Dealing with carbon credit points in city logistics domain

Yaejin Lee

Faculty of Technology, Policy & Management, Delft University of Technology, Jaffalaan 5, 2628BX, Delft, The Netherlands
E-mail address: mirdealist@gmail.com

Abstract
The development of cities has been highly relevant to urban freight transportation, which leads to the optimization of city logistics. However, the movement of goods causes negative effects and thus heterogeneous stakeholders in cities, that are highly affected by those effects, give rise to distributed decision-making system. The research is intended to expand developed agent-based model called Situated Multi-agent Urban Freight System (SMUrFS) that describes city logistics and introduces carbon credit point concept that is based on Kyoto Protocol by applying carbon market mechanisms. This article analyses the mechanisms by means of literature reviews and evaluates policy alternatives by a set of KPIs. The finding indicates that the most desirable policy providing 75% refund for unused points while subsidy was remained unchanged has reduced 12.17% of travelled distance and 2.37 tonnes of CO$_2$ emissions during the simulation phase.

Keywords: Urban freight transportation, City logistics, Agent-based model, Multi-actors, Kyoto protocol, Mechanisms

1. Introduction
Freight transportation has a significant relationship with the economy of urban areas including production, distribution and consumption activities. Taniguchi et al. (1999) has defined city logistics as "the process for totally optimising the logistics and transport activities by private companies in urban areas considering the traffic environment, the traffic congestion and the energy savings within the framework of a market economy". City logistics, however, is exposed to a variety of challenges under the environment of cities. An increasing number of freight vehicles especially lead to environmental damage and traffic congestion (OECD, 2003). To be specific those negative effects would be observed as; congestion, pollution, safety issues, damage to infrastructure, waste of time, waste of money, waste of energy, waste of fossil fuels and nuisance for inhabitants, visitors and traffic (Peters, 2014).

In addition, multiple stakeholders in a city including consumers, retailers, shippers, transporters and municipalities have interactions with those effects. These multiple heterogeneous stakeholders have different goals within restricted resources that would cause distributed decision-making system (Anand et al., 2014). In this system, parties that are asymmetrically informed are seeking for cooperation but are behaving opportunistically for their own autonomous goals. They would be optimizing their own goals rather than the whole system (Schneeweiss, 2003).

The Kyoto Protocol, an international agreement, was signed in 1997 in order to limit or reduce greenhouse gas emissions (United Nations, 2014). Countries with commitments under the Kyoto Protocol must meet their targets primarily through national measures. This represents that the Kyoto protocol not only collect collaborative governmental effort, but also sets legally binding conditions for the committing parties (Abdallah et al., 2011). As an additional means of meeting these targets, Kyoto Protocol offered three market-based mechanisms (United Nations, 2014); International Emission Trading, Clean Development Mechanisms (CDM) and Joint Implementation (JI).

In this paper, city logistics is researched by using agent-based modeling developed by PhD candidate N. R. Anand (2012), which captures interactions and dynamics of decision making between city logistics stakeholders. Agent-Based Modeling (ABM) is a model where agents are considered as unique and autonomous individuals and interact with not only each other but also their local environment (Steven & Railsback, 2011). Researches applying ABM in city logistics domain have been conducted to evaluate the effects of implementing city logistics measures (Taniguchi et al., 2014). The multi-agent model by Tamagawa (2010) represents to a learning model as well as a model for vehicle routing and scheduling problem with time window-forecasted (VRP-TW-F), to test road network. Teo et al. (2014) has evaluated a part of Osaka’s city road network using agent based modeling approach. The model considers the joint scheme, a combination of the load factor control scheme and the urban freight road pricing, as well as the vehicle routing for carrier’s delivery. Besides the researches mentioned above, large number of researches have contributed the usefulness of ABM to validation of city logistics.

Under the urge of the optimization of city logistics, an agent-based model called SMUrFS (Situated Multi-agent Urban Freight System) developed by Anand et al. (2012) describes the movement of urban freight for the city of Rotterdam. The model presented a new concept named carbon credit points (CCP) that would be corresponded to the national target of Kyoto Protocol but carbon market-based mechanisms do not exist yet. Thus, adding the idea of mechanisms to the model would bring more options to the shop agents to deal with CCP and make a difference in outcomes.
2. Research and methodology
2.1 Research objective and question
The research object in the research is to improve freight transportation based on city logistics domain by extending the agent-based model (SMUrFS) with mechanisms derived from Kyoto Protocol to deal with carbon credit points. In other words, the objective of the project is to deliver an extended model with implemented mechanisms derived from Kyoto Protocol. The main research question that is addressed is: “To what extent can freight transportation based on city logistics domain be improved by implementing mechanisms, derived from Kyoto Protocol, to deal with carbon credit points into the agent-based model (SMUrFS)?”

2.2 Scientific and societal relevance
The research is highly related to a societal aspect considering a relationship between city logistics and economic activities of cities. Those activities include manufacturing of goods, supply goods from factories to retailers and spending of customers. Therefore the optimisation of city logistics could highly contribute to the development of cities. In addition, the scientific value of this research comes from the modeling part including model development and simulation. The concept of carbon credit and those mechanisms to deal with does not exist in the city logistics domain yet. Thus it will be relevant to find out the extended model can improve freight transportation on city logistics domain.

2.3 Methodology
In order to answer the research question, research methods to be used are both desk research and case study. First of all, it is necessary to explore what the mechanisms of Kyoto Protocol are and how they will be assessed. Literature reviews will find out the characteristics of the mechanisms presented in Kyoto Protocol and how are the mechanisms applied in the real world. A number of search engines such as Scopus, Google Scholar and ScienceDirect will be used. Search keywords to be used are “Kyoto protocol mechanism”, “carbon market logistics”, “carbon trading application” and etc. Then it is established the set of criteria that can be used to assess the most plausible mechanism for urban freight transportation in city logistics. The criteria are derived not only from literature review but also from the existing model, since the selected mechanisms will be implemented into the model itself.

