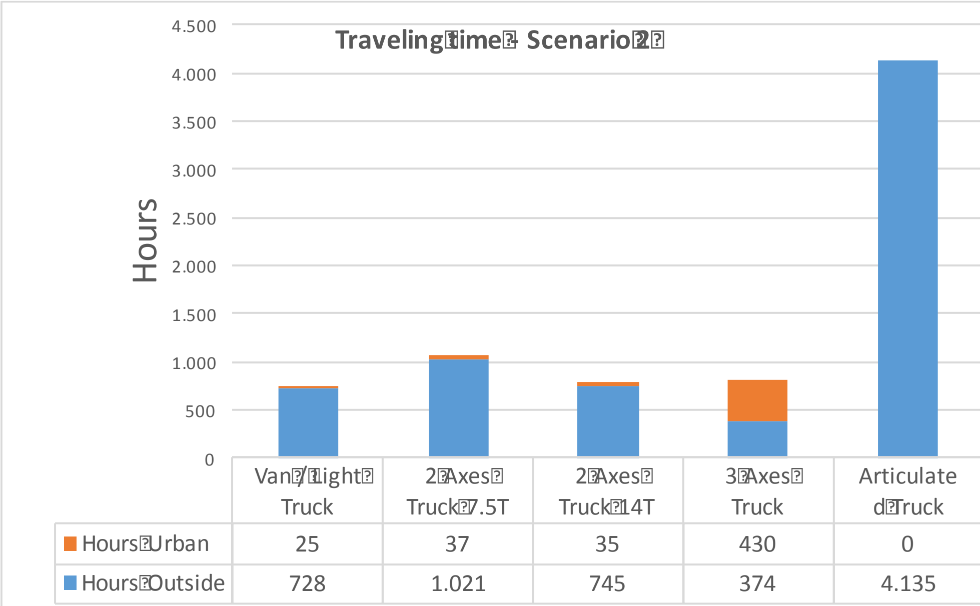
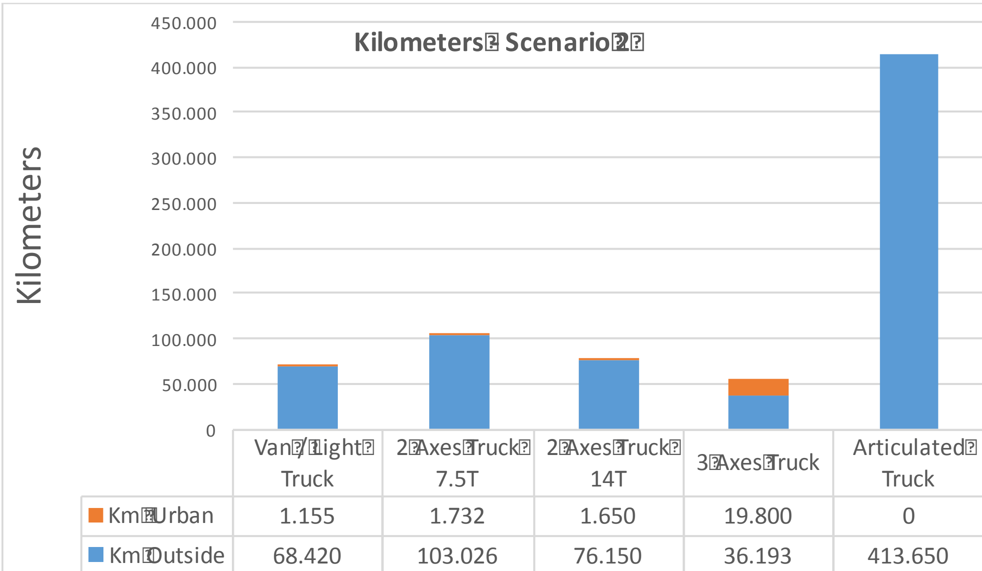


	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	25	37	35	430	0
Hours Outside	728	1.021	745	374	4.135

Figure 139: Traveling times - Valencia - Scenario 2.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	1.155	1.732	1.650	19.800	0
Km Outside	68.420	103.026	76.150	36.193	413.650

Figure 140: Kilometres travelled - Valencia - Scenario 2.

In this scenario, the "big" articulated trucks are the most used for the deliveries to the CCC. They represent about 60% of the kilometres travelled and 2/3 of the traveling duration. Once again, the kilometres and minutes travelled inside the city are at least one order of magnitude smaller than the corresponding values outside the city.

We also observe that there is a prevalence of transports using the two biggest trucks, articulated and 3 axes trucks, which minimizes the number of deliveries. The deliveries with the other kind of trucks are one order of magnitude smaller.

The number of trips outside and inside are different because the use of the CCC. Moreover, the trucks going from the supplier to the CCC are mainly articulated

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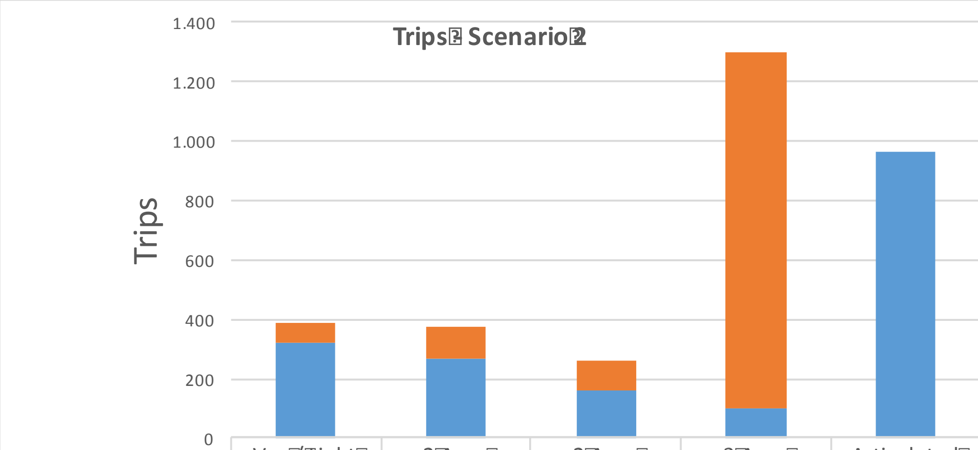
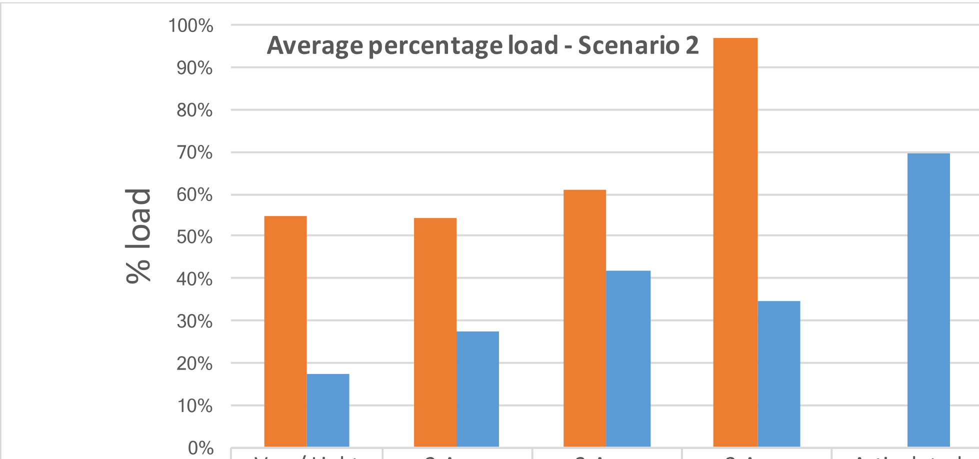
trucks, whereas the deliveries to the construction sites, from the CCC are made using 3 axis trucks and a few smaller vehicles.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	70	105	100	1.200	0
Outside city	321	267	163	101	966

Figure 141: Number of trips - Valencia - Scenario 2.

The following figure reports on the average truck loads.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Urban	55%	54%	61%	97%	0%
Outside city	17%	27%	42%	35%	70%

Figure 142: Percentage loads - Valencia- Scenario 2.

The biggest trucks have the largest loads. The articulated trucks, outside the city and the 3 axes trucks, inside the city, have a load close to the maximum realistic load when we start from the suppliers, CCC, respectively (fixed to 75% and 100% of the nominal capacity). The smaller vehicles have lower load percentage, since they are used only when some residual material quantity cannot be delivered efficiently through the largest vehicles. Note that the vehicles starting

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from the CCC have significantly higher loads than the ones starting from the suppliers.

The next tables give the total tons of pollutants emissions: CO, PM2.5, PM10. NOx and CO2. We remind that the computations are made using the mix of Euroclass from official registration records and used that percentage for the computation. In particular we used the last statistics available for Italy in 2016[1].

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1,15	0,25	0,27	2,22	0,44
2 Axes Truck 7.5T	2,97	0,45	0,48	7,28	0,66
2 Axes Truck 14T	3,45	0,54	0,60	12,54	0,63
3 Axes Truck	65,28	9,54	9,86	259,47	7,55
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**72,85**	**10,79**	**11,22**	**281,51**	**9,28**

Table 37: Pollutants emissions caused by transport inside the city - Valencia- Scenario 2.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	44,7	11,8	12,2	78,33	17,8
2 Axes Truck 7.5T	82,5	12,1	12,6	324,18	35,4
2 Axes Truck 14T	76,3	10,3	11,3	370,18	34,6
3 Axes Truck	50,8	7,2	7,4	234,54	23,6
Articulated Truck	609,8	96,5	104,4	2.092,94	277,8
Tot	**864,15**	**137,81**	**147,88**	**3.100,17**	**389,24**

Table 38: Pollutants emissions caused by transport outside the city - Valencia- Scenario 2.

5.4.4 Scenario 3 – 1 CCC, 1 site, optimization on both echelons

In this scenario, we optimize the deliveries in both echelons: from the Suppliers to the CCC and from the CCC to the sites. The figures inside the city are the same as in scenario 2, since this echelon was already optimized in that scenario.

In the next two figures we report respectively, the time and the number of kilometres for the deliveries in the Valencia simulation.

[1] Elaborazioni dell'Area Studi e Statistiche di ANFIA su dati del Ministero dei Trasporti, I SEM 2017

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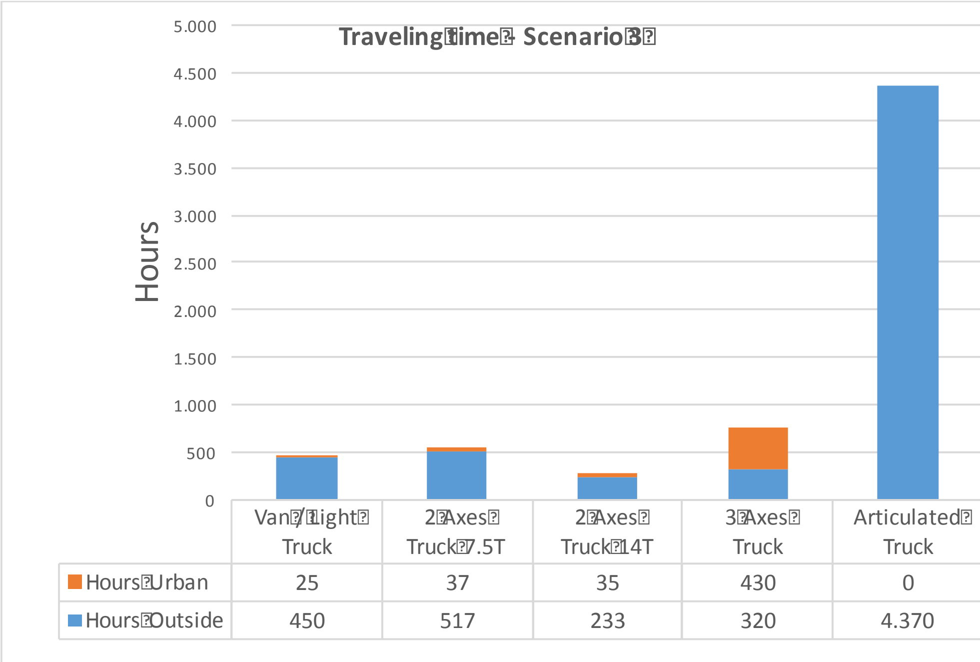

Figure 143: Traveling times - Valencia - Scenario 3.

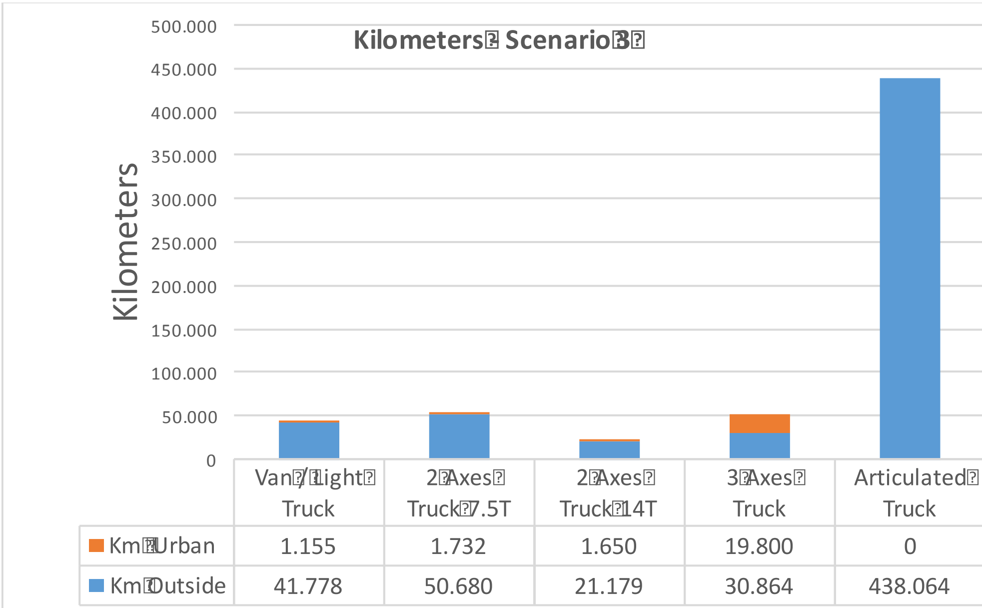

Figure 144: Kilometres travelled - Valencia - Scenario 3.

Also in this scenario, the "big" articulated trucks are the most used for the deliveries to the CCC. However, due to the optimization, they define about 80% of the kilometres travelled and 2/3 of the traveling times. Once again, the kilometres and minutes travelled inside the city are at least one order of magnitude smaller than the corresponding values outside the city.

Inside the city the 3 axes trucks are used for most of the deliveries. The deliveries with the other kind of trucks are one order of magnitude smaller.

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The number of trips outside and inside are different because of the use of a CCC. Moreover, the trucks going from the supplier to the CCC are mainly articulated trucks, whereas the deliveries to the construction sites, from the CCC are made using 3 axis trucks and a few smaller vehicles.

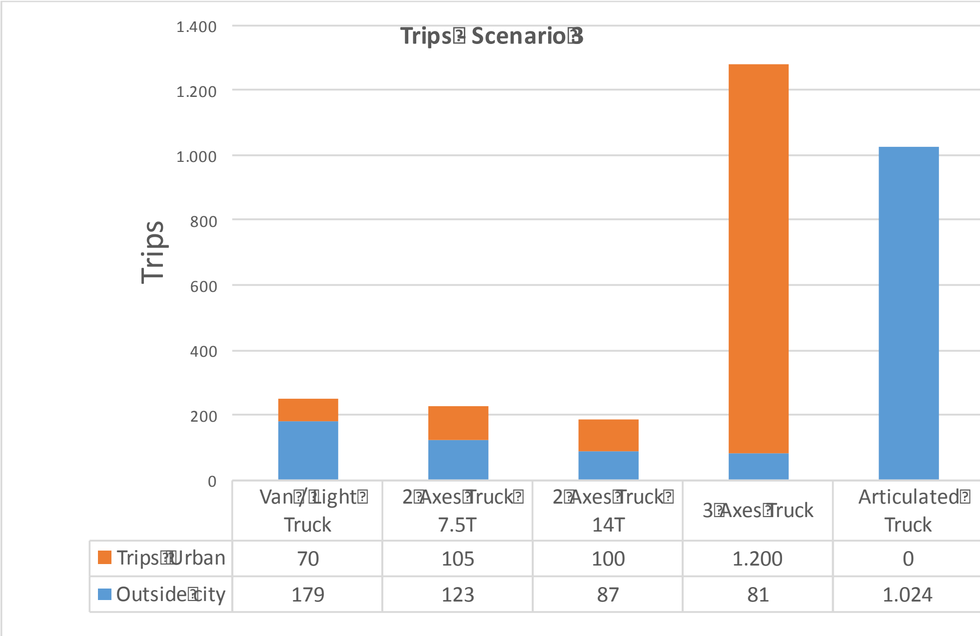

Figure 145: Number of trips - Valencia - Scenario 3.

The following figure reports on the average truck loads.

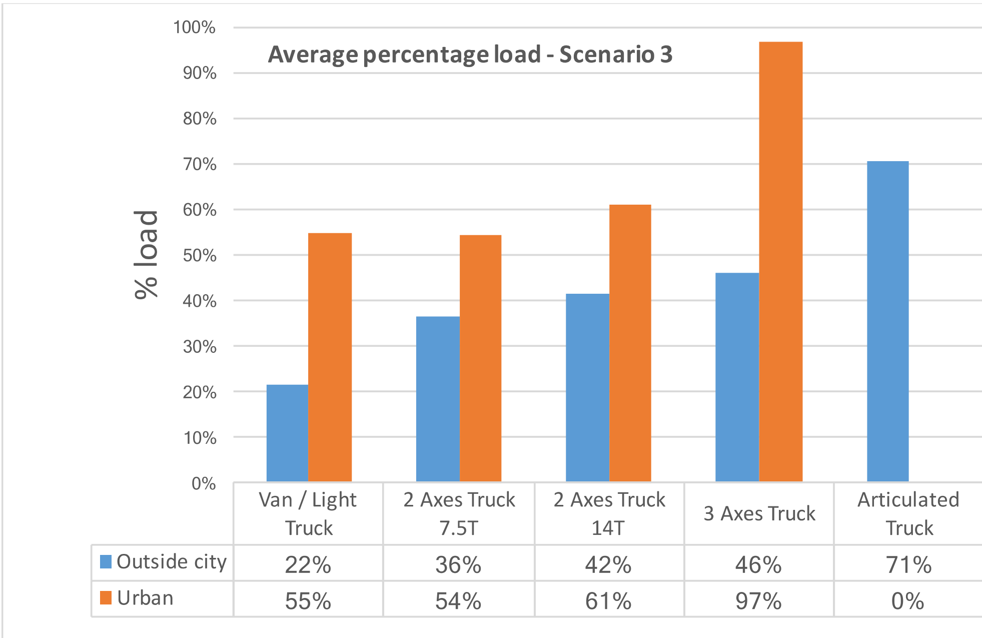

Figure 146: Percentage loads - Valencia- Scenario 3.

