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MODELING AND MULTI-AGENT SIMULATION OF CO_2MANAGEMENT IN AN URBAN CENTER

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ABSTRACT

In this article, a multi-agent based simulator has been designed for the predictive simulation of carbone dioxide (CO_2) which is one of the principal greenhouse gases. The investigations have been conducted on the emissions and absorptions of CO_2, from the main sources at the level of an urban center for sustainable development. All emitting and absorbing objects are considered as agents which are communicating with each other through messages. The designed architecture has been implemented in order to simulate the quantitative evolution of the concerned gas on different emission and absorption configurations. The multi-agent architecture presented is composed of agents from different horizons. The behavior of each agent depends on its mode of use or existence.

Keywords: modeling, simulation, multi-agent system, greenhouse gas, sustainable development.

INTRODUCTION

The importance of multi-agent technology is well established. It is used in various fields such as financial systems, entertainment, telecommunications, control-command, embedded systems, and many others [1-10]. Another important issue is climate change which has been the subject of many resolutions at the global level. However, to achieve the climate change goals for sustainable development, the reduction or control of CO_2 emissions is a path of choice, as it is the main greenhouse gas [11]. Thus, a change of paradigm in the production of CO_2 is needed and is reflected in the need of innovations such as the development of technological tools to simulate the quantitative evolution of its emissions.

Population growth and the ever-increasing urbanization of cities create a strong demand for human activities that are permanently in quest of energy, and this creates problems of air pollution. Hence, studying the anthropogenic impact on the urban environment is necessary [12]. To evaluate the human impact on the environment, calculating and controlling the atmospheric pollution due to CO_2 has become a crucial challenge for researchers in order to reduce the level of environmental pollution. It is therefore necessary to develop tools that are capable of producing predictive information on human's anthropic activities, and their economical, ecological and social consequences. Thus, we propose a multi-agent model for the mechanism of production and consumption of the main greenhouse gas namely carbone dioxide.

CONTEXT OF CO_2 EMISSION AND ABSORPTION IN URBAN AREAS

Modern cities are constantly experiencing accelerated urbanization and a rapid population growth. Added to this phenomenon is the one of a rapid industrialization in many sectors such as production, energy, and so on. These phenomena rise a number of problems among which the one of CO_2 emissions and their consequences on health and climate. In fact, studies have shown that urban areas occupy at least 3% of the world's surface. Estimated at more than half of the world's population in 2011, the city's population is expected to reach nearly 67% by 2050 [13].

The main sources of CO_2 emission

Inventorying all sources of CO_2 emissions is a difficult task. In this work, we only consider the most important sources of emissions. From the existing literature, we have identified two groups of emissions namely the ones related to energy production and the ones related to burning or incineration of waste. In fact, emissions from energy production are mainly due to the burning of fossil fuels. For an urban center, depending on the nature of the combustion and the source, these emissions can be classified into five categories: emissions from mobile engines, stationary engines, air flights, households and waste. The emissions generated by mobile engines are those of road and off-road transport, railways, navy and other transport equipments. They are estimated by the following formula [14]:

$$\text{Emission}_{\text{ME}} = (\rho.\text{v}.10^{-6}.\text{PCI}.\text{FE}_{\text{a}}) + \left(\text{Activity}.\frac{12}{60}.\text{Purity}.\frac{44}{12}.10^{6}\right) \quad (1)$$

where

- Emission $_{ME}$ is the quantity of CO_2 released by a mobile engine (kg);
- ρ represents the density of the burned fuel (kg / m^3);
- v is the volume of fuel burned (m^3);
- PCI is the net calorific value of the burned fuel (TJ / Gg);
- FE_a is the emission factor (kg / TJ) and a represents the type of fuel;
- Activity is the quantity of urea additives consumed in catalytic converters (Gg);
- Purity is the mass fraction of urea in urea additives.

Emissions from stationary engines are due to intentional oxidation of materials [14]. Stationary engines are found in energy production industries and manufacturing industries. They are also found in the

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commercial, institutional, residential, and other sectors. The CO_2 emission of a stationary engine is evaluated through the following formula [14]:

$$\text{Emissions}_{SE} = \rho . v . 10^{-6} . \text{PCI} . \text{FE}_a \quad (2)$$

Air flight emissions are broken down into two groups: cruise phase emissions and Landing Take-Off (LTO) emissions. The cruise phase emissions are those that correspond to the duration of the flight while the LTO emissions are those from the landing and take-off phases including the plane ground operations to a height of 3000 feet (915 m) [15]. At a city level, air flight emissions are limited to those associated with landing and take-off (LTO) phases that can be evaluated as follows [14]:

$$\text{Emissions}_{LTO} = \rho . v . 10^{-6} . \text{PCI} . \text{FE}_a \quad (3)$$

where the parameters ρ, v, PCI and FE_a are all calculated in the LTO phase.