As a phase of model development and simulation, a case study is followed. Generic city logistics ontology (GenCLOn), a multi-stakeholder ontology, should be analyzed in the beginning of the model development since the agent-based model (SMUrFS) is based on the ontology. The selected mechanisms are specified for the formulation of the model as an expansion of the existing one. There will be modification in agent behaviours and interactions, but types of agents and their objectives are based on the existing model. The outcomes of simulation will be discussed and then the validation of the expansion will be determined.

3. Literature review
3.1 Mechanisms derived from Kyoto Protocol
As mentioned earlier, parties under Kyoto Protocol must meet their targets to reduce greenhouse gas emissions and three market-based mechanisms are provided for an additional means of meeting these targets (United Nations, 2014); International Emission Trading (IET), Clean Development Mechanisms (CDM) and Joint Implementation (JI).

- International emission trading (IET) enables countries to sell not used emission units to those are over their targets.
- The Clean Development Mechanism (CDM) gives a country to reduce its emission when implementing an emission-reduction project in developing countries.
- The joint implementation (JI) allows a party to earn emission reduction units from an emission-reduction or emission removal project in another Party.

International emission trading, set out in Article 17 of the Kyoto Protocol, enables countries to sell not used emission units to those are over their targets. As a result, carbon is tracked and traded like a commodity which leads to emerge the newly concept called “Carbon market”. For Bayon (2012), the carbon market means “the buying and selling of emissions permits that have been either distributed by a regulatory body or generated by GHG emission reductions projects”. However, this idea is also known as “cap and trade” in the EU emissions trading system (European Commission, 2014). The Clean Development Mechanism (CDM) gives a country to reduce its emission when implementing an emission-reduction project in developing countries. The joint implementation (JI) allows a party to earn emission reduction units from an emission-reduction or emission removal project in another Party. These mechanisms not only encourage green investment but also help parties offer a cost-effective way for their emission targets.

Kyoto Protocol’s mechanisms have applied in various areas including supply chain, electronic, power plant and so on (Annax A). In particular, the application of transport and logistics is mostly found in researches dealing with the emission trading mechanism. This result contrasts with that of other mechanisms, CDM and JI. It seems possible that the
result is due to the fact that CDM and JI are engaged in implementing environmental projects between two “countries” but IET can be executed between two “parties” having cap.

3.2 Urban freight transportation
Optimization of urban freight transportation is the objective of the city logistics considering the nuisances associated to freight transportation. According to Crainic (2008), the aim of city logistics is “reducing and controlling the number, dimensions, and characteristics of freight vehicles operating within city limits, improving the efficiency of freight movements, and reducing the number of empty vehicle kilometers.”

STRAIGHTSOL, the EU-founded project about strategies and measures for smarter urban freight solutions, developed a framework to evaluate urban freight options (Milan et al., 2014). The framework is composed of key performance indicators, social cost-benefit analyses, business models and multi-actor multi-criteria analysis (MAMCA). Taniguchi & Tamagawa (2005) considered several stakeholders in the evaluation of city logistics measures. In the administrator perspective, especially, the criteria, total NOx emissions in the network and total number of complaints from the residents, are derived from the objectives, society with low environmental impact and society with high economic efficiency. In conclusion, researches have developed frameworks to assess urban freight transportation in different aspects such as traffic, environment, economic, social and so on.

4. Conceptualisation
4.1 Conceptualisation of SMUrFS model
Generic city logistics ontology (GenCLOn)
The term 'ontology' is defined by Studer et al. (1998) as “a formal, explicit specification of a shared conceptualization of a domain of interest”. Anand et al. (2012) developed ontology in city logistics domain called Generic city logistics ontology (GenCLOn) which the agent-based model (SMUrFS) is based on. GenCLOn represents multiple stakeholders (e.g. shipper, carriers, shops etc.) existing in the city logistics domain with their respective objectives, resources, KPIs and activities. GenCLOn allows the agents of the SMUrFS model to have a common knowledge and good communications.

City inhabitants are indicated as person agent who purchases goods from the shops. The person agent are engaged in whether to buy goods or not, how many to order and where. The factors to influence when the person agent chooses shop are the size of the shop, the profit margin of the shop and the on-shelf availability of the shop (the service level).
The decision of customer agent on whether to shop or not is based on Bernoulli distribution and how many units to buy is based on the Poisson distribution. The probability that customer-agent decides on which shop to purchase goods, based on multi-nominal logit (MNL) model, is shown in equation (1):

\[ P(\text{Shop } i) = \frac{e^{U_i}}{\sum_{i=1}^{n} e^{U_i}} \]  

The SMUrFS model assumes that customers would not change their shopping behaviours in response of the system’s condition such as increased nuisance or pollution. Instead, the administrator-agent would take into consideration the challenges under the environment of cities and implement policies to solve problems.
The shop agent is aimed to maximize its profit by controlling several factors as follows: shipper selection, maximum stock level, monthly demand of shop and minimum stock level in the setup phase; re-ordering point and ordering.
quantity in the simulation phase. The distance from the shop to the shipper is the criterion that selects the shipper. In terms of the monthly demand, the shop agent calculates the amount according to the area of the shop using the given total demand for the city in the beginning of the simulation; however, as soon as the simulation is started, the demand of each shop is calculated based on the quantity of the last three months. Carrier agent, hired by shipper agent, delivers goods to shops according to the order of shipper’s. There are two types of costs which result from the movement of carriers’ vehicles: (1) fixed costs such as depreciation of trucks and insurance; (2) variable costs which are dependent on the truck usage such as the average length of a tour, the average number of stops in a tour, the speed of the trucks and driver’s hourly wage. The carrier agents stop auctioning when the demand of shippers is more than the total capacity of trucks since the number of trucks of each carrier is limited. Administrator agent is also involved in the model. In the city, different policies, measures and regulations about urban freight transportation come into effect by municipality. Thus the administrator agent is represented as the municipality in the model. The aim of the municipality is mostly focused on reducing environmental impacts of city logistics such as the reduction of congestion and pollution. The municipality also sets performance criteria as the number of trucks entering into the city and the pollution level based on total truck-km travelled. Urban consolidation centre (UCC), owned by the municipality, provides another option to deliver goods to the shop agent. When the shop chooses UCC for delivery option, carrier is informed to deliver goods to UCC. Then UCC will collect orders and enter the city to the shop. The model assumes that UCC vehicles are smaller in size and runs on cleaner energy under the control of the municipality.