The biggest trucks have the largest loads. The articulated trucks, outside the city and the 3 axes trucks, inside the city, have a load close to the maximum realistic load when we start from the suppliers and from a CCC, respectively fixed to 75%

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and 100% of the nominal capacity. The smaller vehicles have lower load percentage, since they are used only when some residual material quantity cannot be delivered efficiently through the largest vehicles. Note that the vehicles starting from the CCC have significantly higher loads than that starting from the supplier.

The next tables give the total tons of air pollutant emissions: CO, PM2.5, PM10. NOx and CO2:

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1,15	0,25	0,27	2,22	0,44
2 Axes Truck 7.5T	2,97	0,45	0,48	7,28	0,66
2 Axes Truck 14T	3,45	0,54	0,60	12,54	0,63
3 Axes Truck	65,28	9,54	9,86	259,47	7,55
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**72,85**	**10,79**	**11,22**	**281,51**	**9,28**

Table 39: Pollutants emissions caused by transport inside the city - Valencia- Scenario 3.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	27,3	7,2	7,4	47,83	10,9
2 Axes Truck 7.5T	40,6	5,9	6,2	159,47	17,4
2 Axes Truck 14T	21,2	2,9	3,1	102,96	9,6
3 Axes Truck	43,3	6,1	6,3	200,01	20,1
Articulated Truck	645,8	102,2	110,5	2.216,47	294,2
Tot	**778,23**	**124,31**	**133,64**	**2.726,73**	**352,23**

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Table 40: Pollutants emissions caused by transport outside the city - Valencia- Scenario 3.

5.4.5 Scenario with multiple construction sites

5.4.6 Scenario 4 – no CCC, all construction sites optimization for each supplier/period/material

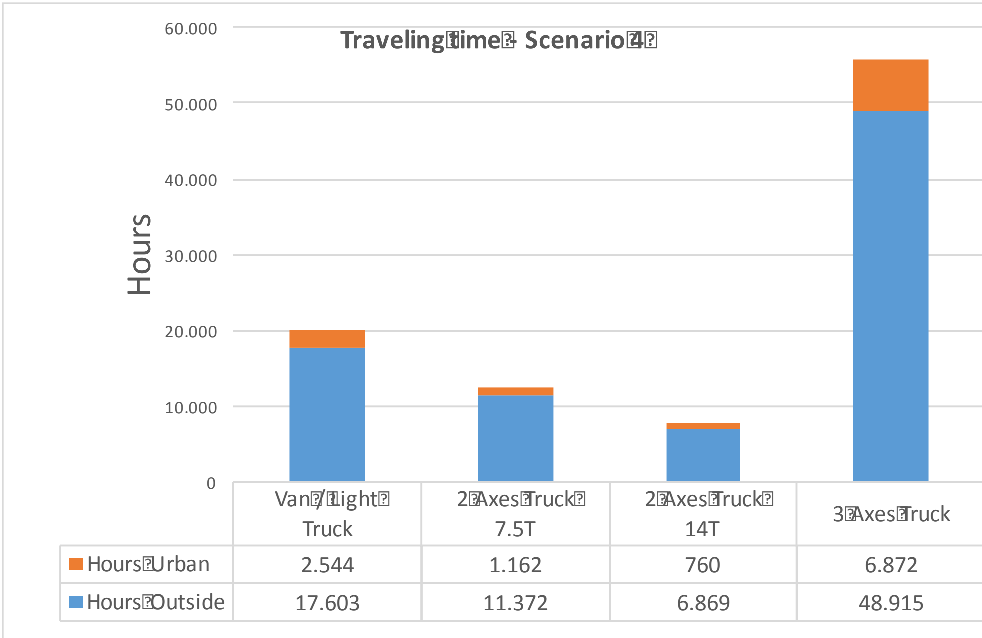

Figure 147: Traveling times - Valencia - Scenario 4.

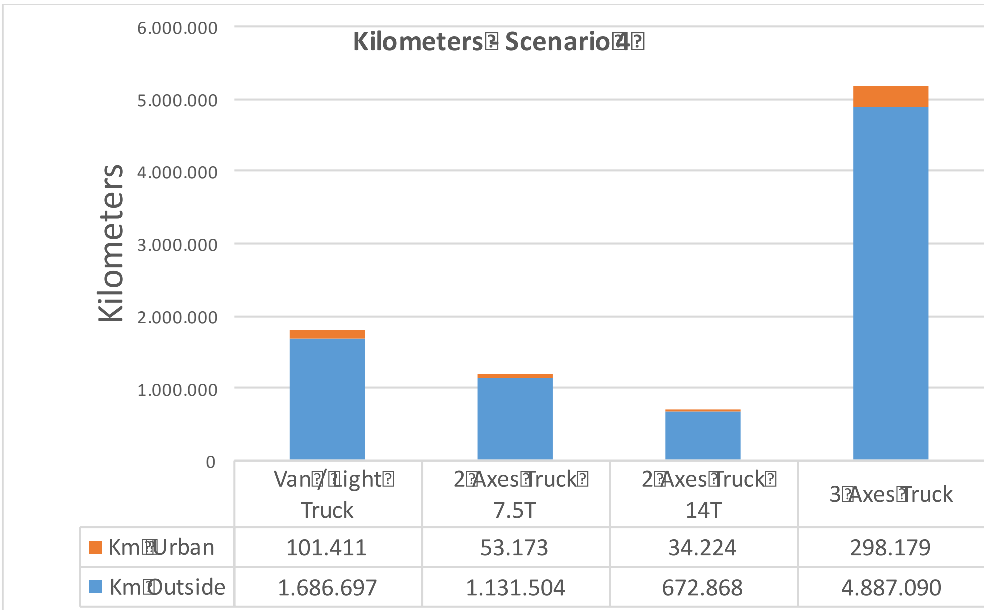

Figure 148: Kilometres travelled - Valencia - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

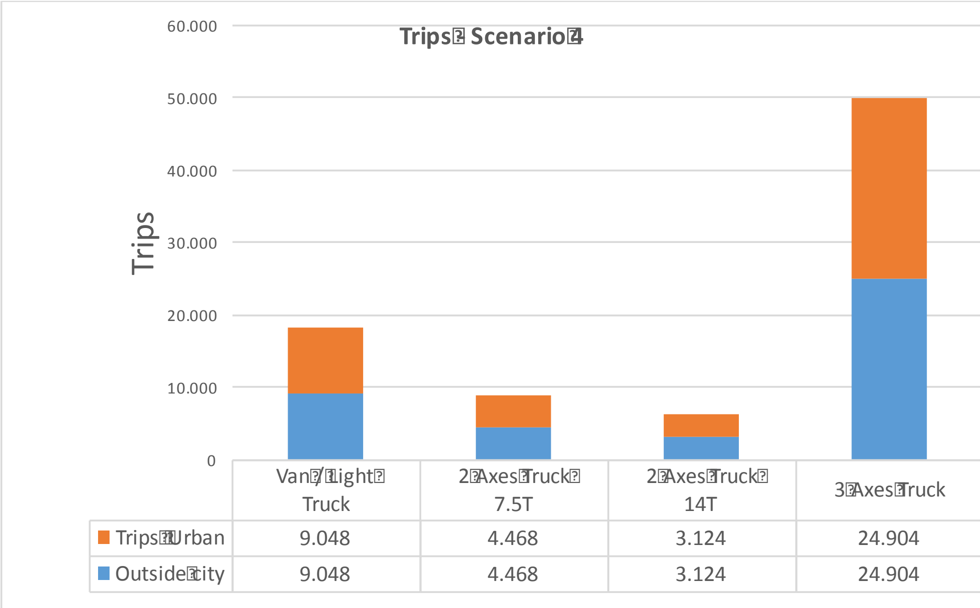

Figure 149: Number of trips - Valencia - Scenario 4.

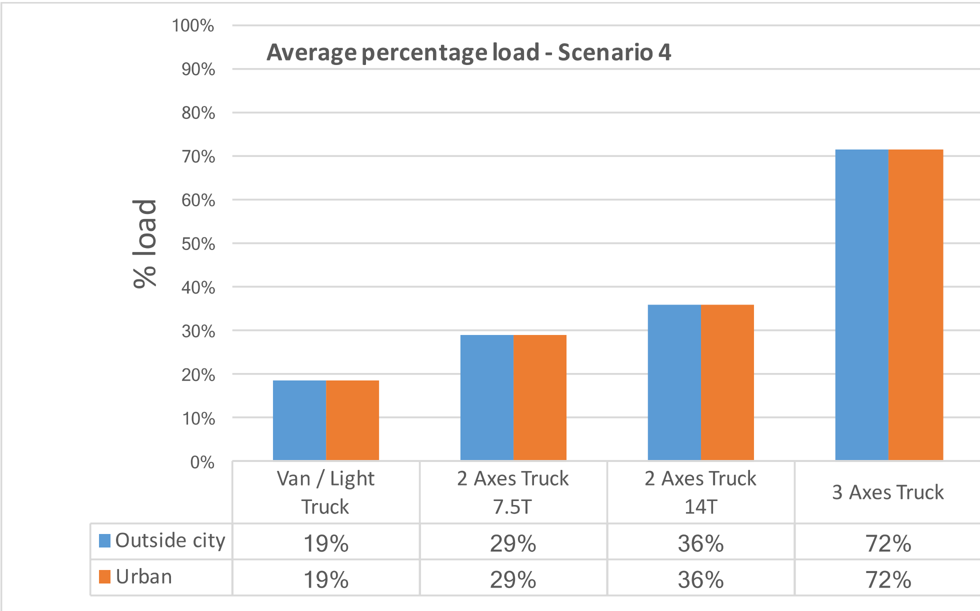

Figure 150: Percentage loads – Valencia - Scenario 4.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	100,69	22,34	23,94	194,91	38,69
2 Axes Truck 7.5T	91,15	13,80	14,61	223,65	20,29
2 Axes Truck 14T	71,63	11,25	12,55	260,00	13,06
3 Axes Truck	983,05	143,69	148,55	3.907,47	113,76
Tot	**1.246,5**	**191,1**	**199,6**	**4.586,0**	**185,8**

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Table 41: Pollutants emissions caused by transport inside the city – Valencia - Scenario 4.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	1.102,2	289,7	300,3	1.931,0	438,1
2 Axes Truck 7.5T	906,1	132,6	138,6	3.560,4	389,2
2 Axes Truck 14T	674,5	90,8	99,7	3.271,0	306,0
3 Axes Truck	6.862,7	973,7	1.003,3	31.669,6	3.190,2
Tot	**9.545,5**	**1.486,9**	**1.541,9**	**40.431,9**	**4.323,5**

Table 42: Pollutants emissions caused by transport outside the city - Valencia- Scenario 4.

5.4.7 Scenario 5 – 1 CCC multiple sites, optimization on the second echelon

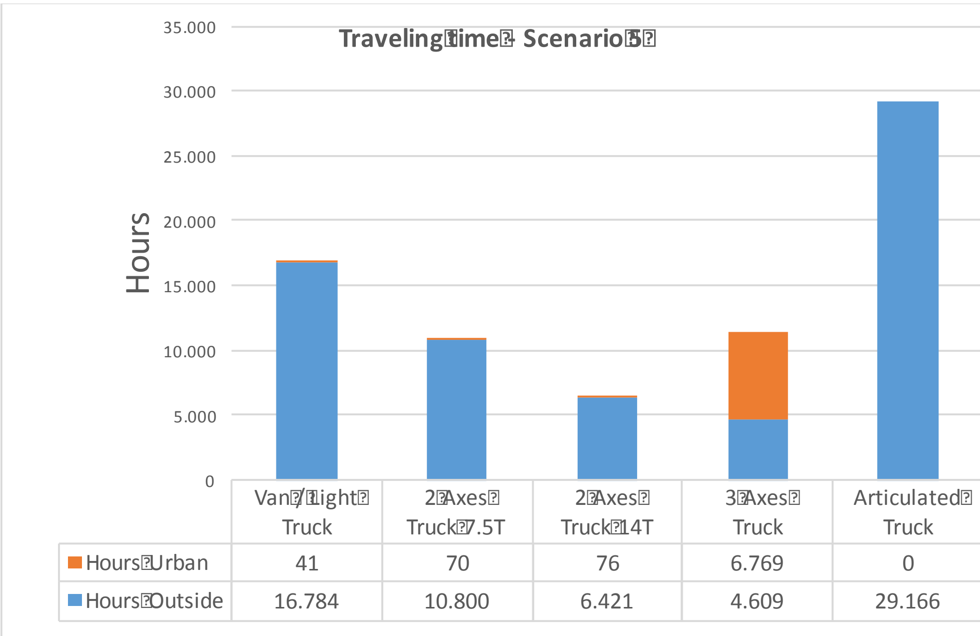
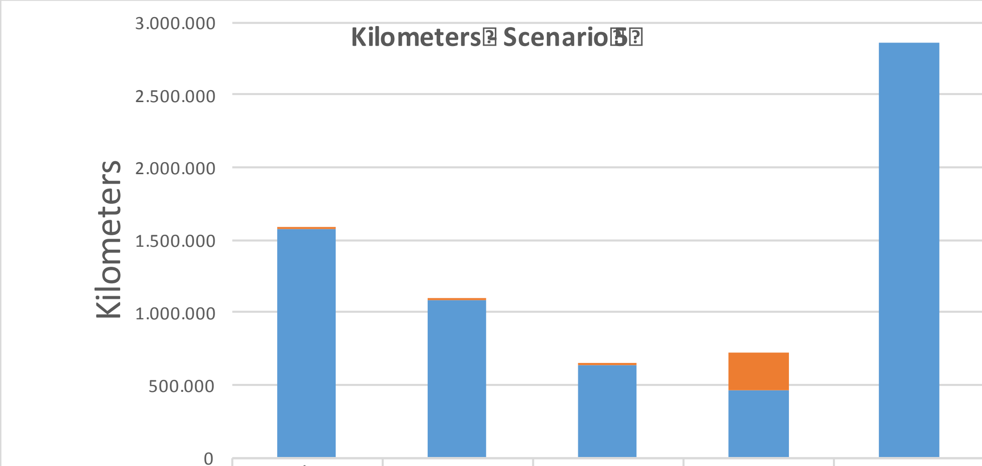


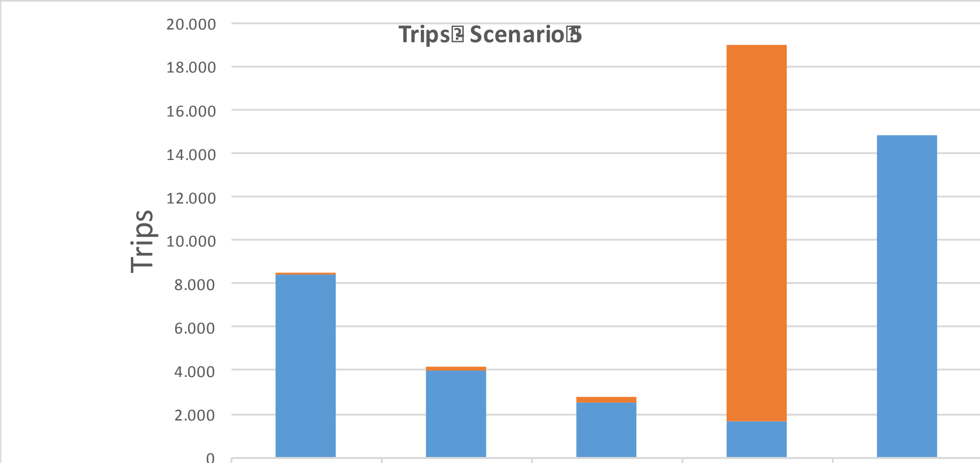
Figure 151: Traveling times - Valencia - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	1.600	2.742	2.971	263.999	0
Km Outside	1.573.272	1.078.882	636.676	460.611	2.856.276

Figure 152: Kilometres travelled - Valencia - Scenario 5.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	105	180	195	17.330	0
Outside city	8.424	3.965	2.563	1.664	14.794

Figure 153: Number of trips - Valencia - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

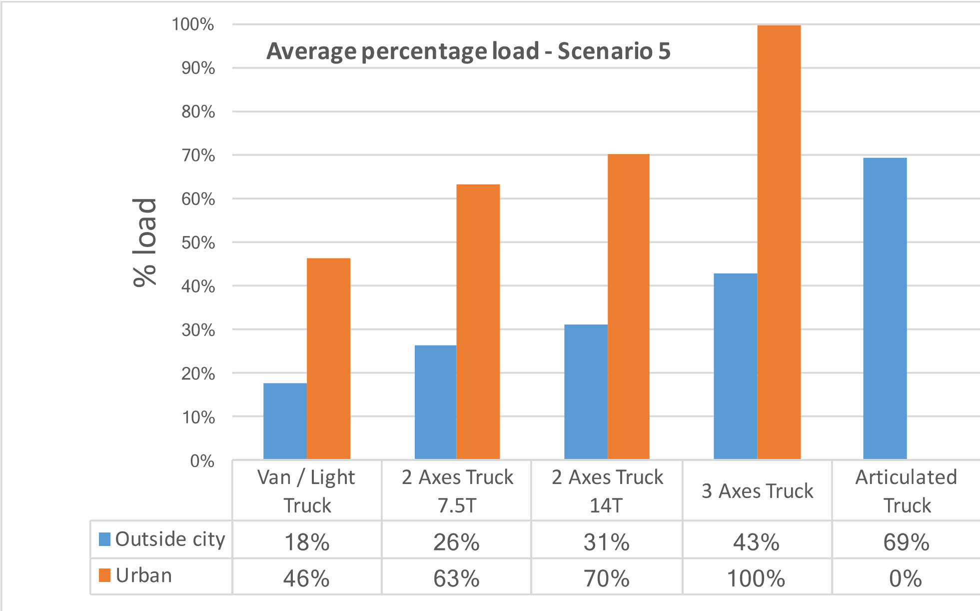


Figure 154: Percentage loads – Valencia - Scenario 5.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	1,59	0,35	0,38	3,08	0,61
2 Axes Truck 7.5T	4,70	0,71	0,75	11,53	1,05
2 Axes Truck 14T	6,22	0,98	1,09	22,57	1,13
3 Axes Truck	870,36	127,22	131,53	3.459,56	100,72
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**882,87**	**129,26**	**133,75**	**3.496,74**	**103,51**

Table 43: Pollutants emissions caused by transport inside the city - Valencia - Scenario 5.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	1.028,12	270,25	280,09	1.801,11	408,60
2 Axes Truck 7.5T	863,94	126,47	132,17	3.394,78	371,09
2 Axes Truck 14T	638,19	85,95	94,36	3.095,02	289,53
3 Axes Truck	646,81	91,77	94,56	2.984,88	300,68
Articulated Truck	4.210,60	666,24	720,62	14.451,87	1.918,07
Tot	**7.387,67**	**1.240,67**	**1.321,80**	**25.727,66**	**3.287,97**

Table 44: Pollutants emissions caused by transport outside the city – Valencia - Scenario 5.