4.2 carbon credit points scenario
The goods delivery of the shop agent is divided into two types: through UCC and direct delivery by carrier. However the shop agent prefers to choose the delivery from carrier for the following reasons even if it requires more costs: First of all, delivery via UCC takes more time since goods are transshipped at the edge of the urban area. Also who is in charge of the goods delivery between UCC and carrier in case is not clearly specified. The model assumes that the vehicles of UCC are a more sustainable alternative than those of carriers’. From the perspective of the municipality, UCC could be a way to reduce nuisances of city logistics by reducing the number of carrier’s vehicles entering the city at the same time. The municipality will encourage shop agents to use UCC by assigning a permit that allows limited number of the direct delivery. Thus shop agents should pay extra money for their own delivery via carrier or use UCC when exceeds the limit. At the beginning of every month, shops are assigned a certain amount of CCP by the municipality. Shopkeepers can use CCP to let their own carriers deliver goods. If they consume all CCP, it can be purchased from the municipality. In addition to allocating, the municipality also sells, purchases and manages CCP. The current model offers shops the only way to earn extra CCP by means of purchasing it from the municipality.

According to the research conducted by Zaidi (2004), the market structure of the SMUrFS model could be seen as the Quote Driven market. The Quote Driven market consists of market makers (traders), as principals in transactions, and the clients, as buyers or sellers. The market makers provide a service and quote prices for bid, the price willing to buy for, and offer, the price willing to sell for. The article defined the Quote Driven market as a system of clearly defined market parameters and roles.

Regarding interactions within the system of carbon credit points scenario, the input is the demand (euros) that customer pay to buy products through shops and, on the other hand, the output is \( CO_2 \) emissions from generated trips. Within the system, agents interact each other by exchanging euros for their own objective. Firstly, the euros entered into the system are passed to shopkeepers. Shops pay for delivery to carrier or UCC as well as inventory costs. Also shops could not only buy extra CCP but also get a refund of unused CCP from the municipality. The authority has its own delivery means called UCC. The government gives subsidy to reduce the price of using UCC and receives its profits of UCC in return. Both delivery means (carrier and UCC) spend some costs for its operation, however the scenario assumed that only carrier emits \( CO_2 \) when operated. However the emissions could be also calculated as euros.

There are activities of stakeholders divided into monthly and daily basis. For the monthly activities, the municipality has messages by itself to set goal distance and assign CCP per shop. The goal distance is set only once in the beginning of the simulation. Then the shop agent decides the monthly demand. The price of UCC is set based on the price of subsidy from the municipality. The municipality also decides the extra CCP price. At the end of the month, the municipality evaluates the distance travelled by carriers during the month and increase/decrease subsidy. On the other hand, everyday the shop agent decides whether to place order and how much to order, and then calculates the price of using UCC. Then alternative interactions are shown whether CCP is available or not. The shop agent compares UCC price with either CCP refund price (when CCP is available) or extra CCP price (when CCP is not available) and decide the mean for delivery. Both cases choose the direct delivery from their own carrier when the price...
of UCC is higher. As noted by the loop combination fragment, the most of messages from the shops are decided daily basis.

Table 1 summarizes a list of stakeholders in the current carbon credit points scenario (Hilson & Simon, 2007). A list of stakeholder is shown in the leftmost column. The next two columns indicate objectives and parameters/variables for each stakeholder. Here, the objective of the system is considered the same as that of the municipality since the model is designed in the perspective of the municipality (Anand et al., 2010). The shaded stakeholders in the table – municipality, UCC and shop – have parameters or variables for the carbon credit scenarios. These stakeholders’ interests, power and attitude are highly related to the system as well.

Table 1. Stakeholder matrix

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Objectives</th>
<th>Parameters/variables</th>
<th>KPIs</th>
</tr>
</thead>
</table>
| Municipality | • Reduce emissions  
• Implement policies in low cost | • Number of CCP assigning each shop  
• Price of CCP  
• Price of refund CCP  
• Subsidy | • Traveled distance by carriers  
• Number of vehicles by carriers  
• Loading rate of carriers vehicles  
• Net profit/loss  
• Subsidy given |
| UCC | • Operate delivery without loss | • Price of using UCC | • Traveled distance by UCC  
• Number of vehicles by UCC  
• Loading rate of UCC vehicles |
| Shop | • Goods availability  
• Maximum profit | • Number of ordering units | • Extra costs |
| Carrier | • Maximum profit |  | • Traveled distance by carriers  
• Number of vehicles by carriers  
• Loading rate of carriers vehicles |
| Shipper |  | • Goods supply in low cost |  |
| Customers | • Low price  
• Goods availability |  |  |

4.3 Evaluation framework
The model will be evaluated by key performance indicators (KPIs). KPIs encourage the system how to make a strategic move having positive impacts on performance (Parmenter, 2010). This paper refers to the approach of KPIs assessment framework developed by STRAIGHTSOL (Balm & Quak, 2012). This framework expands from multi criteria analysis which consists of stakeholders and impact areas as well as KPIs. The following KPIs evaluate the system as different categories as explained below.

- Travelled distance [\text{km}]
  - Distance by UCC vehicles
  - Distance by carrier vehicles
- Net profit/loss of municipality [\text{Euro}]
- Extra costs for shop [\text{Euro}]

5. Specification
5.1 Specification of decision variables
The main actors, engaged in decision making process, involved in the carbon credit point scenario are considered to be: the municipality, UCC and the shops. Firstly, the municipality assigns a certain amount of delivery points ($D_p$) to each shop at the beginning of every month. Shopkeepers can use $D_p$ to let their own carriers deliver goods. The number of $D_p$ per shop is represented by the following formula:

$$D_p = \frac{A_s}{F_{Dp}} \quad \text{[number of delivery points]}$$

(2)

where, $A_s$ = Area of the shop [\text{m}^2] and $F_{Dp}$ = Freight trip generation factor
The initial value of $F_i$ is calculated as 20 since the model assumes that a delivery is made for every 20 m$^2$ of a shop. The municipality decides this factor at the end of every month by evaluating the distance traveled by carriers. If the carrier exceeds the goal distance set by municipality, $F_i$ will be increased by 1 in the reference scenario and thus $D_p$ will be reduced. The price of $P_{dp}$ is given by

$$P_{dp} = \text{Price/unit} \times Q_{\text{min}} \quad \text{[Euro]}$$  

where, $\text{Price/unit} = \text{Price of using UCC per good unit decided by the UCC agent [Euros]}$ and $Q_{\text{min}} = \text{Minimum shipment size}$

The shop will use UCC for delivery when the order quantity is below $Q_{\text{min}}$ since buying extra $D_p$ is worse off in that case. The initial value of $Q_{\text{min}}$ is to 80 in the base scenario. Similar to $D_p$, the value of $Q_{\text{min}}$ will be increased when the distance reduction goal fails to meet. However, the municipality only changes either $D_p$ or $Q_{\text{min}}$ in that case.

The municipality increases subsidy given to UCC by 2(euro) in the reference scenario when the distance by freight vehicles exceeds the goal value but decreases this when the goal distance is reached. The calculation of subsidy is followed by

$$S_t = S_{t-1} \times (1 + R_s) \quad \text{[Euro]} \quad t = 4, 5, ..., 10$$

where, $R_s = \text{Rate of changing subsidy [%]}$

The municipality will refund for unused $D_p$ at the end of every month. The cost is less than buying price, less than 2 euro than buying $D_p$ at this scenario. In the experiments, the refund price $P_{\text{refdp}}$ is calculated as

$$P_{\text{refdp}} = P_{dp} \times (1 - R_{dp}) \quad \text{[Euro]}$$

where, $R_{dp} = \text{Refund rate [%]}$

The net profit/loss of municipality is calculated as

$$P_m = \text{UCC profits} + D_p \text{ profits} \quad \text{[Euro]}$$

where, $\text{UCC profits} = \text{Profits from UCC operations [Euro]}$ and $D_p \text{ profits} = \text{Profits of selling extra }D_p \text{ [Euro]}$

The UCC agent charges the shop agent for using UCC as delivery means. First of all, the cost should take into consideration the working condition of both vehicles and drivers. These variables are represented as $R_a$ and $R_b$ by following formulas:

$$R_a = \frac{\text{Driver cost [Euro/hr]}}{\text{Speed [Euro/hr]}} + \frac{\text{Fuel cost [Euro/kwh]}}{\text{Fuel efficiency [km/kwh]}} \quad \text{[Euro]}$$

$$R_b = \text{Driver cost} \times \text{Service time per stop} \quad \text{[Euro]}$$

As seen the above, $R_{ca}$ is calculated by hourly salary of the driver, average speed of the truck, fuel cost and fuel efficiency and $R_{cb}$ is calculated with salary of the driver and average service time per stop. The model sets $R_{ca}$ as 0.5(euro) and $R_{cb}$ as 2(euro).

The running cost ($R$) of UCC is following as:

$$R = R_a T_i + R_b S_n \quad \text{[Euro]}$$

where, $T_i = \text{Average tour length [km]}$ and $S_n = \text{Average numbers of stops}$

The total cost per tour ($U_{\text{cost/tour}}$) is:

$$U_{\text{cost/tour}} = R + F \quad \text{[Euro]}$$
where, \( R \) = Total running cost [Euro] and \( F \) = Fixed costs which is set as 0.7(€) in the base scenario [Euro]

The average loading rate (\( LR_{avg} \)) is:

\[
LR_{avg} = \frac{\text{Monthly demand}}{\text{Number of tours} \times U_{veh\_cap}}
\]

where, \( LR_{avg} \) = Average loading rate and \( U_{veh\_cap} \) = UCC vehicle capacity
The capacity of carrier’s vehicles is assumed 3000 units and only 1500 units are equipped to UCC’s vehicles.

Thus, the cost of delivering a single unit (\( U_{cost/unit} \)) is calculated by:

\[
U_{cost/unit} = \frac{U_{cost/tour}}{LR_{avg} \times U_{veh\_cap}} \text{ [Euro]}
\]

This cost will be provided to the shop when using UCC.