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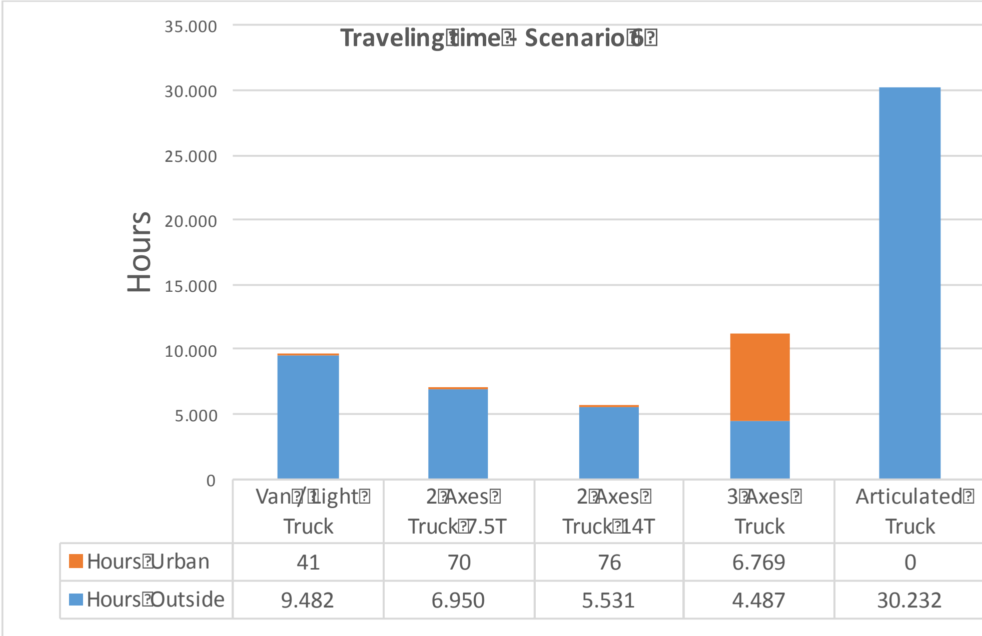
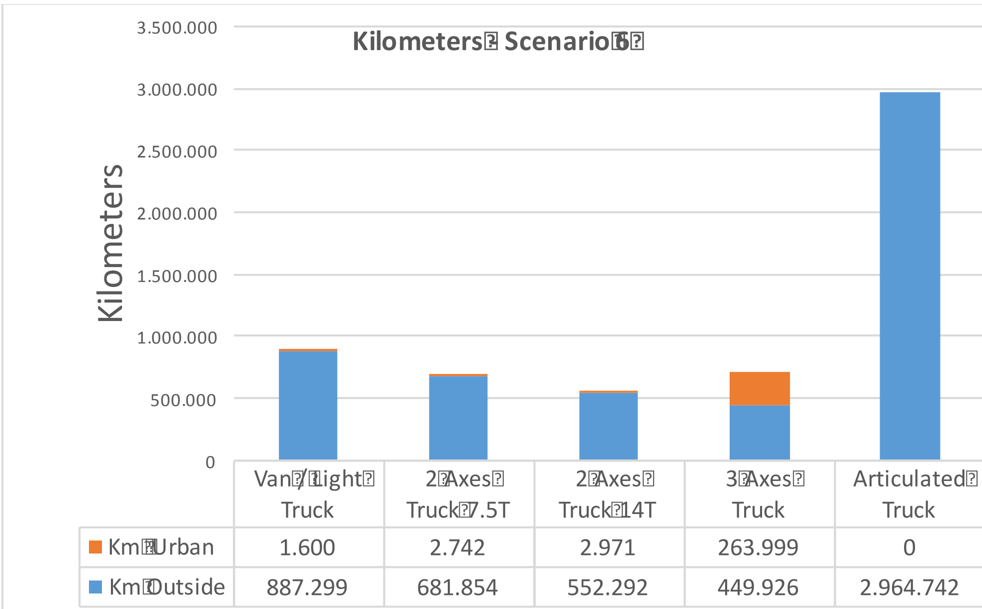
5.4.8 Scenario 6 – 1 CCC multiple sites, optimization on both echelons



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	41	70	76	6.769	0
Hours Outside	9.482	6.950	5.531	4.487	30.232

Figure 155: Traveling times - Valencia - Scenario 6.



	Van / light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	1.600	2.742	2.971	263.999	0
Km Outside	887.299	681.854	552.292	449.926	2.964.742

Figure 156: Kilometres travelled - Valencia - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

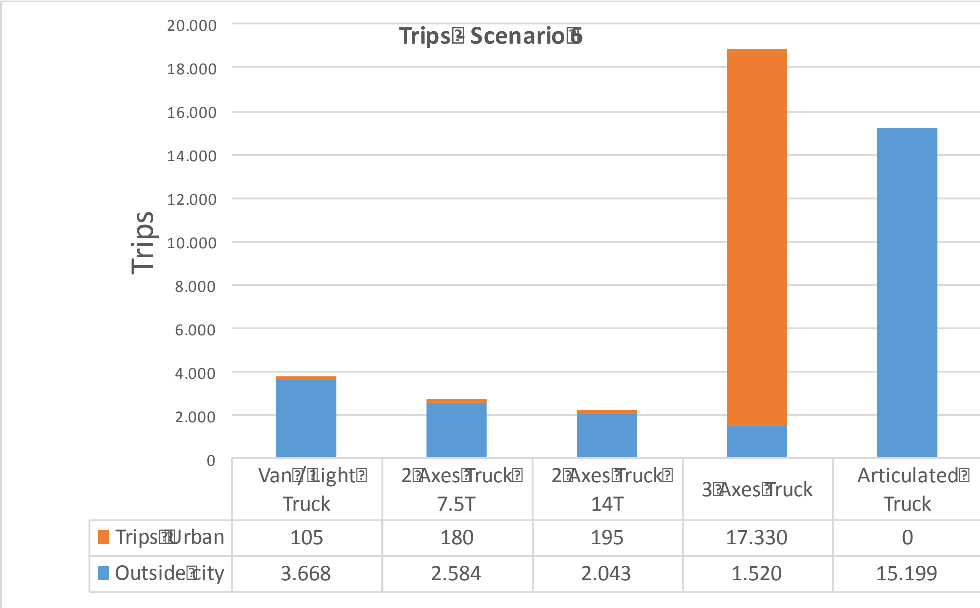


Figure 157: Number of trips – Valencia - Scenario 6.

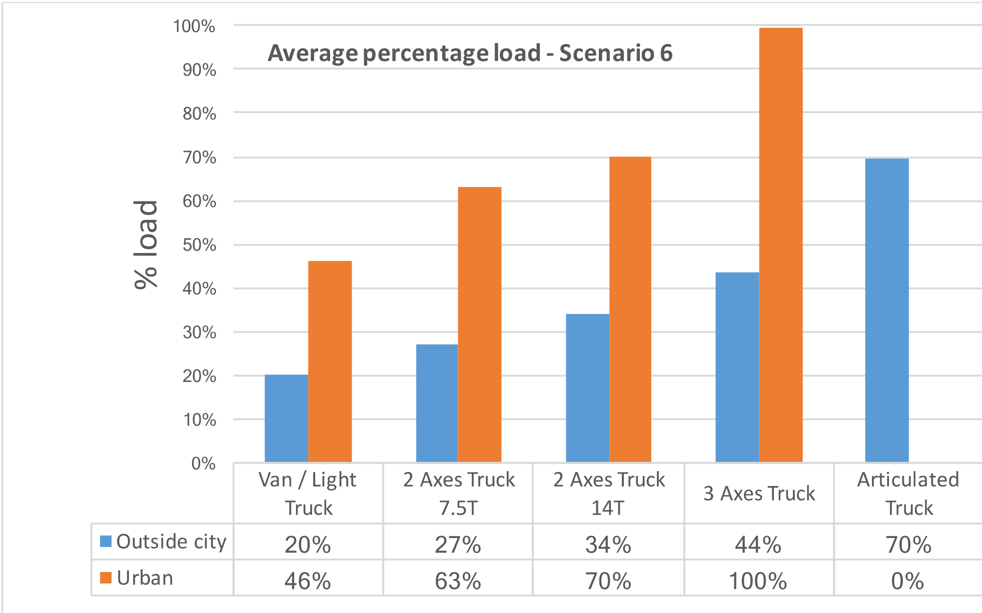


Figure 158: Percentage loads - Valencia - Scenario 6.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	1,59	0,35	0,38	3,08	0,61
2 Axes Truck 7.5T	4,70	0,71	0,75	11,53	1,05
2 Axes Truck 14T	6,22	0,98	1,09	22,57	1,13
3 Axes Truck	870,36	127,22	131,53	3.459,56	100,72
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**882,87**	**129,26**	**133,75**	**3.496,74**	**103,51**

Table 45: Pollutants emissions caused by transport inside the city - Valencia - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	579,84	152,42	157,96	1.015,80	230,44
2 Axes Truck 7.5T	546,01	79,93	83,53	2.145,50	234,53
2 Axes Truck 14T	553,61	74,56	81,85	2.684,81	251,16
3 Axes Truck	631,81	89,64	92,37	2.915,63	293,71
Articulated Truck	4.370,50	691,54	747,98	15.000,67	1.990,91
Tot	**6.681,77**	**1.088,08**	**1.163,70**	**23.762,42**	**3.000,74**

Table 46: Pollutants emissions caused by transport outside the city - Valencia - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.5 Verona

5.5.1 Scenario with a single big site

5.5.2 Scenario 1 - no CCC - 1 site – baseline

In the following figure, the traveling time for the deliveries in the Verona simulation has been reported.

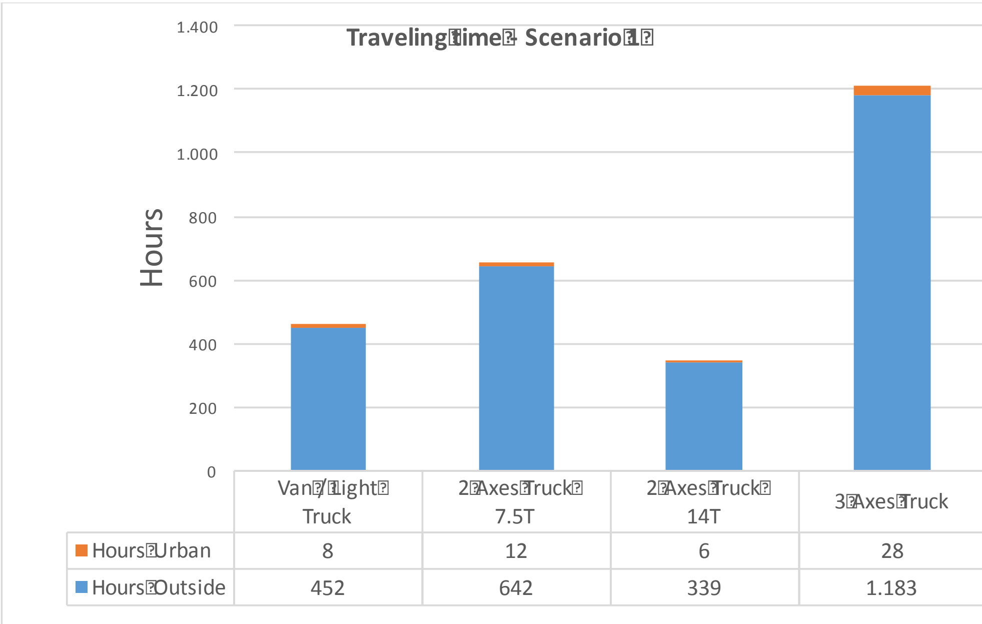
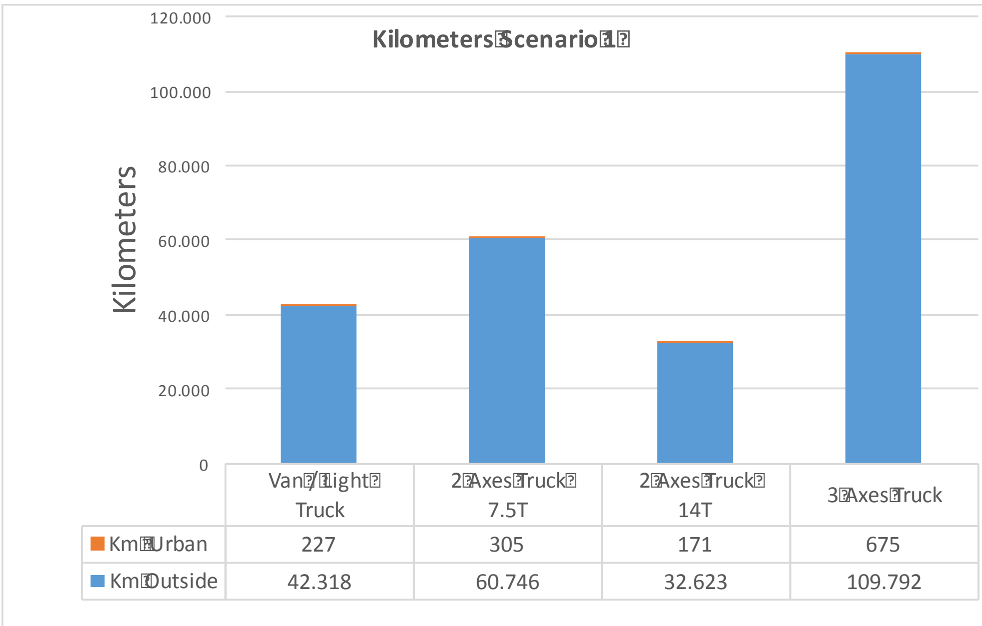


Figure 159: Traveling times - Verona - Scenario 1.

In the following figure, the kilometres for the deliveries in the Verona simulation have been reported.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Figure 160: Kilometres travelled - Verona - Scenario 1.

In the following figures, the trips and the average percentage of truck loads can be clearly noticed.

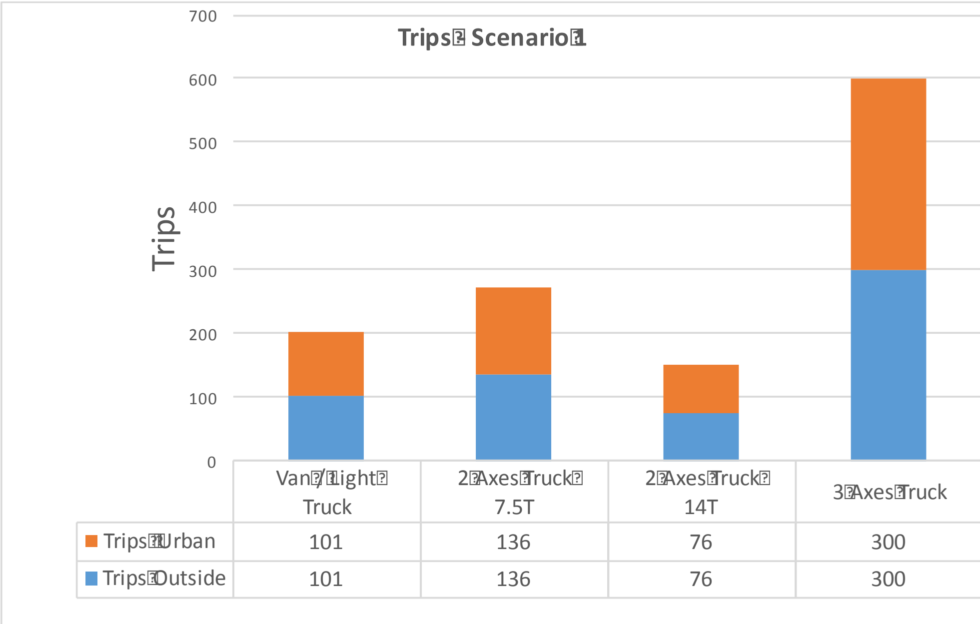


Figure 161: Number of trips - Verona - Scenario 1.

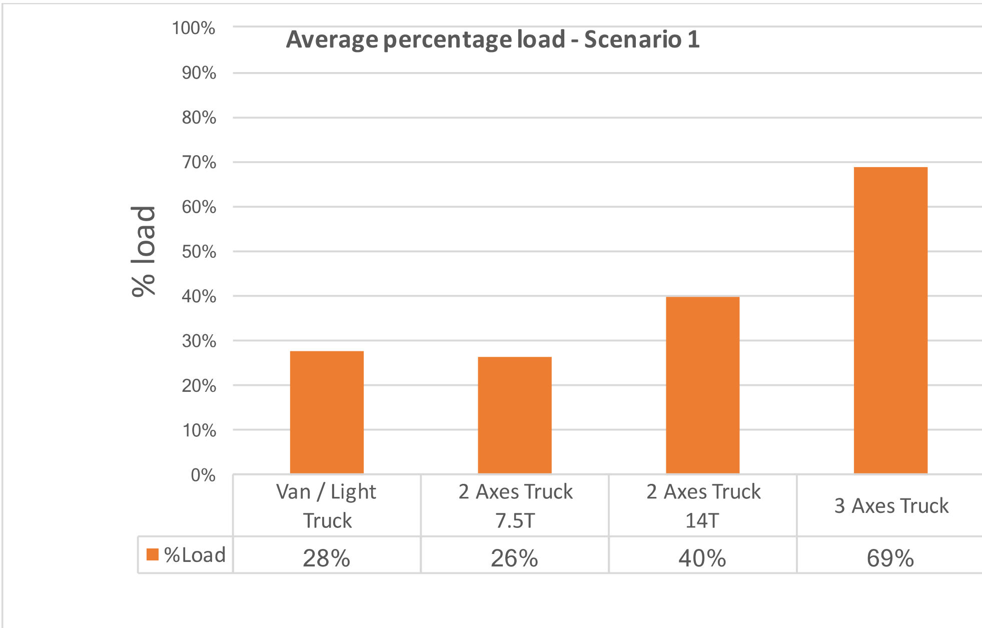


Figure 162: Percentage loads – Verona - Scenario 1.