However, the price could differentiate when the municipality provides subsidy to prevent the loss for UCC. In this case, the price of using UCC (\( U_{price/unit} \)) is calculated as:

\[
U_{price/tour} = U_{cost/unit} \times (1 - S_s) \text{ [Euro]}
\]

Lastly, the shop agent controls two factors in the simulation phase as follows: re-ordering point (ROP) and ordering quantity (OQ).
The formula of re-ordering point is:

\[
ROP = (\text{Average daily demand} \times \text{Lead time in days}) + \text{Safety stock}
\]

Also the shop agent looks for so-called economic ordering quantity (EOQ) level to optimise the total cost. The economic ordering quantity is estimated using the following formula:

\[
Q^* = \sqrt{\frac{2OD}{I}}
\]

where, \( Q^* \) = Order quantity, \( O \) = Ordering costs per order [Euro], \( D \) = Demand per month and \( I \) = Inventory costs per item per month [Euro]

The shop-agent decides everyday whether to place an order or not. When they need delivery, the price of using UCC (\( U_{price} \)) will be calculated as following:

\[
U_{price} = U_{price/unit} \times Q_s \text{ [Euro]}
\]

where, \( Q_s \) = Number of ordering units
Then the shop checks whether available \( D_p \) is enough and then have two different responses: (1) get the refund price of \( D_p \) and compare with \( U_{price} \) when \( D_p \) is available; (2) get the price of \( D_p \) and compare with \( U_{price} \) when \( D_p \) is not available. The decision of choosing delivery option is entirely dependent on the price. In other words, delivery is done by UCC when the price of using UCC is cheaper for both cases. Otherwise the shop agent will order goods via carriers even if extra cost is needed to buy \( D_p \).

The formula (19) indicates the total cost:

\[
\text{Extra Costs} = \text{Extra}D_p + \text{UCCusage}
\]

where, \( \text{Extra}D_p \) = Total costs that bought extra \( D_p \) [Euro] and \( \text{UCCusage} \) = Total UCC usage costs [Euro]
Overall, the decision variables by the municipality and UCC (mechanisms) work to achieve the goal distance travelled by the vehicles (control) based on the demand of the shop agents (input). The end results of the system would be travelled distance and total subsidy given to UCC (outcome).

![Figure 2. Overview of the system](image)

**6. Verification and Validation**

6.1 Model setup

The model named SMUrFS, used in the research, is developed by Anand et al. (2012) using Repast Simphony platform in the form of Java language. Repast Simphony is software that provides to build an agent-based model with large-scale agent environments (Macal & North, 2009). The tool allows to develop specific logical structure of the model, the type of agents, the behaviours of the agents and the interactions between them. Many researches develop agent-based models using Repast Simphony including supply chains (Repast, 2013).

The model consists of 100 shop-agents, 10 shipper-agents and 7 carrier-agents. The parameters used in the model – units per m² area, price per goods-unit and average total demand per month – is sourced from the website of ‘Hoofdbedrijfschap Detailhandel’ (http://www.hdb.nl/). This website provides information about retail trends for different product types in which employers’ and workers’ organisations in the retail collaborate.

Geographic information system (GIS) projections, which simulate different agents and road network, have used in the model with the data of Rotterdam city in the Netherlands. Shapefile is a geospatial vector data format that represents geographical information for GIS software. Shapefiles have various information about road, shop, supplier, carrier and vehicles. The model considers 30 days as one month and up to 300 days can be simulated. The model used the road network of Rotterdam city which is provided by the municipality of Rotterdam and TNO.

The SMUrFS model applied GIS projections to simulate different agents and road network of the city of Rotterdam. The shops are located with postcode 3012 and 3014. UCC is located at the edge of the city center, where 3km as tour lengths and 3 as average no of stops for the tour. The running cost of UCC is calibrated as 2 euro per km for average tour of 7 km with 3 stops.

6.2 Number of replications

The experiment of the model should be done several times for its reliability. For example, the demand, the number of units bought by customer, is based on the Poisson distribution (Anand, 2012), which leads to random number generation. According to van Soest (1992), the desired number of replications relies on values in the base scenario. The formulation of the desired number of replication is:

\[
\text{n of replications} = \text{n of repl. test run} \times \frac{\text{half width confidence interval}}{\left(\text{highest value} \times 0.05\right)}
\]

The current model, not applied any alternative, is used for test run. The test run has replicated for nine times, with the average highest distance of 1156.44km and the half width confidence interval of 16km.

\[
\text{n of replications} = 9 \times \frac{16}{\left(1156.44 \times 0.05\right)} = 4.98
\]

The desired number of replications is five times as calculated the above.
6.3 Sensitivity analysis

Prior to alternative generation, the degree of variability for parameters is firstly examined. The sensitivity analysis discovers how much the outcome of the model is affected by changing values of the parameters.

As shown in the previous chapter, the decision variables, which could affect the outcome of the system, are the minimum shipment size \(Q_{\text{min}}\), the price of \(D_1\) \(P_{D_1}\), the refund price of \(D_1\) \(P_{F_1}\), the refund rate of \(D_1\) \(R_{F_1}\), the number of \(D_1\), the freight trip generation factor \(F_{D_1}\), subsidy \(S\), the subsidy rate \(R\) and the price of using UCC \(U_{\text{price/unit}}\).

However, the minimum shipment size \(Q_{\text{min}}\) and the freight trip generation factor \(F_{D_1}\) are fixed value due to the physical limitation. Also the price of \(D_1\) \(P_{D_1}\) and the price of using UCC \(U_{\text{price/unit}}\) are dependent on how much subsidy \(S\) is given to UCC. Thus alternatives are constructed by controlling only these parameters – the number of \(D_1\), the refund rate of \(D_1\) \(R_{F_1}\) and subsidy \(S\) – and those are examined in the sensitivity analysis. Followed the replication number in the previous paragraph, each test iterated by 5 times. The compared value is how much the distance goal is met, based on 10% reduction in the reference scenario.

The table below summarises the outcomes of the sensitivity analysis for variables. The number in the table indicates the reduction of travelled distance (%) between the beginning of three months and UCC usage periods. From the data, it can be seen that the most influential parameter is the refund rate \(R_{F_1}\) and, on the other hand, the number of \(D_1\) is the least affected to the outcome. Besides the travelled distance, more KPIs are evaluated after experiments.