In the next tables, there are the total tons of pollutants emission: CO, PM2.5, PM10, NOx and CO2, both in the urban area and outside the city.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0.23	0.05	0.05	0.44	0.09
2 Axes Truck 7.5T	0.52	0.08	0.08	1.28	0.12
2 Axes Truck 14T	0.36	0.06	0.06	1.30	0.07
3 Axes Truck	2.23	0.33	0.34	8.85	0.26
Tot	**3.33**	**0.51**	**0.54**	**11.86**	**0.53**

Table 47: Pollutants emissions caused by transport inside the city – Verona - Scenario 1.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	27,7	7,3	7,5	48,4	11,0
2 Axes Truck 7.5T	48,6	7,1	7,4	191,1	20,9
2 Axes Truck 14T	32,7	4,4	4,8	158,6	14,8
3 Axes Truck	154,2	21,9	22,5	711,5	71,7
Tot	**263,2**	**40,7**	**42,4**	**1.109,7**	**118,4**

Table 48: Pollutants emissions caused by transport outside the city – Verona - Scenario 1.

5.5.3 Scenario 2 - CCC-1 site – optimization on the second echelon

In the Scenario 2 there is the introduction of the CCC. In the next two figures the time and the kilometres for the deliveries in Verona simulation are reported.

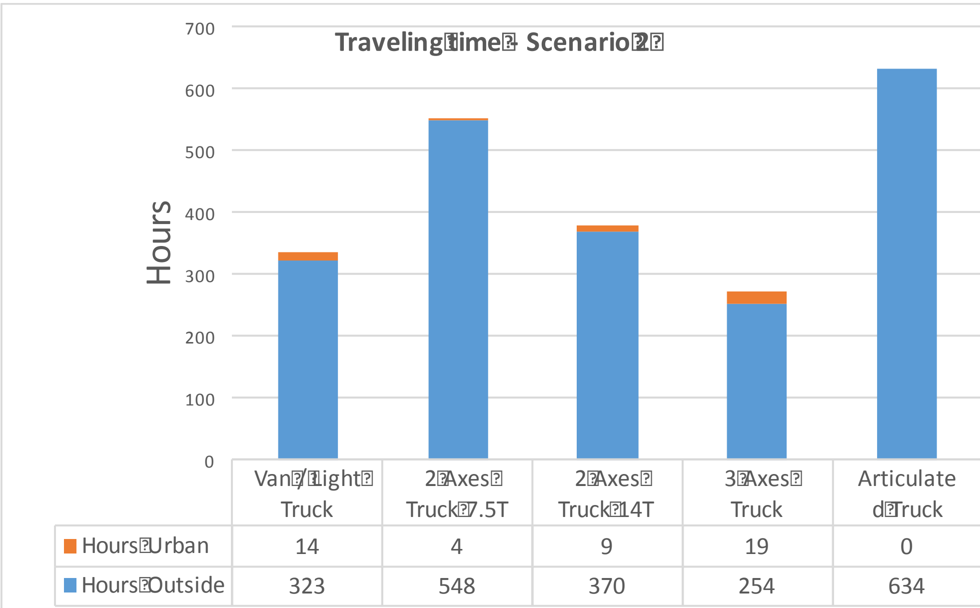
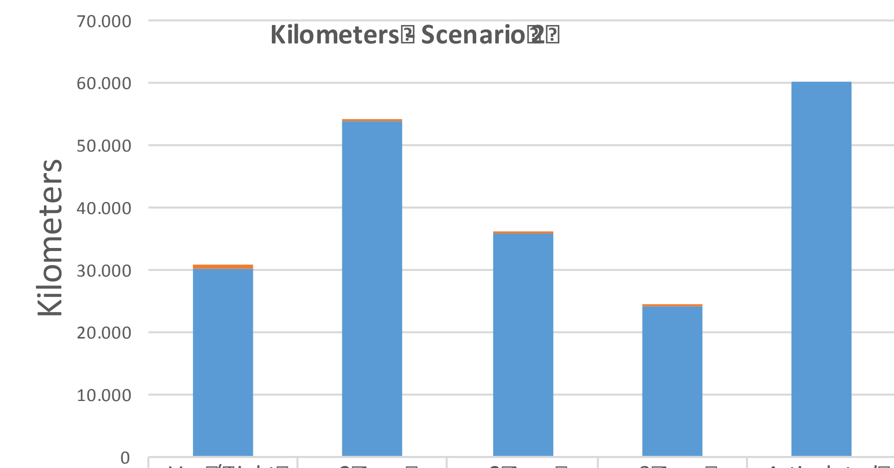


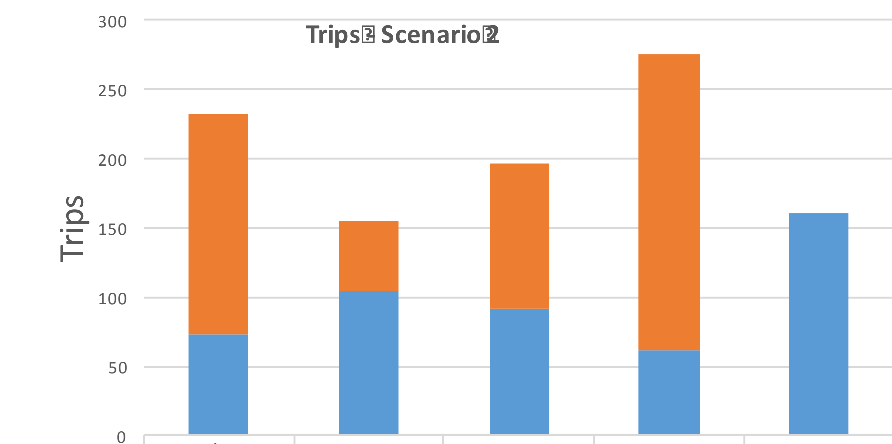
Figure 163: Traveling times - Verona - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	364	114	239	490	0
Km Outside	30.159	53.573	35.666	24.018	59.893

Figure 164: Kilometres travelled - Verona - Scenario 2.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	160	50	105	215	0
Outside city	73	105	92	61	160

Figure 165: Number of trips - Verona - Scenario 2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

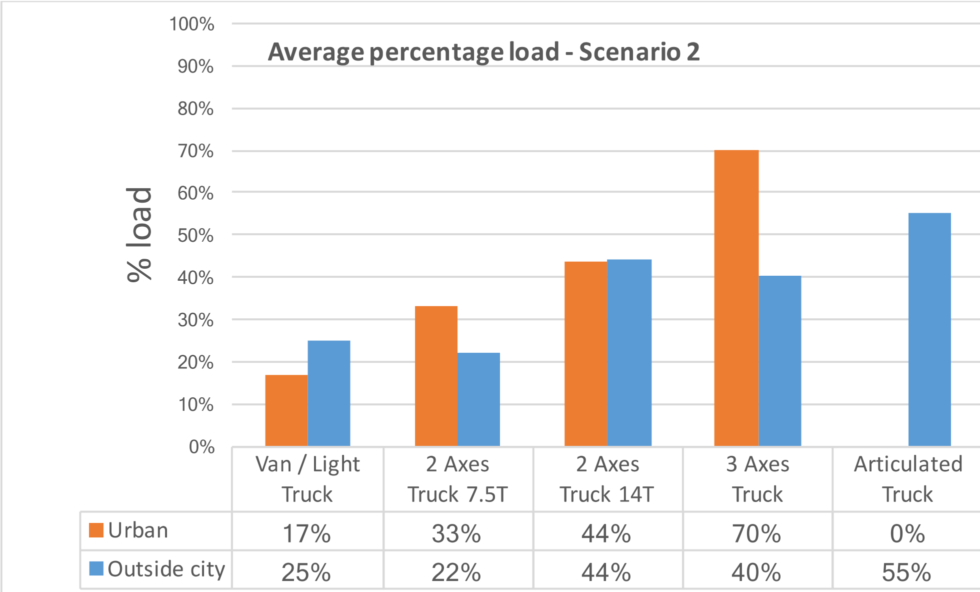


Figure 166: Percentage loads – Verona - Scenario 2.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,36	0,08	0,09	0,70	0,14
2 Axes Truck 7.5T	0,20	0,03	0,03	0,48	0,04
2 Axes Truck 14T	0,50	0,08	0,09	1,82	0,09
3 Axes Truck	1,62	0,24	0,24	6,42	0,19
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**2,67**	**0,42**	**0,45**	**9,42**	**0,46**

Table 49: Pollutants emissions caused by transport inside the city – Verona - Scenario 2.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	19,7	5,2	5,4	34,5	7,8
2 Axes Truck 7.5T	42,9	6,3	6,6	168,6	18,4
2 Axes Truck 14T	35,8	4,8	5,3	173,4	16,2
3 Axes Truck	33,7	4,8	4,9	155,6	15,7
Articulated Truck	88,3	14,0	15,1	303,0	40,2
Tot	**220,38**	**35,03077**	**37,259583**	**835,160913**	**98,3773306**

Table 50: Pollutants emissions caused by transport inside the city – Verona - Scenario 2.

5.5.4 Scenario 3 – 1 CCC, 1 site, optimization on both echelons

In this third scenario, there was the optimization of the deliveries in both echelons: from the suppliers to the CCC and also from the CCC to the site.

The following figure will show the time for the deliveries in the Verona simulation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

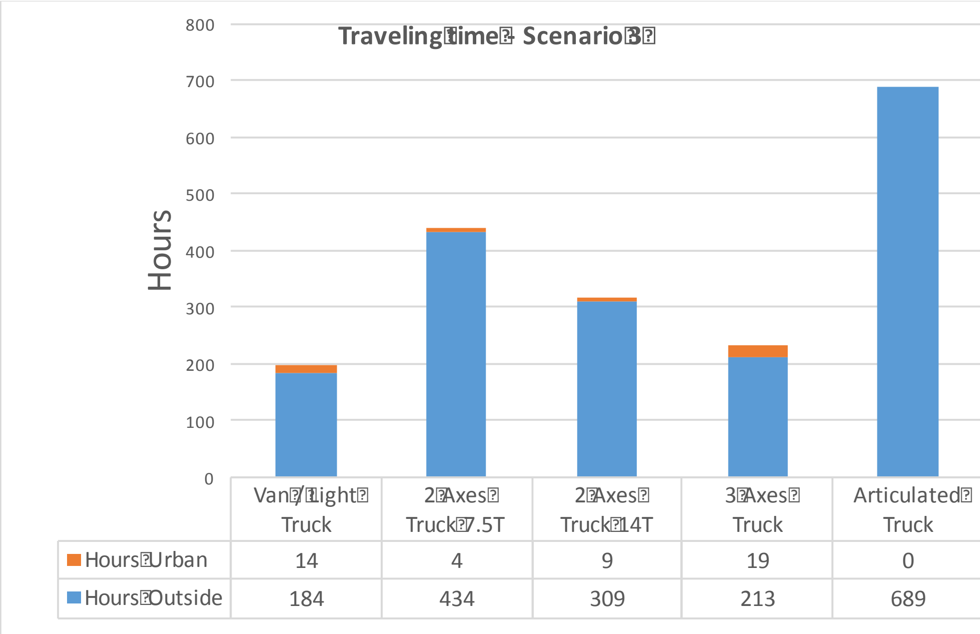


Figure 167: Traveling times - Verona - Scenario 3.

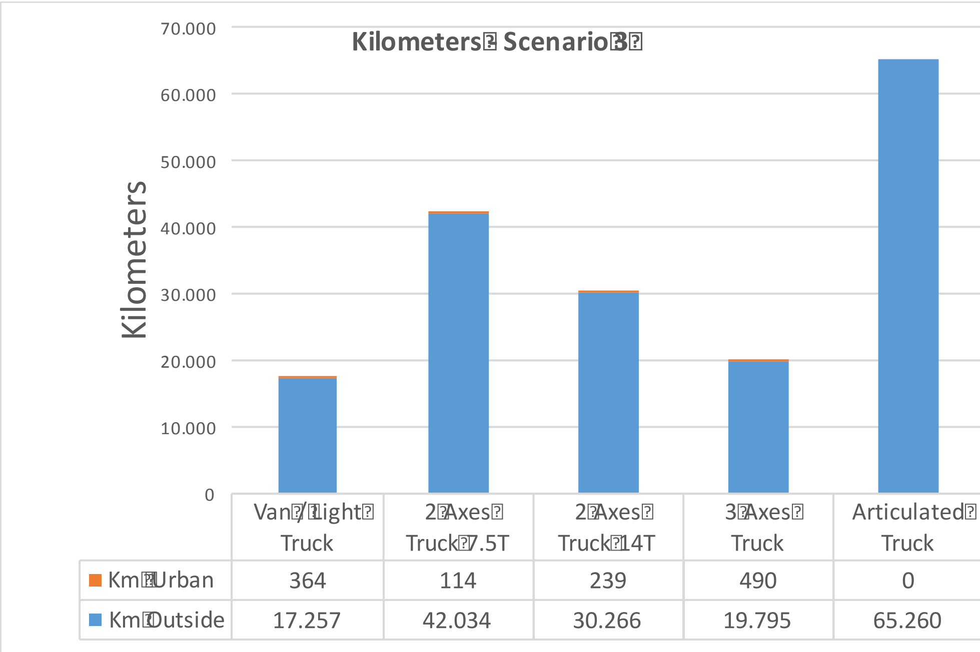


Figure 168: Kilometres travelled - Verona - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

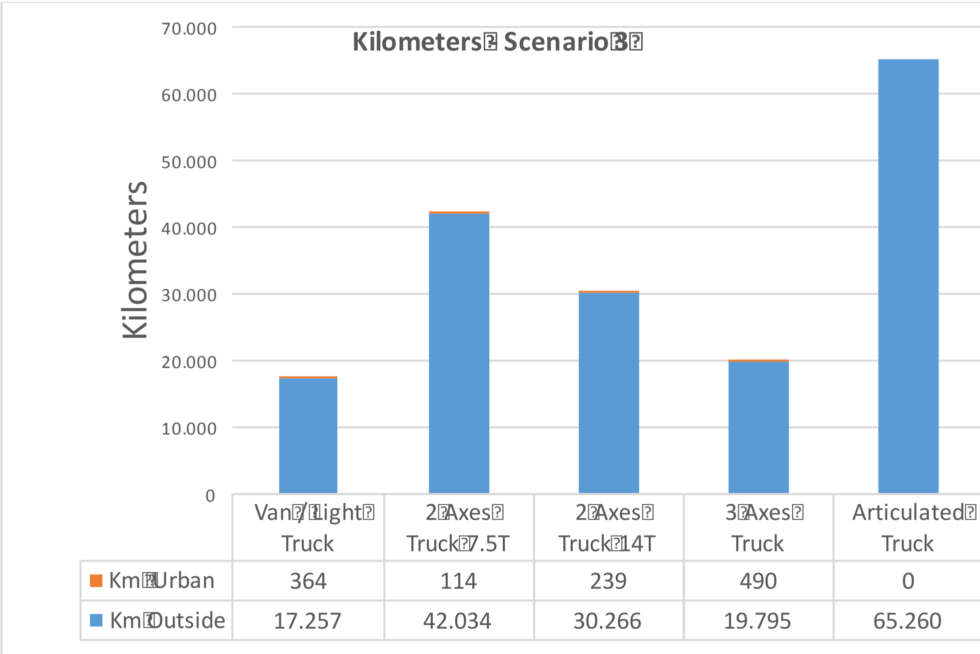


Figure 169: Number of trips - Verona - Scenario 3.

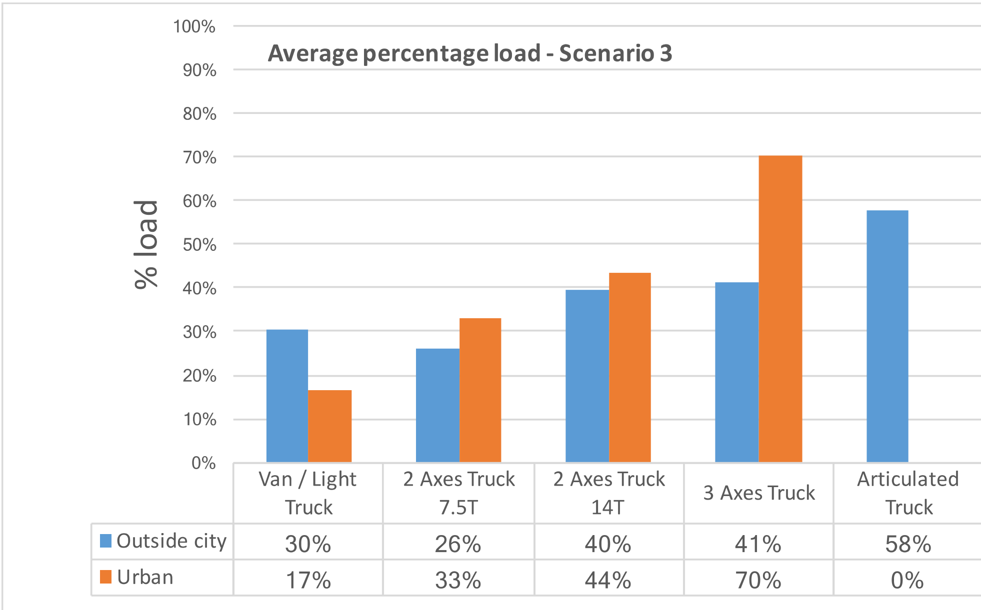


Figure 170: Percentage loads – Verona - Scenario 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,36	0,08	0,09	0,70	0,14
2 Axes Truck 7.5T	0,20	0,03	0,03	0,48	0,04
2 Axes Truck 14T	0,50	0,08	0,09	1,82	0,09
3 Axes Truck	1,62	0,24	0,24	6,42	0,19
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**2,67**	**0,42**	**0,45**	**9,42**	**0,46**

Table 51: Pollutants emissions caused by transport inside the city – Verona - Scenario 3.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	11,3	3,0	3,1	19,8	4,5
2 Axes Truck 7.5T	33,7	4,9	5,1	132,3	14,5
2 Axes Truck 14T	30,3	4,1	4,5	147,1	13,8
3 Axes Truck	27,8	3,9	4,1	128,3	12,9
Articulated Truck	96,2	15,2	16,5	330,2	43,8
Tot	**199,28**	**31,14342**	**33,235794**	**757,620819**	**89,4492642**

Table 52: Pollutants emissions caused by transport outside the city – Verona - Scenario 3.