### Table 2. Results of sensitivity analysis

<table>
<thead>
<tr>
<th>Reduced travelled distance [%]</th>
<th>Subsidy=0</th>
<th>Subsidy=50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration 1</td>
<td>7.21</td>
<td>7.62</td>
</tr>
<tr>
<td>Iteration 2</td>
<td>9.62</td>
<td>12.42</td>
</tr>
<tr>
<td>Iteration 3</td>
<td>12.56</td>
<td>12.41</td>
</tr>
<tr>
<td>Iteration 4</td>
<td>12.67</td>
<td>11.16</td>
</tr>
<tr>
<td>Iteration 5</td>
<td>7.75</td>
<td>12.27</td>
</tr>
<tr>
<td>Average</td>
<td>9.96</td>
<td>11.18</td>
</tr>
<tr>
<td>Stdev(^1)</td>
<td>2.58</td>
<td>2.05</td>
</tr>
<tr>
<td>Difference</td>
<td>1.12</td>
<td>5.86</td>
</tr>
</tbody>
</table>

7. Experimentation

7.1 Alternative generation

In this paragraph, policy alternatives are constructed by a morphological chart. As shown in the previous chapter, the parameters to affect to the outcome are the refund rate of \(D_1\) and subsidy and those parameters would take into consideration to generate alternatives. In Table 3, the leftmost column shows the functions/variables that mentioned previously. The means for each variable are identified and listed in the corresponding row.

### Table 3. Morphological chart

<table>
<thead>
<tr>
<th>Refund rate of (D_1)</th>
<th>Mean feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Full price</td>
<td>75%</td>
</tr>
<tr>
<td>0</td>
<td>20%</td>
</tr>
</tbody>
</table>

The ratio of subsidy rate indicates:

\[
Ratio = \frac{\text{Travelled distance} - \text{Goal distance}}{\text{Goal distance}}
\]  

By the combination of the design space, the number of design alternatives is \(5 \times 3 = 15\). In other words, each alternative is executed by five times (explained in the previous chapter) and thus the number of total run is \(15 \times 5 = 75\) times.

\(^1\) Standard deviation
7.2 Evaluation

**Travelled distance by vehicles**

The direct delivery by carrier vehicles has serious impact on emissions, which is the main concern of the municipality. The evaluation of travelled distance by carriers is examined by how much distance goal is met, shown in 8th column, after UCC usage (4th to 10th months) compared to beforehand (1st to 3rd months). The result of the reference scenario is shown in the bottom.

From the result in Table 4, it is found that (1) the travelled distance by carrier vehicles are more likely to be reduced when the refund rate of \(D_p\) is 100% as shown in the first, second and third alternatives; (2) the standard deviation of distance from the first to third months are higher than that of the 4th to 10th month. It can be assumed that UCC makes the system more stable.

The difference of distance among alternatives is maximum 60km which is rather considerable regarding the model is limited in the certain area. Also all policies show significant reduction of travelled distance rather than the reference scenario that carriers travelled 1036.82km.

### Table 4. Travelled distance by vehicles

<table>
<thead>
<tr>
<th>Policy No.</th>
<th>Refund rate (%)</th>
<th>Subsidy rate (%)</th>
<th>1-3 months</th>
<th>4-10 months</th>
<th>Reduced distance (%)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average (km)</td>
<td>Stddev (km)</td>
<td>Average (km)</td>
<td>Stddev (km)</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>0</td>
<td>1077.67</td>
<td>48.61</td>
<td>933.91</td>
<td>12.41</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>1057.13</td>
<td>61.00</td>
<td>936.66</td>
<td>17.99</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>Ratio</td>
<td>1069.40</td>
<td>88.03</td>
<td>945.54</td>
<td>14.62</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>0</td>
<td>1068.53</td>
<td>69.06</td>
<td>952.60</td>
<td>23.75</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>20</td>
<td>1043.47</td>
<td>37.83</td>
<td>957.14</td>
<td>26.90</td>
</tr>
<tr>
<td>6</td>
<td>75</td>
<td>Ratio</td>
<td>1045.40</td>
<td>58.66</td>
<td>946.66</td>
<td>14.19</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>0</td>
<td>1016.40</td>
<td>45.96</td>
<td>948.57</td>
<td>15.05</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>20</td>
<td>1041.00</td>
<td>58.43</td>
<td>947.74</td>
<td>12.47</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>Ratio</td>
<td>1056.87</td>
<td>80.45</td>
<td>953.94</td>
<td>22.92</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>0</td>
<td>1046.60</td>
<td>92.96</td>
<td>937.63</td>
<td>10.19</td>
</tr>
<tr>
<td>11</td>
<td>25</td>
<td>20</td>
<td>1049.27</td>
<td>77.19</td>
<td>955.86</td>
<td>25.16</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>Ratio</td>
<td>1030.87</td>
<td>94.58</td>
<td>931.91</td>
<td>9.77</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
<td>1054.33</td>
<td>74.81</td>
<td>951.20</td>
<td>17.90</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>20</td>
<td>1047.07</td>
<td>107.92</td>
<td>957.11</td>
<td>25.50</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>Ratio</td>
<td>1052.67</td>
<td>62.43</td>
<td>948.74</td>
<td>12.67</td>
</tr>
<tr>
<td>Reference scenario</td>
<td></td>
<td></td>
<td>Average</td>
<td>1036.82</td>
<td>Stddev</td>
<td>54.77</td>
</tr>
</tbody>
</table>

#### Net profit/loss of municipality

To implement policies in low costs, the municipality needs to evaluate net profit/loss as one of the objectives. Table 5 presents the results obtained from the simulation. It is noted that the value of standard deviation is pretty high, where some of them are higher than the average itself.