5.5.5 Scenario with multiple construction sites

5.5.6 Scenario 4 – no CCC, all construction sites optimization for each supplier/period/material

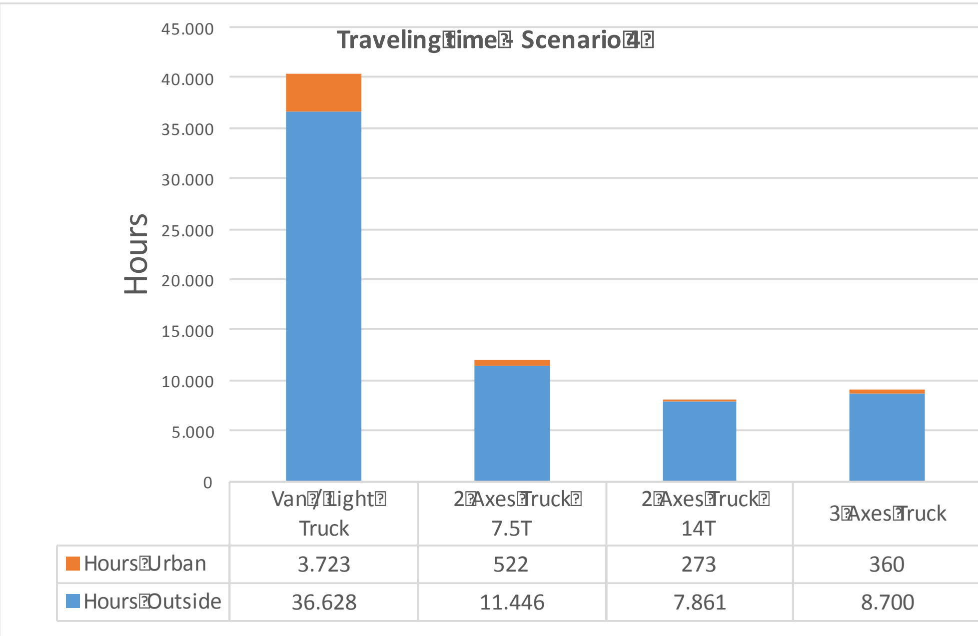


Figure 171: Traveling times - Verona - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

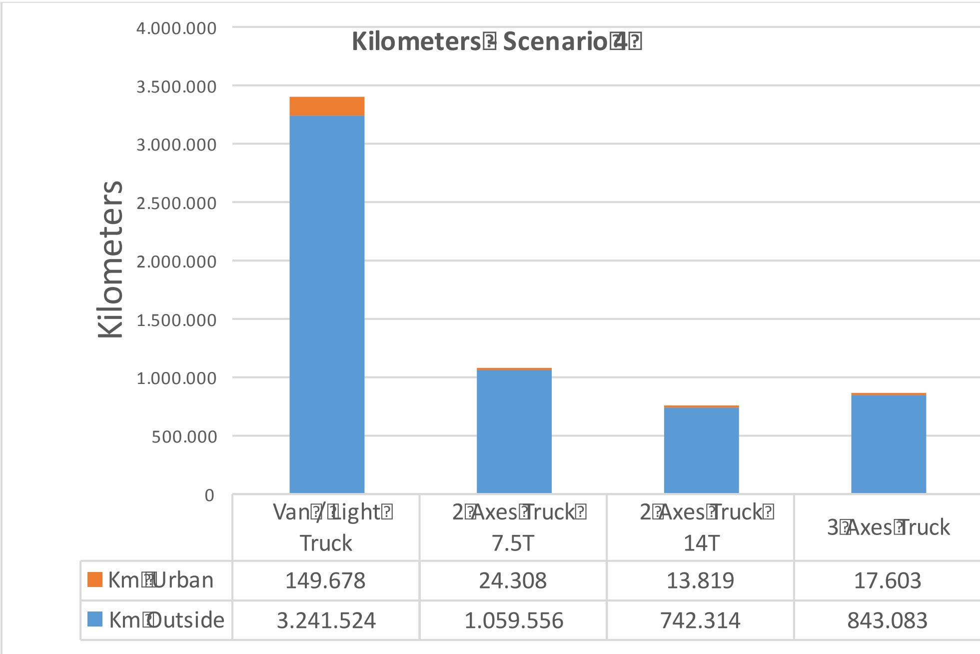


Figure 172: Kilometres travelled - Verona - Scenario 4.

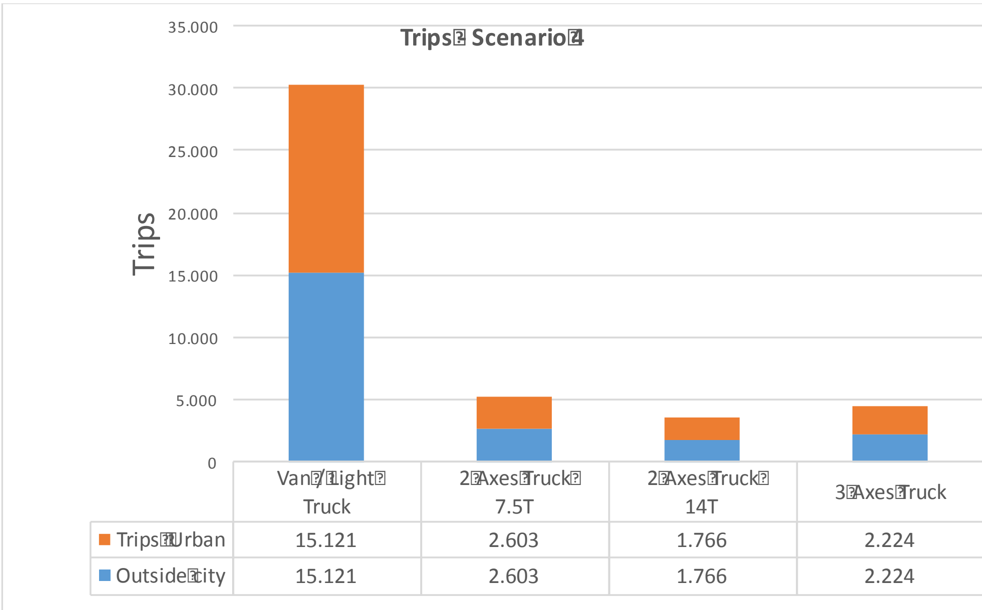


Figure 173: Number of trips - Verona - Scenario 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

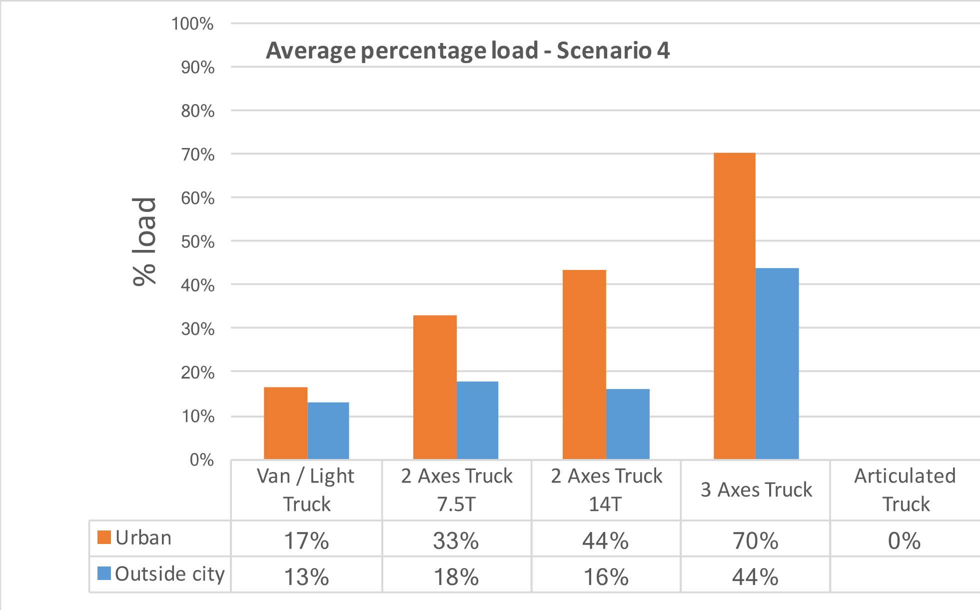


Figure 174: Percentage loads – Verona - Scenario 4.

	Urban				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	148,61	32,97	35,33	287,67	57,10
2 Axes Truck 7.5T	41,67	6,31	6,68	102,24	9,27
2 Axes Truck 14T	28,92	4,54	5,07	104,98	5,27
3 Axes Truck	58,03	8,48	8,77	230,68	6,72
Tot	**277,2**	**52,3**	**55,8**	**725,6**	**78,4**

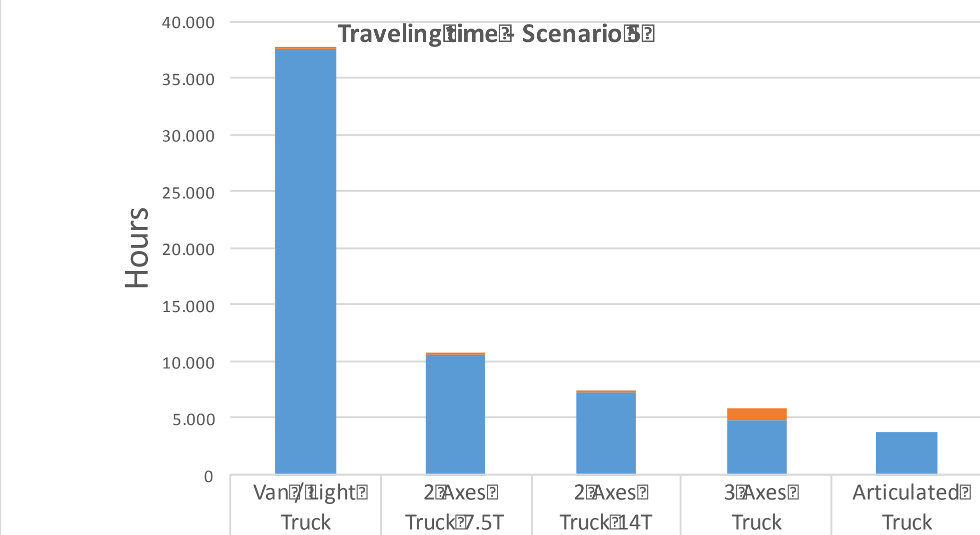
Table 53: Pollutants emissions caused by transport inside the city – Verona - Scenario 4.

	Outside city				
	CO (Kg)	**PM2.5 (Kg)**	**PM10 (Kg)**	**Nox (Kg)**	**CO2 (ton)**
Van / Light Truck	2.118,3	556,8	577,1	3.711,0	841,9
2 Axes Truck 7.5T	848,5	124,2	129,8	3.334,0	364,4
2 Axes Truck 14T	744,1	100,2	110,0	3.608,6	337,6
3 Axes Truck	1.183,9	168,0	173,1	5.463,4	550,4
Tot	**4.894,8**	**949,2**	**990,0**	**16.116,9**	**2.094,2**

Table 54: Pollutants emissions caused by transport inside the city – Verona - Scenario 4.

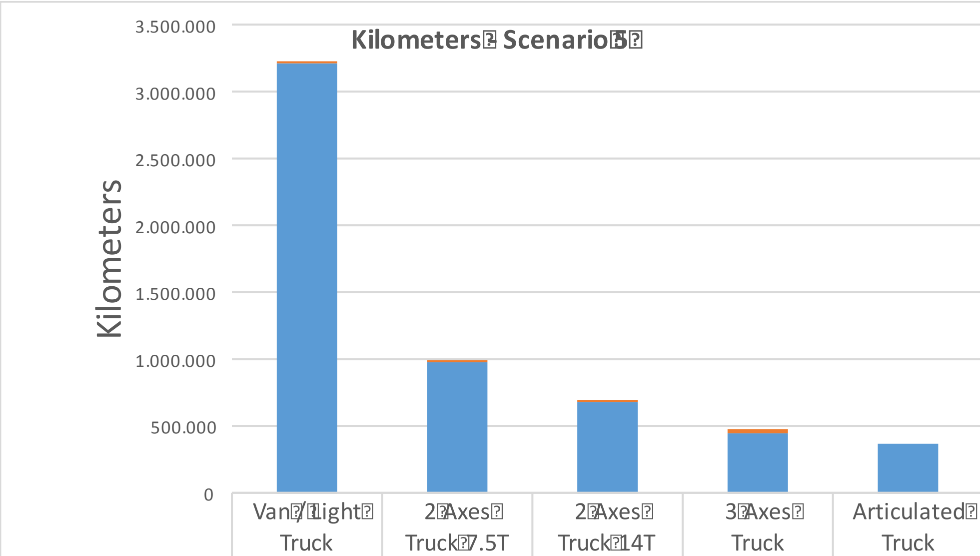
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

5.5.7 Scenario 5 – 1 CCC multiple sites, optimization on the second echelon



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Hours Urban	45	41	121	1.177	0
Hours Outside	37.621	10.666	7.230	4.768	3.768

Figure 175: Traveling times - Verona - Scenario 5.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	969	881	2.599	25.152	0
Km Outside	3.215.973	976.498	675.934	452.858	363.909

Figure 176: Kilometres travelled - Verona - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

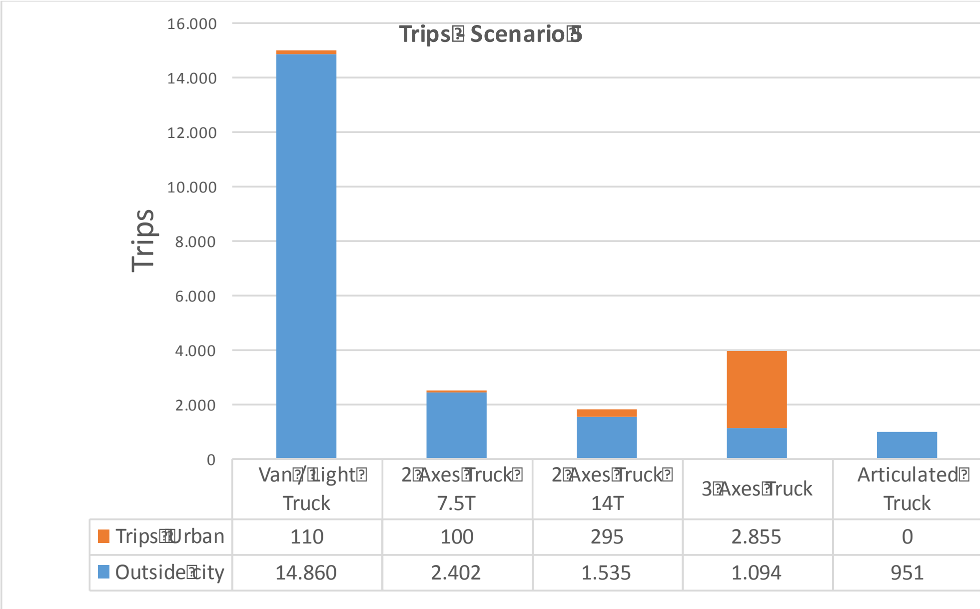


Figure 177: Number of trips - Verona - Scenario 5.

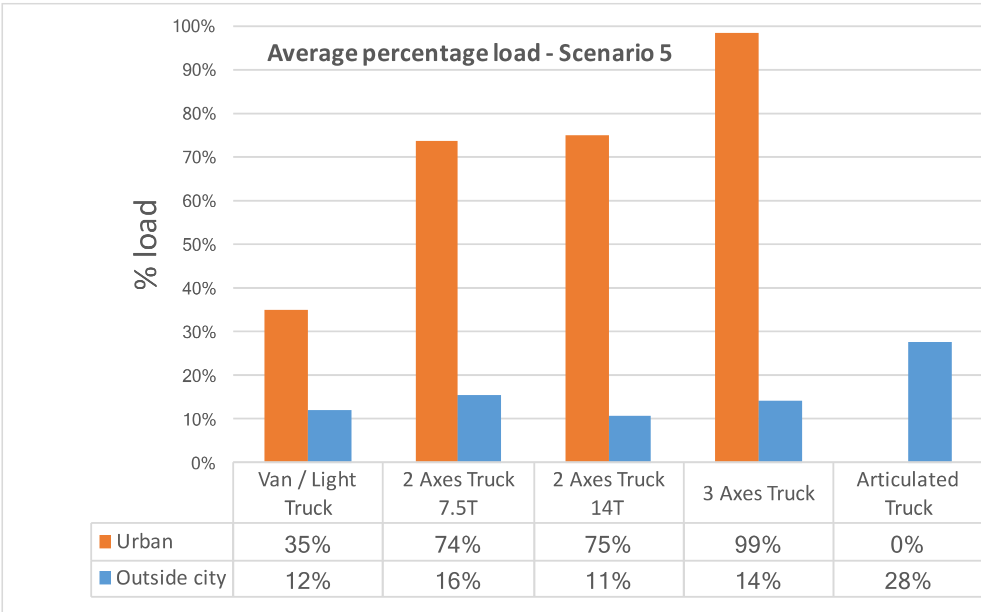


Figure 178: Percentage loads – Verona - Scenario 5.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,96	0,21	0,23	1,86	0,37
2 Axes Truck 7.5T	1,51	0,23	0,24	3,71	0,34
2 Axes Truck 14T	5,44	0,85	0,95	19,74	0,99
3 Axes Truck	82,92	12,12	12,53	329,60	9,60
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**90,83**	**13,42**	**13,95**	**354,92**	**11,29**

Table 55: Pollutants emissions caused by transport inside the city – Verona - Scenario 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	2.101,6	552,4	572,5	3.681,7	835,2
2 Axes Truck 7.5T	782,0	114,5	119,6	3.072,6	335,9
2 Axes Truck 14T	677,5	91,3	100,2	3.285,9	307,4
3 Axes Truck	635,9	90,2	93,0	2.934,6	295,6
Articulated Truck	536,5	84,9	91,8	1.841,3	244,4
Tot	**4733,51**	**933,2484**	**977,12313**	**14816,0907**	**2018,48844**

Table 56: Pollutants emissions caused by transport outside the city – Verona - Scenario 5.