The result shows that the municipality yields profits in most alternatives except for the first three policies. A negative correlation is found between the net profit/loss of municipality and the reduced travelled distance by carrier vehicles. That is to say that the municipality reduced travelled distance by carrier vehicles the most but it also imply the highest costs.

As observed in the first, second and third alternatives, 100% of the refund rate leads to high loss to the municipality. In other words, the refund price of \(D_p\) has highly impacts on the financial status of the municipality since shops prefer to get refund \(D_p\) rather than use it. Also, in general, high profits tend to come when the subsidy rate is 0.

### Table 5. Net profit/loss of municipality

| Policy No. | Refund rate (%) | Subsidy rate (%) | Average (Euro) | Stddev (Euro) | Rank |
Extra costs for shops

The KPI of shops is how much the extra costs spent, which include the costs for using UCC and buying extra $D_p$. Each shop tends to spend average around 13 euros to 17 euros every month in any policy. The result is quite creditable since the standard deviation is not that high (around 1 euro to 3 euros). The shop who spent the most is 17.20 euros of the tenth policy and the opposite is the fifth policy which spent only 13.38 euros on average.

From the outcome of the simulation (see Table 6), it is more likely to incur higher costs for shop when the refund rate is high, which is shown in the first to third policy. Also shops show a tendency to spend more money when the subsidy rate is zero. However this KPI does not have any correlation with any other KPIs since it is the only factor that affects shops.

Table 6. Extra costs for shops

<table>
<thead>
<tr>
<th>Policy No.</th>
<th>Refund rate (%)</th>
<th>Subsidy rate (%)</th>
<th>Average (Euro)</th>
<th>Stdev</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>0</td>
<td>-16.28</td>
<td>2.62</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>20</td>
<td>-16.45</td>
<td>2.86</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>Ratio</td>
<td>-15.59</td>
<td>3.60</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>0</td>
<td>-15.52</td>
<td>1.72</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>20</td>
<td>-13.38</td>
<td>1.22</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>75</td>
<td>Ratio</td>
<td>-14.91</td>
<td>2.24</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>0</td>
<td>-15.75</td>
<td>2.26</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>20</td>
<td>-13.56</td>
<td>1.41</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>Ratio</td>
<td>-14.54</td>
<td>1.38</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>0</td>
<td>-17.20</td>
<td>3.75</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>25</td>
<td>20</td>
<td>-14.63</td>
<td>1.11</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>Ratio</td>
<td>-14.49</td>
<td>2.04</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
<td>-15.40</td>
<td>1.85</td>
<td>8</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>20</td>
<td>-15.54</td>
<td>2.91</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>Ratio</td>
<td>-14.95</td>
<td>1.61</td>
<td>7</td>
</tr>
</tbody>
</table>

Multi criteria analysis

Overall each stakeholder has its best policy as seen above. However in order to select a preferred alternative taking into consideration different perspectives, a multi criteria analysis (MCA) was conducted.

All of 15 alternatives are evaluated by a set of criteria: (1) travelled distance of carrier vehicles; (2) net profit/loss of municipality; (3) extra costs of shops (It is noted that two of three criteria are economic-related). Other criteria, loading rate and subsidy, which are used in the previous paragraph are not considered in the MCA since those do not have big impacts on the output of the system.

The MCA was carried out in three different perspectives: system, environment and economy. The last three columns in Table 7 show the result of the analysis. For different perspectives, the weight factors of criteria range from 0 to 1 and the sum of criteria is 1 at all times. In the first column, the system considers that both environmental and economy perspectives have the same influence. Thus the weight on travelled distance is 0.5 and net profit/loss of municipality and extra costs for shops are weighted 0.25 each (e.g. the first policy is calculated as 1*0.5+15*0.25+13*0.25). In this way the sum of weights is 1 and the proportion of both perspectives are the same weighted as 0.5.

For the environmental perspective, the weight on the travelled distance is 0.75 and the rests are 0.125 (e.g. the first policy is calculated as 1*0.75+15*0.125+13*0.125). In other words, this perspective regards that environmental criteria is 3 times more important than those of economic.
Lastly, the economic perspective gives 0.375 weights to the economic related criteria (net profit/loss of the municipality and extra costs for shops) and the travelled distance has 0.25 of weight (e.g. the first policy is calculated as 1*0.25+15*0.375+13*0.375). The table below only indicates ranks.

Analysing the different perspectives, the fourth and sixth policy are the most attractive options from the economic perspective and, on the other hand, the first alternative is regarded as the best when the importance of environment is stressed. However the most desirable policy would be the fourth alternative since it has the highest rank on the system’s perspective. Additionally it also achieves high ranks in the economic weighed perspective and the environmental aspect (first and third respectively). The detailed scenario of the fourth alternative is shown in the next chapter.

### Table 7. Multi criteria analysis

<table>
<thead>
<tr>
<th>Policy No.</th>
<th>Distance of carrier</th>
<th>Net profit/loss</th>
<th>Extra costs</th>
<th>System</th>
<th>Environmental-weighted</th>
<th>Economic-weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>15</td>
<td>13</td>
<td>7</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>13</td>
<td>11</td>
<td>4</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>12</td>
<td>1</td>
<td>13</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>1</td>
<td>12</td>
<td>15</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>11</td>
<td>2</td>
<td>11</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>10</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>2</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>13</td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

8. The most desirable alternative – the fourth policy

8.1 Reduction of travelled distance and internalized costs of CO2 emissions

As shown in the below, both the travelled distance by carrier vehicles decreased as UCC started its operation. From 4th month, UCC vehicles increase the delivery on the contrary to the carrier vehicles.