5.5.8 Scenario 6 – 1 CCC multiple sites, optimization on both echelons

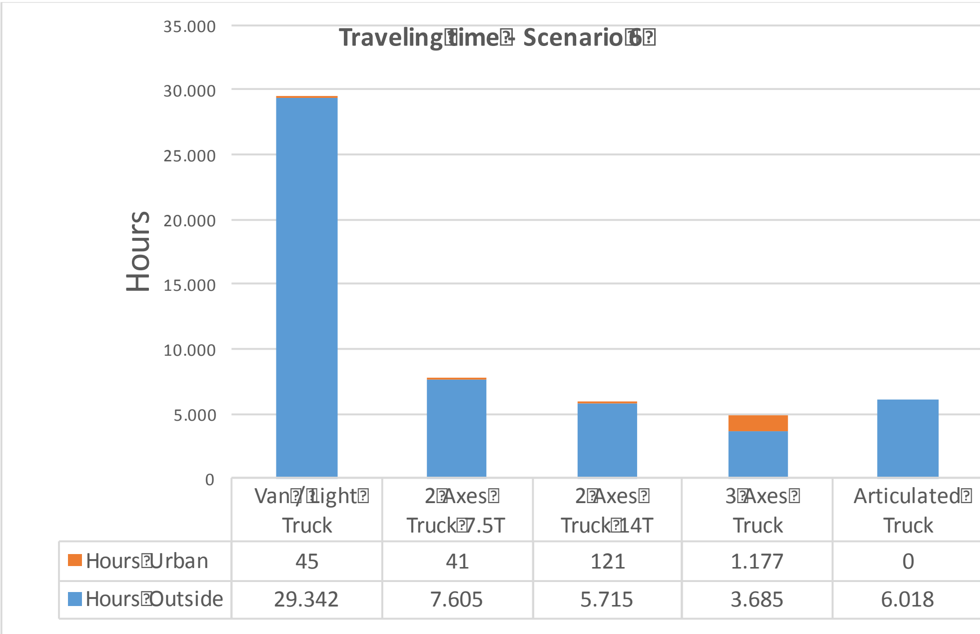
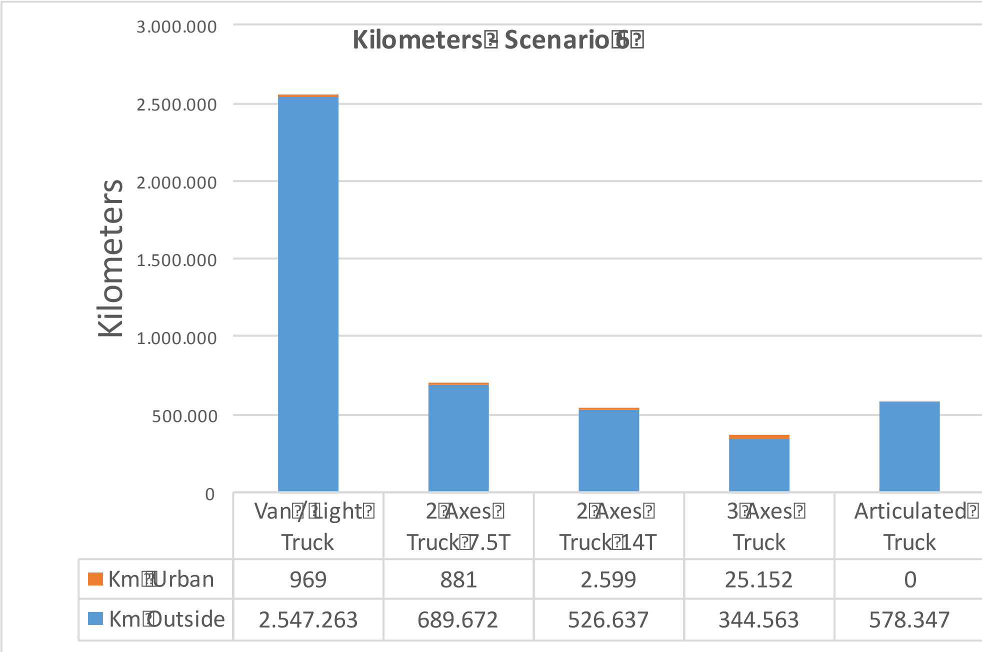


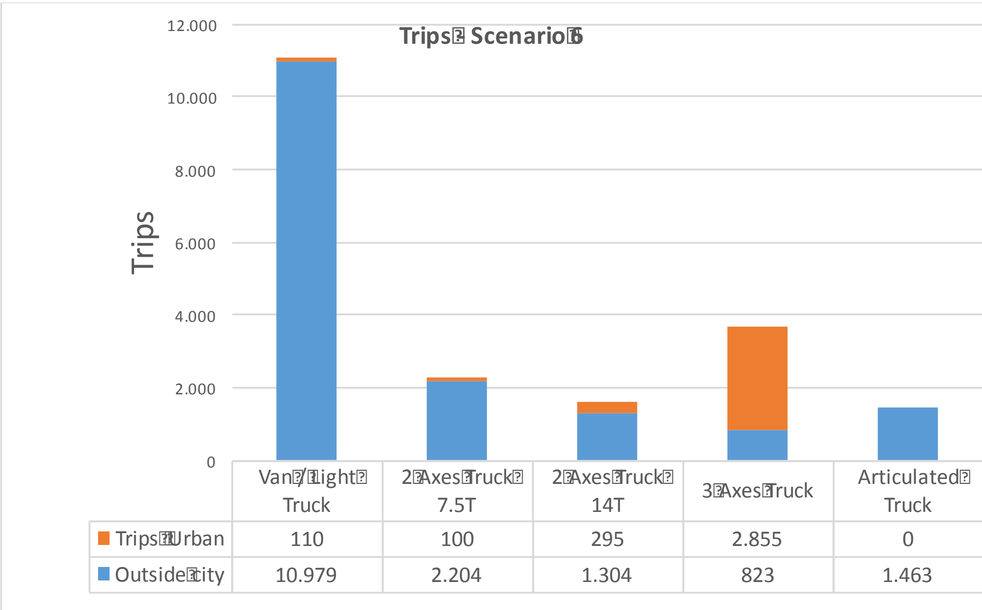
Figure 179: Traveling times - Verona - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Km Urban	969	881	2.599	25.152	0
Km Outside	2.547.263	689.672	526.637	344.563	578.347

Figure 180: Kilometres travelled - Verona - Scenario 6.



	Van / Light Truck	2 Axes Truck 7.5T	2 Axes Truck 14T	3 Axes Truck	Articulated Truck
Trips Urban	110	100	295	2.855	0
Outside city	10.979	2.204	1.304	823	1.463

Figure 181: Number of trips - Verona - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

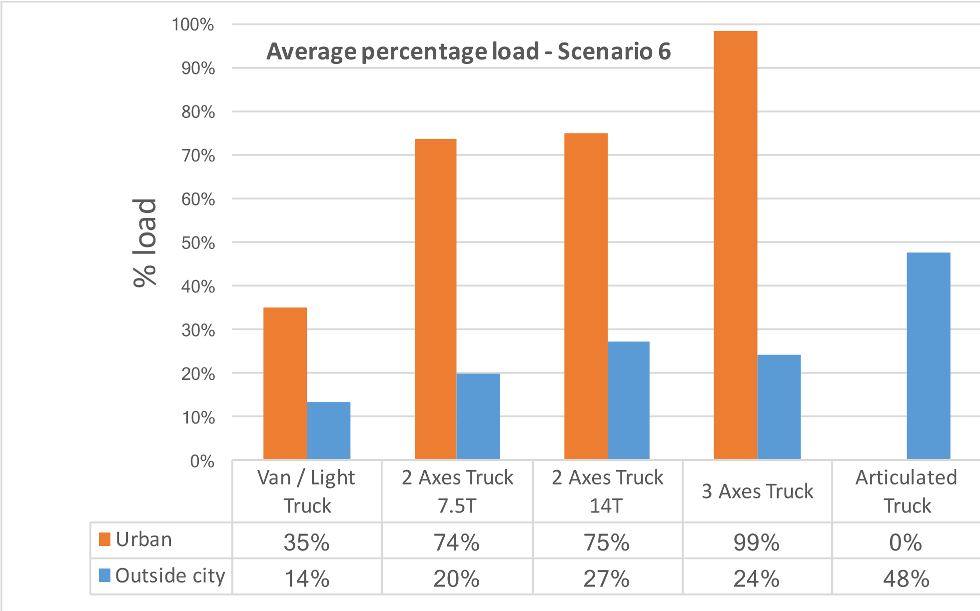


Figure 182: Percentage loads - Verona - Scenario 6.

	Urban				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	0,96	0,21	0,23	1,86	0,37
2 Axes Truck 7.5T	1,51	0,23	0,24	3,71	0,34
2 Axes Truck 14T	5,44	0,85	0,95	19,74	0,99
3 Axes Truck	82,92	12,12	12,53	329,60	9,60
Articulated Truck	0,00	0,00	0,00	0,00	0,00
Tot	**90,83**	**13,42**	**13,95**	**354,92**	**11,29**

Table 57: Pollutants emissions caused by transport inside the city - Verona- Scenario 6.

	Outside city				
	CO (Kg)	PM2.5 (Kg)	PM10 (Kg)	Nox (Kg)	CO2 (ton)
Van / Light Truck	1.664,6	437,6	453,5	2.916,2	661,6
2 Axes Truck 7.5T	552,3	80,8	84,5	2.170,1	237,2
2 Axes Truck 14T	527,9	71,1	78,0	2.560,1	239,5
3 Axes Truck	483,9	68,6	70,7	2.232,9	224,9
Articulated Truck	852,6	134,9	145,9	2.926,3	388,4
Tot	**4081,21**	**793,046**	**832,67658**	**12805,4655**	**1751,57275**

Table 58: Pollutants emissions caused by transport outside the city – Verona - Scenario 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

6 Annex II CBA details

6.1 CBA of CCCs for Construction Companies: Assumptions' description

General Assumptions:

Operational Hours per day in the CCC [h]	12h
Description: Number of daily hours in which the CCC is operative delivering the construction sites. The CCC can be open 24/7 receiving goods from suppliers. However, it was assumed that the CCC delivers to the construction sites during a period of 12h per day. This assumption was used for the fleet dimensioning.	
Labor Force: Working Hours per day [h]	8h
Description: Number of daily hours that a person works. This parameter is used for the labor force dimensioning.	
Labor Force Productivity Improvement [%]	5%
Description: Percentage of improvement of the overall productivity of the labor force on site due to the CCC implementation. In the WP2 it was measured that the average labor force productivity of the four pilots was around 70%. It is assumed that due to the CCC operations, the productivity can be increased up to 5%. This parameter is used to estimate the potential savings that the CCC could bring to the construction company.	
Reduction of Material Wasted, Damaged and Stolen [%]	3%
Description: Percentage of improvement of materials utilization. It is assumed that due to the CCC operations, the productivity can be increased up to 3% (better use of the material, reduction in material loss and theft, etc.). This parameter is used to estimate the potential savings that the CCC could bring to the construction company.	
Reduction of Material Acquisition Cost [%]	2%
Description: Cost saving in materials purchasing processes. The CCC provides higher bargaining power to the construction company due to lower transport cost of the suppliers and the easier delivery processes thanks to the CCC operations. Thus, cheaper materials acquisition. It is assumed that due to the CCC operations, material purchasing processes can be reduced by 3%. This parameter is used to estimate the potential savings that the CCC could bring to the construction company.	
Cost of Unsorted Bins [%]	0.093%
Description:	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

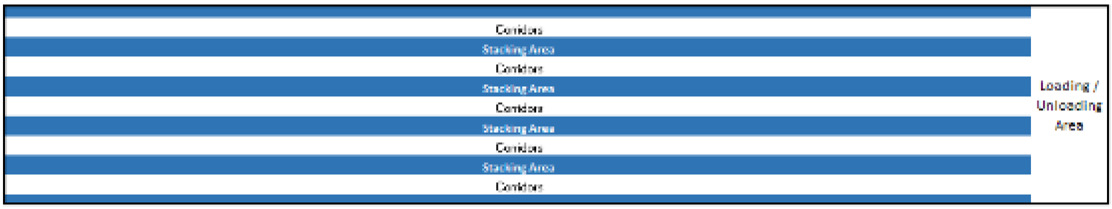
Average cost of the unsorted bins compared to the total project budget of the four pilot sites of the SUCCESS project. This parameter was obtained from the data collected in WP2. This parameter is used to estimate the potential savings that the CCC could bring to the construction company.	
Cost Reduction of Unsorted Bins [%]	80%
Description: Target cost reduction of the unsorted bins according to the D4.1 about target improvements. This parameter is used to estimate the potential savings that the CCC could bring to the construction company regarding the cost of the unsorted bins.	
Average labor force cost [%]	28.4%
Description: Average cost of the labor force compared to the total project budget that is susceptible of performance improvements due to the CCC implementation. In the calculation of this labor force cost, the cost of the tasks in which no performance improvements can be reach with a CCC are neglected (e.g. concrete works). For the estimation of the potential benefits that implementing a CCC could produce in terms of labor force productivity improvements, there were calculated (on average) the costs of the labor force of the different tasks in two different types of projects (a hospital and a warehouse). This parameter was used to estimate the potential savings that the CCC could bring to the construction company.	
Average Material cost [%]	30.6%
Description: Average material cost compared to the total project budget that are susceptible of performance improvements due to the CCC implementation. In the calculation of the material cost, the cost of the tasks in which no performance improvements can be reach with a CCC are neglected (e.g. concrete works). For the estimation of the potential benefits that implementing a CCC could produce in terms of materials utilization there were calculated (on average) the costs of the materials of the different tasks in two different types of projects a hospital and a warehouse). This parameter was used to estimate the potential savings that the CCC could bring to the construction company.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Assumptions for the CCC facility dimensioning:

Average Stock Time in the CCC [Days]	7days
Description: Number of days (on average) that the materials are stored in the CCC. This parameter is used to estimate the total surface requirements for the CCC dimensioning. The more stock days, the larger the area needed for the CCC.	
Percentage of the Total Materials in Shelves [%]	60%
Description: Percentage of the total materials that are stored in shelves inside the CCC. This parameter is used to estimate the total surface requirements for the CCC. The bigger the percentage of materials in shelves, the smaller the CCC.	
Average height of the Cargo [m]	1.2m
Description: This parameter is used to estimate the total surface requirements for the CCC by converting the material flows (outputs of the simulation in m3/week) into squared meters (m2).	
Storage High of shelves in the CCC [N° of Shelves]	4 shelves
Description: Total number of heights of the shelves of the storage area. It was assumed that the storage area can store 4 levels of pallets/cargo.	
Daily Average Storage Occupancy [%]	80%
Description: For operational purposes, it was assumed that the average occupancy rate of the storage area was set at 80% of the total capacity. Higher levels of occupancy could lead to operational issues. This parameter was used for the dimensioning of the CCC area requirements, increasing the area needed due to operational purposes.	
Ratio corridors/stacking area surface	1
Description: The CCC needs corridors for the maneuvering of the machinery. This parameters is represents the area dedicated to corridors compared to the area dedicated to store material. The value of the ratio equal to one means that the same area is dedicated for corridors than for storage (taking into account the surface occupied by the shelves). The higher the ratio, the bigger the CCC area dedicated to corridors and maneuvering zones. Following figure shows a schematic of the CCC dimensioning.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.



Space for Loading/Unloading Operations [%]	20%
Description: Total area of the CCC dedicated to loading/unloading truck operations. It is needed a specific area for the trucks and the maneuvering of the machinery in loading/unloading operations. The area is calculated of a percentage of the area dedicated to storage and corridors. Then this area is added for the final facility dimensioning of the CCC.	
Space for other common Areas [%]	3%
Description: Total area of the CCC dedicated to common areas such as offices, toilets, maintenance, etc. These areas are calculated as a global percentage of the area dedicated to storage and corridors. Then these areas are added for the final facility dimensioning of the CCC.	

Assumptions for the CCC operations dimensioning:

Average Time Needed for Unloading Trucks [min]	25min
Description: Average time needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the fleet of the CCC.	
Personnel Needed for Unloading Trucks [Units]	1.5 operators
Description: Average number of operators needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the labor force of the CCC.	
Forklifts Needed for Unloading Trucks [Units]	1 forklift
Description: Average number of forklifts needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Pallet Trucks Needed for Unloading Trucks [Units]	1 pallet truck
Description: Average number of pallet trucks needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Average Time Needed for Loading Trucks [min]	35min
Description: Average time needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the fleet of the CCC.	
Personnel Needed for Loading Trucks [Units]	1.5 operators
Description: Average number of operators needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the labor force of the CCC.	
Forklifts Needed for Loading Trucks [Units]	1 forklift
Description: Average number of forklifts needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Pallet Trucks Needed for Loading Trucks [Units]	1 pallet truck
Description: Average number of pallet trucks needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Forklifts Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x forklift/s
Description: Average number of forklifts needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Pallet Trucks Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x pallet truck/s
Description:	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Average number of pallet trucks needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Personnel Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x operator/s
Description: Average number operators needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Other Personnel Needed for CCC [Units]	x operator/s
Description: Number workers needed for the CCC that do not participate directly in the main logistics operations carried out in the facility. This assumption was set manually case-by-case in the different scenarios and business models assessed. In this category were included: • Manager: Responsible of the CCC • Other workers: that may include administrative staff and/or technicians for the maintenance • Truck drivers	

Assumptions for the CCC investments:

Pallet Trucks Cost [€]	4.000€ per Unit
Description: Price in € per unit of equipment (i.e. pallet truck). The machinery dimensioning and the price per unit determine the expenses for the equipment acquisitions, which are done in the year 1 of the CBA and also when their lifespan finish.	
Pallet Truck lifespan [Year]	5 years
Description: Average lifespan of the equipment in years (i.e. pallet truck). In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan.	
Forklift Cost [€]	18.000€ per Unit
Description: Price in € per unit of equipment (i.e. forklift). The machinery dimensioning and the price per unit determine the expenses for the equipment acquisitions, which are done in the year 1 of the CBA and also when their lifespan finish.	
Forklift lifespan [Year]	10 years
Description:	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Average lifespan of the equipment in years (i.e. forklift). In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan.	
Residual Value of machinery and vehicles [%]	10 %
Description: Percentage of the acquisition value of the machinery that determines its value when their lifespan ends. In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan and the residual value is considered as an income at that time.	
CCC project implementation [€]	75.000€
Description: Initial investment required to start running the CCC. The expenses of the project implementation are considered in the year 1 of the CBA. This initial expenditure may include some investments such as the racks, software, tools, etc. that are needed to start the operations in the CCC. This parameter was set as a constant value for all the scenarios.	

Assumptions for the CCC labor cost:

CCC Personnel Costs [€/year]	X €/year

Description:

Personnel cost of the different workers needed for running the CCC. Due to the difference between the salaries of the countries participating in the SUCCESS project, the values of the different salaries were set case-by-case in each city pilot.

The personnel cost considers the cost of the company (including taxes, social security, etc.), not the gross salary of the worker. In this category were included:

- Manager: Responsible of the CCC
- Other workers: that may include administrative staff and/or technicians for the maintenance
- Truck drivers
- Operators

Cost	Luxembourg	Paris	Valencia	Verona
Manger [€/year]	47.918	58.800	50.000	67.500
Logistic Operator [€/year]	38.786	28.200	25.000	48.500
Driver [€/year]	35.229	44.400	38.000	46.500
Administrative & Technical Staff [€/year]	39.000	38.400	35.000	52.500

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Assumptions for the CCC operational cost:

CCC facility rental [€/m2/month]	X €/m2/month

Description:

Price of the rental cost of the CCC expressed in euros per squared meters and month. Due to the difference between the rental prices of the countries participating in the SUCCESS project, the values were set case-by-case in each city pilot.

Cost	Luxembourg	Paris	Valencia	Verona
Rental Price [€/m2/month]	12,0	8	4,0	5,3

CCC general expenses [%]	10%

Description:

Percentage of the facility rental cost that estimates the cost of general expenses of the CCC such as water, power, telephone, etc. The general costs are expressed as a percentage of the monthly rental cost of the facility. Consequently, the bigger the CCC, the higher cost of the general expenses.

CCC facility & equipment maintenance [%]	5%

Description:

Percentage of the facility rental cost that estimates the cost of the maintenance cost of facility. It is expressed as a percentage of the monthly rental cost of the facility, thus, the bigger the CCC, the higher cost of the general expenses

Transport Costs [€/km]	X €/km

Description:

Transport cost of the CCC fleet expressed in euros per km travelled. In the case of a business model of a CCC managed by a construction company, the company pays a monthly renting for the truck fleet. Thus, the transport costs include the maintenance, spare parts and the fuel. Other transport cost are covered by the renting price (e.g. insurances, taxes, etc.)

Besides, the driver cost is considered separately in the analysis (see driver costs).

The vehicle acquisition is considered separately in the analysis (see truck cost per unit).

Due to the difference between the fuel prices of the countries participating in the SUCCESS project, the values were set case-by-case in each city pilot considering the fuel prices in each of them.

For the estimation of the transport cost, it was used the software ACOTRAM and it was taken into account that the majority of the kilometers are done in urban areas. In addition, even though there are several type of trucks, there was considered an average value for all of them.

Cost	Luxembourg	Paris	Valencia	Verona
Diesel Price [€/l]	1,06	1,40	1,25	1,41

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Finally the transport cost per city are:

Transport Cost [CCC managed by the Const. Company]	0,28	0,38	0,34	0,38

Truck renting cost [€/month]	X €/tuck/month

Description:

In the business model of a CCC managed by a construction company it was considered that the most suitable way of acquiring trucks was a monthly renting. In this regard, a renting price per type of truck and month was considered as constant for all the pilots:

- 25t - 3 Axes Truck Costs: Average Cost per unit 2.250 €/month
- 14t - 2 Axes Truck Costs: Average Cost per unit 2.000 €/month
- 7.5t - 2 Axes Truck Costs: Average Cost per unit 1.750 €/month
- Van/Light Truck Costs: Average Value per unit 1.250 €/month

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6.2 CBA of CCCs for Logistics Operators: Assumptions' description

General Assumptions:

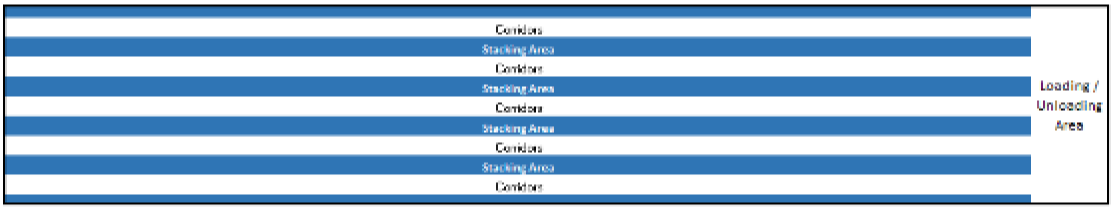
Operational Hours per day in the CCC [h]	12h
Description: Number of daily hours in which the CCC is operative delivering the construction sites. The CCC can be open 24/7 receiving goods from suppliers. However, it was assumed that the CCC delivers the construction sites during a period of 12h per day. This assumption was used for the fleet dimensioning.	
Labor Force: Working Hours per day [h]	8h
Description: Number of daily hours that a person works. This parameter is used for the labor force dimensioning.	

Assumptions for the CCC facility dimensioning:

Average Stock Time in the CCC [Days]	7days
Description: Number of days (on average) that the materials are stored in the CCC. This parameter is used to estimate the total surface requirements for the CCC dimensioning. The more stock days, the larger the area needed for the CCC.	
Percentage of Palletized Cargo [%]	80%
Description: Percentage of the cargo (output of the simulation in m^3) that is packaged in pallets. The remaining cargo was considered in m^3. This assumption was used to dimension the CCC facility and also to obtain the revenues of the CCC services	
Average height of the Cargo [m]	1.2m
Description: This parameter is used to estimate the total surface requirements for the CCC by converting the material flows (outputs of the simulation in m^3/week) into squared meters (m^2). Besides, this parameter was also used to estimate the number of pallets that the CCC moves in daily basis. The standard pallet considered in the analysis was the Euro-Pallet (1200*800mm)	
Storage High of shelves in the CCC [N° of Shelves]	4 shelves
Description: Total number of heights of the shelves of the storage area. It was assumed that the storage area could store 4 levels of pallets/cargo.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Daily Average Storage Occupancy [%]	80%
Description: For operational purposes, it was assumed that the average occupancy rate of the storage area was set at 80% of the total capacity. Higher levels of occupancy could lead to operational issues. This parameter was used for the dimensioning of the CCC area requirements, increasing the area needed for the CCC due to operational purposes.	
Ratio corridors/stacking area surface	1
Description: The CCC needs corridors for the maneuvering of the machinery. This parameters is represents the area dedicated to corridors compared to the area dedicated to store material. The value of the ratio equal to one means that the same area is dedicated for corridors than for storage (taking into account the surface occupied by the shelves). The higher the ratio, the bigger the CCC area dedicated to corridors and maneuvering zones. Following figure shows a schematic of the CCC dimensioning.	



Space for Loading/Unloading Operations [%]	20%
Description: Total area of the CCC dedicated to loading/unloading truck operations. It is needed a specific area for the trucks and the maneuvering of the machinery in loading/unloading operations. The area is calculated of a percentage of the area dedicated to storage and corridors. Then this area is added for the final facility dimensioning of the CCC.	
Space for other common Areas [%]	3%
Description: Total area of the CCC dedicated to common areas such as offices, toilets, maintenance, etc. These areas are calculated as a global percentage of the area dedicated to storage and corridors. Then these areas are added for the final facility dimensioning of the CCC.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Assumptions for the CCC operations dimensioning:

Average Time Needed for Unloading Trucks [min]	25min
Description: Average time needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the fleet of the CCC.	
Personnel Needed for Unloading Trucks [Units]	1.5 operators
Description: Average number of operators needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the labor force of the CCC.	
Forklifts Needed for Unloading Trucks [Units]	1 forklift
Description: Average number of forklifts needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Pallet Trucks Needed for Unloading Trucks [Units]	1 pallet truck
Description: Average number of pallet trucks needed for completely unload the cargo of a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Average Time Needed for Loading Trucks [min]	35min
Description: Average time needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the fleet of the CCC.	
Personnel Needed for Loading Trucks [Units]	1.5 operators
Description: Average number of operators needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the labor force of the CCC.	
Forklifts Needed for Loading Trucks [Units]	1 forklift
Description:	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Average number of forklifts needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Pallet Trucks Needed for Loading Trucks [Units]	1 pallet truck
Description: Average number of pallet trucks needed for completely load the cargo inside a truck. Even though there are several types of trucks considered, it was estimated an average value for all of them. This assumption was used for the dimensioning of the machinery of the CCC.	
Forklifts Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x forklift/s
Description: Average number of forklifts needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Pallet Trucks Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x pallet truck/s
Description: Average number of pallet trucks needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Personnel Needed for Housekeeping & Repacking Operations inside the CCC [Units]	x operator/s
Description: Average number operators needed for the housekeeping and repacking operations. This assumption was set manually case-by-case in the different scenarios and business models assessed.	
Other Personnel Needed for CCC [Units]	x operator/s
Description: Number workers needed for the CCC that do not participate directly in the main logistics operations carried out in the facility. This assumption was set manually case-by-case in the different scenarios and business models assessed. In this category were included: • Manager: Responsible of the CCC • Other workers: that may include administrative staff and/or technicians for the maintenance • Truck drivers	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Assumptions for the CCC investments:

Pallet Trucks Cost [€]	4.000€ per Unit
Description: Price in € per unit of equipment (i.e. pallet truck). The machinery dimensioning and the price per unit determine the expenses for the equipment acquisitions, which are done in the year 1 of the CBA and also when their lifespan finish.	
Pallet Truck lifespan [Year]	5 years
Description: Average lifespan of the equipment in years (i.e. pallet truck). In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan.	
Forklift Cost [€]	18.000€ per Unit
Description: Price in € per unit of equipment (i.e. forklift). The machinery dimensioning and the price per unit determine the expenses for the equipment acquisitions, which are done in the year 1 of the CBA and also when their lifespan finish.	
Forklift lifespan [Year]	10 years
Description: Average lifespan of the equipment in years (i.e. forklift). In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan.	
Residual Value of machinery and vehicles [%]	10 %
Description: Percentage of the acquisition value of the machinery that determines its value when their lifespan ends. In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan and the residual value is considered as an income at that time.	
CCC project implementation [€]	75.000€
Description: Initial investment required to start running the CCC. The expenses of the project implementation are considered in the year 1 of the CBA. This initial expenditure may include some investments such as the racks, software, tools, etc. that are needed to start the operations in the CCC. This parameter was set as a constant value for all the scenarios.	
Trucks Cost [€]	X € per Unit
Description: Purchasing price in € per truck. The fleet dimensioning and the price per unit determine the expenses for the trucks acquisitions, which are done in the year 1 of the CBA and also when their lifespan finish.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

In this CBA, as a logistics operator manages the CCC in permanent basis, it was considered that the CCC operator acquires the trucks instead of renting them. The price were considered as constant in the different pilots. Following table illustrates the different truck costs depending on the type:

Type of truck	Price	Units
Vans/Light Truck purchase price per unit	22.000	€/Unit
2 Axes Truck <7.5t purchase price per unit	40.000	€/Unit
2 Axes Truck <14t purchase price per unit	50.000	€/Unit
3 Axes Truck <25t purchase price per unit	60.000	€/Unit

Truck lifespan [Year]	5 years

Description:

Average lifespan of the truck in years. In the analysis, a renewal of the equipment is assumed when they cover completely their lifespan.

Assumptions for the CCC labor cost:

CCC Personnel Costs [€/year]	X €/year

Description:

Personnel cost of the different workers needed for running the CCC. Due to the difference between the salaries of the countries participating in the SUCCESS project, the values of the different salaries were set case-by-case in each city pilot.

The personnel cost considers the cost of the company (including taxes, social security, etc.), not the gross salary of the worker. In this category were included:

- Manager: Responsible of the CCC
- Other workers: that may include administrative staff and/or technicians for the maintenance
- Truck drivers
- Operators

Cost	Luxembourg	Paris	Valencia	Verona
Manger [€/year]	47.918	58.800	50.000	67.500
Logistic Operator [€/year]	38.786	28.200	25.000	48.500
Driver [€/year]	35.229	44.400	38.000	46.500
Administrative & Technical Staff [€/year]	39.000	38.400	35.000	52.500

Assumptions for the CCC operational cost:

CCC facility rental [€/m2/month]	X €/m2/month

Description:

Price of the rental cost of the CCC expressed in euros per squared meters and month. Due to the difference between the rental prices of the countries participating in the SUCCESS project, the values were set case-by-case in each city pilot.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Cost	Luxembourg	Paris	Valencia	Verona
Rental Price [€/m2/month]	12,0	8	4,0	5,3

CCC general expenses [%]	10%

Description:

Percentage of the facility rental cost that estimates the cost of general expenses of the CCC such as water, power, telephone, etc. The general costs are expressed as a percentage of the monthly rental cost of the facility. Consequently, the bigger the CCC, the higher cost of the general expenses.

CCC facility & equipment maintenance [%]	5%

Description:

Percentage of the facility rental cost that estimates the cost of the maintenance cost of facility. It is expressed as a percentage of the monthly rental cost of the facility, thus, the bigger the CCC, the higher cost of the general expenses.

Transport Costs [€/km]	X €/km

Description:

Transport cost of the CCC fleet expressed in euros per km travelled. In the case of a business model of a CCC managed by a logistics operator, the transport costs include the maintenance, spare parts, the fuel, insurances, taxes, etc. This is the reason why they are higher compared to the previous business model.

The driver cost is considered separately in the analysis (see driver costs).

The vehicle acquisition is considered separately in the analysis (see truck cost per unit).

Due to the difference between the fuel prices of the countries participating in the SUCCESS project, the values were set case-by-case in each city pilot considering the fuel prices in each of them.

For the estimation of the transport cost, it was used the software ACOTRAM and it was taken into account that the majority of the kilometers are done in urban areas. In addition, even though there are several type of trucks, there was considered an average value for all of them.

Cost	Luxembourg	Paris	Valencia	Verona
Diesel Price [€/l]	1,06	1,40	1,25	1,41

Finally, the average transport cost per pilot are:

Transport Cost [CCC managed by the Logistics Operator]	1,26	1,67	1,49	1,68

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

Assumptions for the CCC incomes:

Percentage of Standard Pallet Moved [%]	50 %
Description: Percentage of the palletized cargo that uses standard and stackable pallets. This parameter was used to estimate revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of Standard & Non-Stackable Pallet Moved [%]	35 %
Description: Percentage of the palletized cargo that uses standard but non-stackable pallets. This parameter was used to estimate revenues of the CCC but also the dimensioning of the facility. It was assumed that 70% of non-stackable pallets were standard pallets. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of Non-Standard & Non-Stackable Pallet Moved [%]	15 %
Description: Percentage of the palletized cargo that uses non-standard and non-stackable pallets. This parameter was used to estimate revenues of the CCC but also the dimensioning of the facility. It was assumed that 30% of non-stackable pallets were also non-standard pallets. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of Work-Pack creation (% of pallets moved) [%]	40 %
Description: Percentage of the palletized cargo (% of the total pallets moved) that is re-packed inside the CCC (kitting operations) aiming to improve the performance of the construction activities on site. The work-pack creation (kitting) is a service provided by the CCC that packages different materials from different suppliers into one single kit to optimize logistics and site operations. This percentage was used to estimate the number of kits prepared and the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of unit extra-store (1 week) [%]	20 %
Description: Percentage of the cargo (in m^3) that is in the storage one week (or a fraction) extra. This percentage was used to estimate the revenues of the CCC.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633338.

The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of unit extra-store (2 week) [%]	10 %
Description: Percentage of the cargo (in m^3) that is in the storage between 1 and 2 weeks extra. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of unit extra-store (1 month) [%]	5 %
Description: Percentage of the cargo (in m^3) that is in the storage between 3 weeks and more than 1 month extra. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of express delivery [% of total deliveries]	5 %
Description: Percentage of the total amount of deliveries that are done urgently due to a construction site demand. Express deliveries is a service provided by the CCC. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Percentage of off-peak delivery [% of total deliveries]	5 %
Description: Percentage of the total amount of deliveries that are done in off-peak hours (e.g. during night) due to a construction site demand. Off-peak deliveries is a service provided by the CCC. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Area dedicated to pre-construction activities [m²]	150m²
Description: Area of the CCC dedicated to pre-construction activities that the contractors and construction companies can use. This service is provided inside the CCC facilities and is used to estimate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per Standard Pallet Moved [€/pallet]	10 €/pallet
Description: Price per standard pallet moved and stored inside the facilities of the CCC. It includes loading and unloading operations plus one-week storage.	

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The number of units moved and the price was used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per Standard & Non-Stackable Pallet Moved [€/pallet]	12 €/pallet
Description: Price per standard & non-stackable pallet moved and stored inside the facilities of the CCC. It includes loading and unloading operations plus one-week storage. The number of units moved and the price was used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per Non-Standard & Non-Stackable Pallet Moved [€/pallet]	15 €/pallet
Description: Price per non-standard & non-stackable pallet moved and stored inside the facilities of the CCC. It includes loading and unloading operations plus one-week storage. The number of units moved and the price was used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per Non-palletized Cargo Moved [€/m³]	20 €/m³
Description: Price per unit of non-palletized cargo moved and stored inside the facilities of the CCC. It includes loading and unloading operations plus one-week storage. The number of units moved and the price was used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per Work-Pack creation [€/unit]	10 €/unit
Description: Price per unit re-packed inside the CCC (kitting operations) for the performance improvement of the construction activities on site. The work-pack creation (kitting) is a service provided by the CCC that packages different materials from different suppliers into one single kit to optimize logistics and site operations. The number of units re-packed and the price was used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Rental price for pre-construction activity [€/m²]	20 €/m²
Description:	

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Price per square meter rent for pre-construction activities. This service is provided inside the CCC facilities and is used to calculate the incomes of the CCC The parameter remains constant in all the pilots and scenarios evaluated.	
Average occupancy rate of the area for pre-construction activity [%]	75 %
Description: Average occupancy rate of the area dedicated to pre-construction activities. This service is provided inside the CCC facilities and is used to calculate the incomes of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per unit extra-store (1 week) [€/m³]	5 €/unit
Description: Price of the cargo (per m³) that is storage between 1 and 2 weeks extra. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per unit extra-store (2 week) [€/m³]	10 €/unit
Description: Price of the cargo (per m³) that is storage between 2 and 3 weeks extra. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per unit extra-store (1 month) [€/m³]	15 €/unit
Description: Price of the cargo (per m³) that is storage between 3 weeks and 1 month extra. This percentage was used to estimate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per express delivery [€/delivery]	150 €/delivery
Description: Percentage per deliver done during off-peak hours (e.g. during night) due to a site demand. Off-peak deliveries is a service provided by the CCC that has an extra cost. This percentage was used to calculate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.	
Price per off-peak delivery [€/delivery]	100 €/delivery
Description:	

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Percentage per express delivery done due to specific site's demand. Express deliveries is a service provided by the CCC that has an extra cost. This percentage was used to calculate the revenues of the CCC. The parameter remains constant in all the pilots and scenarios evaluated.