![Figure 3. Travelled distance of the fourth policy](image)

The reduced travelled distance of carrier vehicles brings a cost reduction of CO2 emissions. According to guideline published by CEFIC (The European Chemical Industry Council, 2011), CO2 emissions can be estimated using the following formula:

\[
CO_2 \text{ emissions} = \text{volume} \times \text{distance} \times CO2 \text{ emission factor} \quad [\text{gram}]
\]  

(21)

Where,

- Transport volume = Transport volume by transport mode [Tonnes]
- Distance = Average transport distance by transport mode [km]
CO₂ emission factor = Average CO₂-emission factor per tonne-km by transport mode \([g \text{ CO}_2 \text{ per tonne} - \text{km}]\). The average loading rate, 0.3, should take into consideration despite of the fact that the capacity of carrier vehicles is 5 tonne (Anand et al., 2012). From Table 4, the reduced distance is 1068.53 – 952.6 = 115.93 km. The CO₂ emission factor is 550 g CO₂ per tonne – km based on the actual load tonne which is 1.5 tonnes (McKinnon & Piecyk, 2010).

The amount of CO₂ emissions from the average reduced distance of the 1st alternative are:

\[
CO_2 \text{emissions} = 5 \times 115.93 \times 550 = 318,808 \text{ gram}
\]  

(22)

According to the formula (25), the reduced CO₂ emissions are 318808 gram which is 0.318808 tonne every month. UCC operates from 4 to 10 month, the total reduced CO₂ emissions are 0.318808*7 = 2.23 tonnes during the simulation phase. EU ETS sets the carbon price between 6.22 euros and 6.4 euros a metric ton (Vitelli, 2013). Thus the first policy alternative can save around 2.23 * 6.31 = 14.07 euros in total.

8.3 Robustness of the policy

This paragraph examines the robustness of the policy in two experiments by comparing a set of KPIs with those of the reference scenario. How much KPIs differ between a new experiment and the reference scenario decides the degree of robustness of the model.

**Changes in delivery frequency: 3 days order**

In the current model shops decide to place an order everyday, and carriers or UCC operate their service according to the demand. The first robustness test is the difference in delivery frequency, where shops make a decision about delivery every three days.

Table 8 summarises KPIs comparison of two experiments. The travelled distance has not reduced significantly in delivery every 3 days as seen in the above. The biggest difference between two outcomes is shown as net profit/loss of the municipality, which is calculated with the sum of extra \(D_p\) profits and UCC profits. The extra costs for shops do not show a big difference in both experiments. The result shows that this change is better off for municipality from the economic perspective but this does not show the robustness of the model since two KPIs have very different results.

<table>
<thead>
<tr>
<th>Reduction of distance (%)</th>
<th>Net profit/loss of municipality (Euro)</th>
<th>Shop extra costs (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Stdev</td>
</tr>
<tr>
<td>Reference</td>
<td>12.17</td>
<td>328.34</td>
</tr>
<tr>
<td>3days</td>
<td>3.46</td>
<td>1130.94</td>
</tr>
</tbody>
</table>

**Changes in the number of shops: 50 shops**

The second experiment has the aim to cut the number of shops to half in which current model has 100 shops in the area. Thus the total demand and the total area of shops also reduced to the half. The KPIs of the second experiment to test robustness is shown in Table 9 with those of the reference scenario. The travelled distance by carrier vehicles is reduced 11.6% compared pre- and post- UCC service. There is a notable contrast between two experiments for net profit/loss of municipality, the sum of extra \(D_p\) profits and UCC profits, and shop extra costs, used for delivery. This suggests that shops tend to buy more \(D_p\), as seen in shop extra costs to let their own carriers transport the freight. In conclusion, this experiment does not prove the robustness of this change in the model regarding net profit/loss of municipality and shop extra costs.

Table 9. KPIs comparison of the second robustness test

<table>
<thead>
<tr>
<th>Reduction of distance (%)</th>
<th>Net profit/loss of municipality (Euro)</th>
<th>Shop extra costs (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Stdev</td>
</tr>
<tr>
<td>Reference</td>
<td>12.17</td>
<td>328.34</td>
</tr>
<tr>
<td>3days</td>
<td>11.6</td>
<td>917.94</td>
</tr>
</tbody>
</table>
9. Conclusion
The research is aimed to show whether mechanisms derived from Kyoto Protocol dealt with carbon credit points improve freight transportation based on city logistics domain by extending the agent-based model (SMUrFS).

The outcome of the simulation indicates that freight transportation could be improved by carbon market mechanisms. The emission trading between the shop agents and the municipality has implemented in the model, and decision variables of stakeholders have changed to optimize the city logistics. First of all, how much the shops can get a refund for unused carbon credit points is considered as a key parameter for shops since they behave to maximize their profits. Also, subsidy given to UCC has an important role in shops behaviours where the price of using UCC is decided based on subsidy. In other words, shops are more likely to choose UCC for delivery when the price of using UCC is cheaper than buying extra delivery points.

The simulation has revealed that the most desirable policy would provide 75% refund for unused points while subsidy was remained unchanged on the simulation period. In this case, the travelled distance of carrier vehicles is reduced 12.17% from 1068.53 km to 952.6 km, and UCC vehicles travelled average 116.55 km a month. The loading rate of carrier vehicles is changed from 38% to 29% and that of UCC vehicles is 21%. Both the travelled distance and the loading rate reduced as UCC service starts. Also the municipality would earn 328.34 euros to implement the policy including 30 euros spending as subsidy. Shops would spend 15.52 euros for using UCC or buying extra carbon credit points. In terms of CO$_2$ emissions, the policy would save 395,340 gram of CO$_2$ every month and total 2.37 tonnes for the simulation period that will lead to a reduction of 14.95 euros in total.
Reference:

- **Journal**

- **Book**

- **Website**