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6.3 Sensitivity analysis

For the assessment of the variability of the Cost Benefit Analyses carried out to study the feasibility of the implementation of CCCs, two sensitivity analyses were carried out for each of the two business models proposed: a CCC managed by a construction company and a CCC managed by a logistics operator.

A sensitivity analysis enables the identification of the critical variables of the projects considering the variations that can be either positive or negative and that have the largest impact on the project's financial and/or economic results.

The sensitivity analyses for the two business models were carried out using "Crystal Ball", an excel spreadsheet-based application for predictive modeling, forecasting, simulation, and optimization that by varying one variable at a time determines the effect of that change on the targeted value, in our case the NPV.

The analyses done for the two different business models considered the Scenario 6 (i.e. single CCC that serves several sites) and then, there were assigned probability distributions to each of the critical variables considered. In both cases, the inputs of the Costs Benefit Analysis were the outputs values of the simulations models but instead of using the date of one simulation, the sensitivity analysis of both business was done considering the averaged values of the 4 pilots (Luxembourg, Paris, Valencia and Verona). Later, a normal distribution with a standard deviation of the 10% of each of the average values was considered for each of the critical variables.

Having established the probability distributions for the critical variables, it is possible to proceed with the calculation of the probability distribution of net present value (NPV) of the project. For this purpose, the Monte Carlo methodology was used because it consists of the repeated random extraction of a set of values for the critical variables, taken within the respective defined intervals, and then the calculation of the performance indices for the project (NPV) resulting from each set of extracted values.

By repeating this procedure for a large enough number of extractions, it is possible to obtain a pre-defined convergence of the calculation as the probability distribution of the NPV.

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6.3.1 Sensitivity Analysis: CBA of a CCC managed by a Construction Company

Input data of the CBA

Following table lists the input variables selected for establishing the probability distribution in the sensitivity analysis of a CCC managed by a construction company. The value of each parameter shown is the average value of the four pilots (Luxembourg, Paris, Valencia and Verona). Besides, a normal distribution with a standard deviation of the 10% of the average value was considered for each of the critical variables.

Variable	Value	Unit
Number of Construction Sites	11,7	sites
Daily Average Deliveries per Construction Site	2,7	Deliveries
Average Weekly Storage Capacity needed	698,61	m3
Average yearly budget of all construction projects	79.174.737	€
3 Axes Truck <25t price per unit [€/month]	2.250	€/Unit
CCC Rental Cost [Euros/m2/month]	6,4	€/m2/month
Operational Transport Cost [€/km]	0,34	€/km

Assumptions

Following table lists the assumptions selected for establishing the probability distribution in the sensitivity analysis of a CCC managed by a construction company. The value of each assumption shown is the average value of the four pilots (Luxembourg, Paris, Valencia and Verona). Besides, a normal distribution with a standard deviation of the 10% of the average value was considered for each of the critical variables.

Assumption	Value	Unit
Labour Force Productivity Improvement [%]	5%	%
Reduction of Material Wasted, Damaged and Stolen	3%	%
Reduction of Material Acquisition Cost	2%	%
Average Labour Force Cost [%]	30%	%
Average Material Cost [%]	28%	%
Percentage of the Total Storage Area in Shelves	60%	%
Average Stock time	7	days
Average Height of the cargo	1,2	m

Results:

After 100.000 iterations, the value of the NPV ranges between 876.015 € and 15.659.840 €, being the base case an NPV of 6.992.957 €. Following figure illustrates the distribution of the NPV results:

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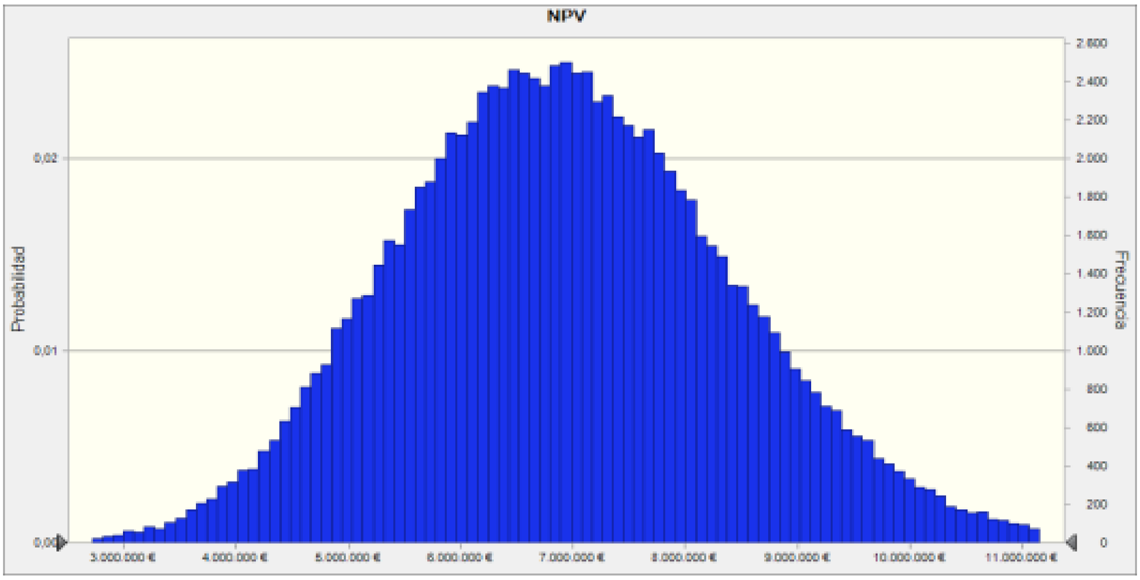
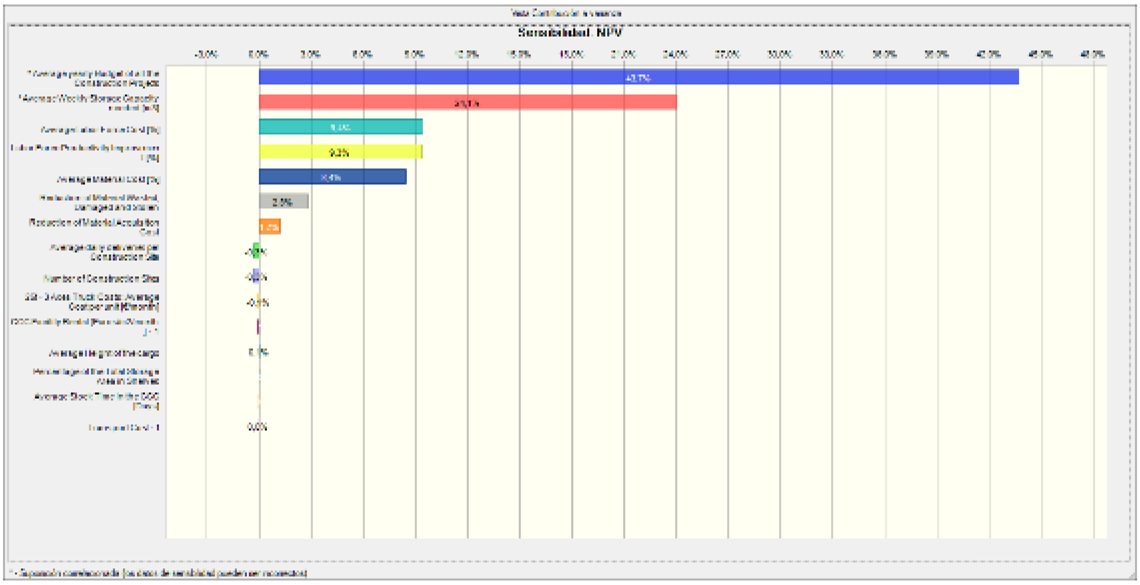


In reference to the sensitivity analysis of the set of variables and assumptions selected, following figure illustrates, in percentage, the variability of the NVP that is explained by each of the variables and assumptions:



As can be seen from the figure the majority of the variability is due to the parameter "average yearly budget of the construction projects". This variable determines the annual budget of the construction projects that are served by the CCC and explains almost 45% of the variability of our model. In this regard, our analysis clearly illustrates the importance of having large construction projects that are served by a CCC in order to reach economies of scale and be able to obtain enough costs savings in the construction activity that compensate the extra cost of implementing a CCC.

The parameter "Average weekly storage capacity needed" explains almost 25% of the variability of our model. This is important because this parameter is the main output of the simulation (weekly material flows in m3) and is the main

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variable that we use for the facility dimensioning. In this regard, small variations of this parameter that comes from the simulation models also affect strongly the feasibility or not of the CCC. Consequently, the estimation of the potential material flows that a will CCC manage has a huge impact on its long-term feasibility. This is an important conclusion because the construction industry works on project basis and the flows are not constant through the time, so their estimation may vary based on the ongoing projects and the different phases and activates perform on them.

Finally, the following parameters that all together explain almost 30% of the variability of our model are the assumptions of "percentage of the cost of the personnel" and "percentage of the cost of the materials" compared to the total cost of the project, and the performance improvements that can be obtained thanks to the CCC implementation. Firstly, the assumptions concerning the percentage of the cost compared to the total budget were set considering only those tasks that in which a productivity improvement can be reach thanks to the CCC. However, for those percentages there were considered two different projects: a hospital and a warehouse, so a fine-tuning process of these assumptions is needed especially if the projects that are going to use the CCC are not any of those typologies. Secondly, the percentage of improvement that can be obtained due to the CCC operations may vary project by project, so the adjustment of these performance improvements is required in each project but also is recommended to do it by tasks.

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6.3.2 Sensitivity Analysis: CBA of a CCC managed by a Logistics Operator

Input data of the CBA

Following table lists the input variables selected for establishing the probability distribution in the sensitivity analysis for the CCC managed by a logistics operator. The value of each variable shown is the average value of the four pilots (Luxembourg, Paris, Valencia and Verona). Besides, a normal distribution with a standard deviation of the 10% of the average value was considered for each of the critical variables.

Variable	Value	Unit
Number of Construction Sites	19	sites
Daily Average Deliveries per Construction Site	2,66	Deliveries
Average Weekly Storage Capacity needed	1.904,37	m3
Price per Standard Pallet Moved [Euros/pallet]	10,0	€/Pallet
3 Axes Truck <25t purchase price per unit	60.000	€/Unit
CCC Facility Project Implementation Costs	75.000	€
CCC Rental Cost [Euros/m2/month]	6,4	€/m2/month
Operational Transport Cost [€/km]	1,52	€/km
Driver Annual Salary	41.032	€/Year
Logistics Operator Annual Salary	35.122	€/Year

Assumptions

Following table lists the assumptions selected for establishing the probability distribution in the sensitivity analysis for the CCC managed by a logistics operator. The value of each assumption shown is the average value of the four pilots (Luxembourg, Paris, Valencia and Verona). Besides, a normal distribution with a standard deviation of the 10% of the average value was considered for each of the critical variables.

Assumption	Value	Unit
Average Height Cargo	1,20	m
Percentage of Palletized Cargo	80%	%
% of daily Standard Pallets Moved	50%	%
% of daily Work Packs Prepared [% of Daily Pallets]	40%	%
% of Units Extra-stored [1 week]	20%	%
% of Daily Express Deliveries	5%	%
% of Daily Off-Peak Deliveries	5%	%
Average Stock time	7	days
Ratio Corridors/Stacking Area Surface	1	

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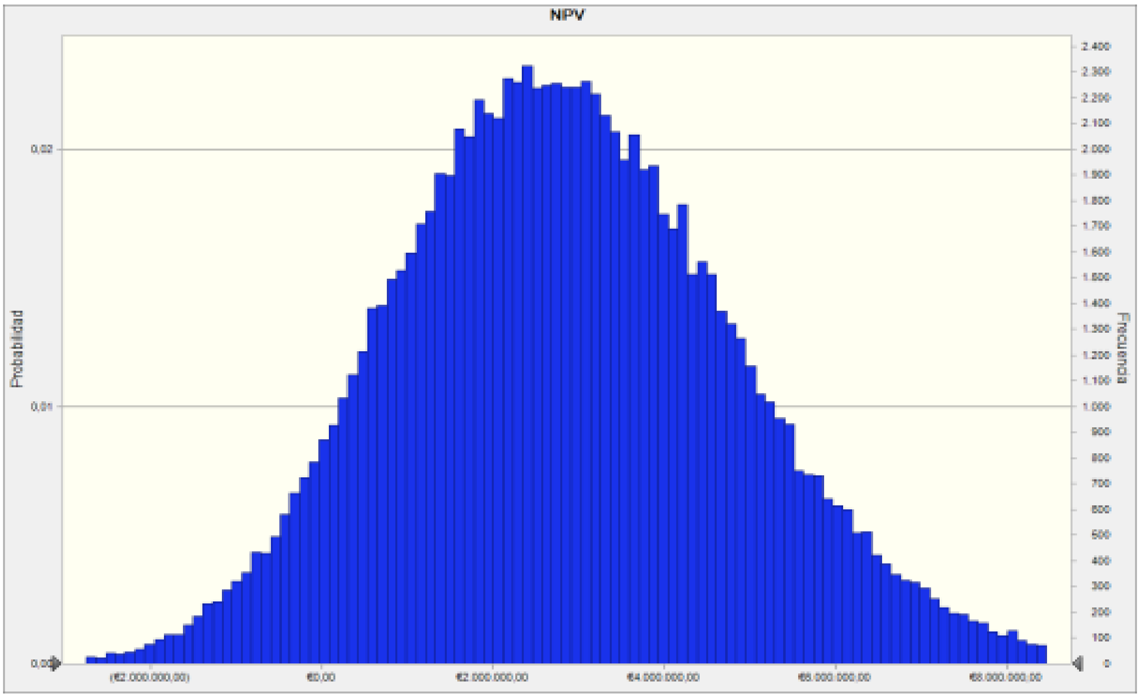
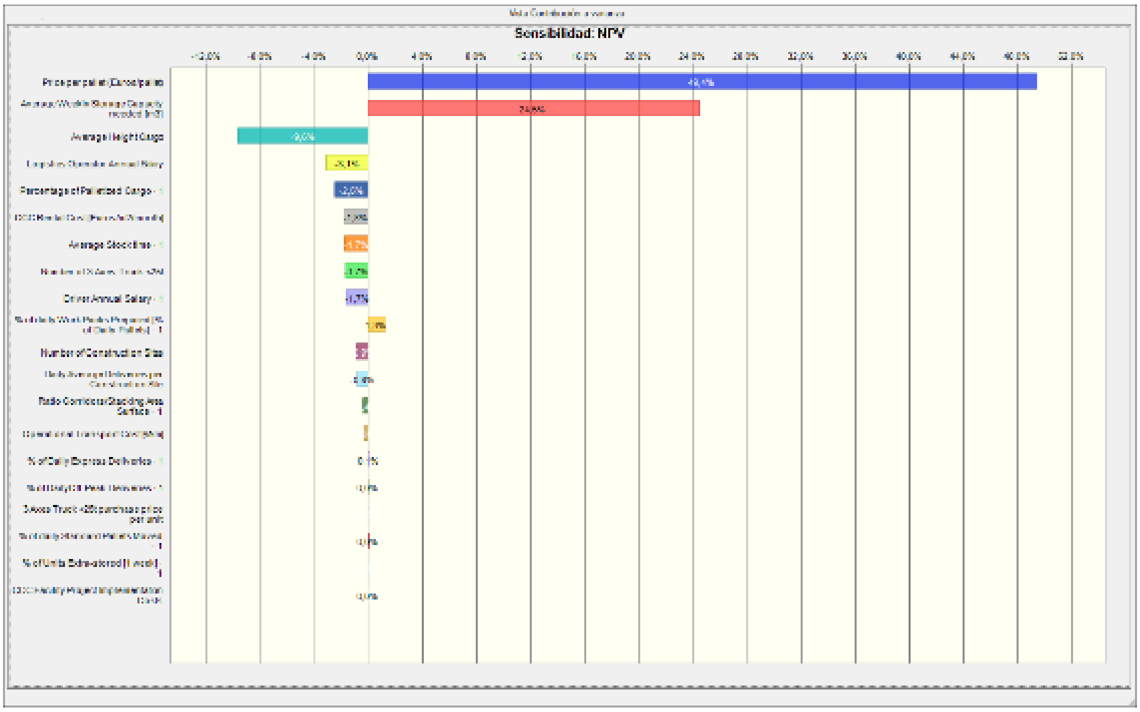
Results:

After 100.000 iterations, the value of the NPV ranges between -4.955.835€ a 12.884.320€, being the NPV of the base case 2.774.915€. Following figure illustrates the distribution of the NPV results:



In reference to the sensitivity analysis of the set of variables and assumptions selected, following figure illustrates, in percentage, the variability of the NVP that is explained by each of the variables and assumptions:



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As can be seen from the figure the most important variable is the price per pallet moved, which explains almost 50% of the variability of our model. Consequently, the definition and adjustment of this parameter is key in the success of the CCC.

To see the effect of the price, following table shows a 1€ variation in the price per pallet considering the rest of variables and assumptions as constants.

Price per pallet	NPV
10€	2.774.914 €
9€	1.405.633 €
8€	36.352 €
7€	-1.332.928 €

In addition, the two following parameters explain almost 35% of the variability of our analysis:

- "Average weekly storage capacity needed", which is the main output of the simulation (weekly material flows in m3) and is the main variable that we have for the facility dimensioning. In this regard, small variations of this parameter that comes from the simulation models also affect remarkably the feasibility or not of the CCC. Consequently, the estimation of the potential material flows that a will CCC manage has a huge impact on its long-term feasibility. This is an important conclusion because the construction industry works on project base and the flows are not constant through the time, so its estimation may vary based on the ongoing projects and the different phases and activates perform on them.
- "Average height of the cargo", which is an assumption considered in both analysis and that is used, in one side for the facility dimensioning and, in the other side for the estimation of the total number of pallets that the CCC manages. This variable was set because it was needed to convert the outputs of the simulation (m3/week) into some quantitative variable (i.e. pallets), but is a rough estimation of the height of a pallet. Besides, the construction industry manages materials that are not palletized so this assumption needs to be carefully considered.

In reference to the cost, the most important parameters that affect the CCC feasibility are the logistics cost of the personnel dedicated to the operations inside the CCC, the percentage of palletized cargo and then the rental costs of the facility. These results point out the importance of a correct dimensioning of the operations (also linked with the material flows) and the location of the CCC.

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