For the production of fire in households, restaurants, etc., the use of fire wood, coal, kerosene, butane gas, and others are sources of CO_2 emissions. These issues are based on the following formula [14]:

$$\text{Emissions}_{H} = \text{QC}_{burned} . \text{PCI} . \text{FE}_a \quad (4)$$

where QC_{burned} is the quantity of burned object (Gg)

Like other forms of combustion, incineration and open burning of waste are sources of CO_2 emissions. There are several types of waste, each of which is characterized by its degree of combustion. There are two categories of waste: solids and liquids. For solid waste, emissions are estimated according to the following formula [16]:

$$\text{Emissions}_{SW} = \text{DSM} . \sum_j (\text{WF}_j . \text{dm}_j . \text{CF}_j . \text{FCF}_j . \text{OF}_j . \frac{44}{12}) \quad (5)$$

where

- $Emissions_{sw}$ represents the CO_2 emissions in the inventory year (Gg / year);
- DSM is the total volume of municipal solid waste (wet weight) burned in the open air, (Gg / year);
- WF_j is the type / waste fraction of component j in DSM (wet weight) burned in the open air;
- dm_j is the dry matter content of the component j in DSM or burned in the open air;
- CF_j is the carbon fraction in the dry matter of component j;
- FCF_j is the fraction of fossil carbon in the total carbon content of component j;
- OF_j is the oxidation factor.

For liquid wastes, which are industrial and municipal residues based on mineral oils, natural gas or other fossil fuels, emissions are evaluated according to the following formula [16]:

$$\text{Emissions}_{LW} = \sum_i (\text{AL}_i . \text{CL}_i . \text{OF}_i) . \frac{44}{12} \quad (6)$$

where

- $AL_i$is the incinerated volume of type i liquid fossil waste (Gg);
- $CL_i$is the carbon content of type i liquid fossil waste;
- $OF_i$is the oxidation factor for type i liquid fossil waste.

The main sources of CO_2 absorption

Like emission sources, inventorying all sources of CO_2 absorption is a difficult task. However, the main sources of CO_2 absorption are trees. Indeed, various studies have shown the potential for CO_2 sequestration by trees in urban areas [17-27]. Present throughout the city, trees contribute significantly to the reduction of CO_2. Through their leaves, branches and roots, they constitute an important reservoir of CO_2. They are found on streets, homes and gardens. Each type of tree has a favorable period for its growth leading to an optimal CO_2 sequestration. For example, the Canadian Tree Foundation estimates the quantity of sequestrated carbon per tree over a period of 80 years at 200 - 225 kg, which is 2.5 to 2.8 kg per year [17]. For absorptions, trees are the main terrestrial reservoirs of carbon likely to behave as a well or a source [18]. The storage of carbon dioxide in an urban tree depends on several parameters including, among others, species, size, trunk diameter, edaphic conditions and climatic conditions [19]. In general, the species that sequestrate more CO_2 are big and of long life and growth expectations [20]. The absorption of CO_2 by photosynthesis is therefore an alternative to partially compensate the carbon emissions in urban areas [21]. Three groups of the biomass are concerned: trees, shrubs and herbaceous plants. The following formula (7) makes it possible to estimate the absorption of CO_2 taking into account the changes in carbon stocks of the biomass [27]:

$$\text{Absorption}_{T} = \frac{44}{12} . \sum_{ij} \text{NA}_{i,j} . \text{C}_{i,j} \quad (7)$$

where

- $NA_{ij}$is the number of trees of category i and type j;
- $C_{ij}$is the average annual accumulation of carbon per tree of category i and type j.

A MULTI-AGENT MODEL FOR CO_2 MANAGEMENT

The analysis of the context of changes in the quantity of CO_2 reveals two main mechanisms that interact with each other, namely emissions and absorptions. Emissions are those emitted by sources likely to emit a significant quantity and absorptions are those of sources that can absorb a significant quantity of CO_2. Figure-1 illustrates the factors surrounding the interaction between the emitting and the absorbing sources in order to compute the quantity of CO_2 at a given time.

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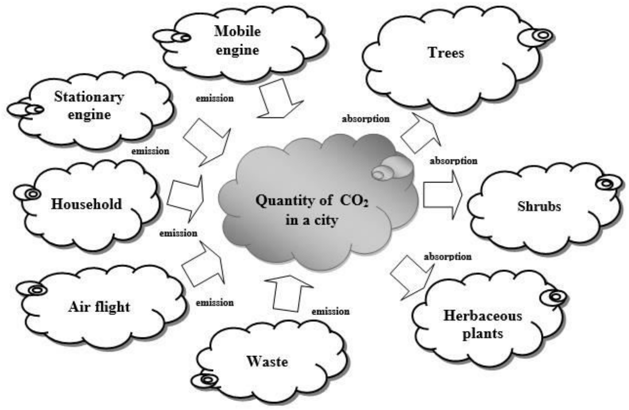

Figure-1. Background diagram of CO_2 emissions and absorptions in cities.

For the design of the multi-agent simulator called "SMAGCO", two categories of agents are used say, temporary and permanent. However, all the agents interact with a special permanent agent of the platform called MIS (Main Interface SMAGCO). This agent is the main coordinator but also the central node of the platform. It communicates with all other permanent agents and users of the system. All temporary agents are emitters or absorbers. Emitters are of six types:

- Mobile Engine Agent (MEA): road and off-road transport, railway, navy and other mobile transport equipments;
- Stationary Engine Agent (SEA): energy production from stationary sources such as power plants, generators, etc.;
- Air Transport Agent (ATA): flights of aircrafts;
- Household Agent (HA): any device that can produce fire at the level of households, restaurants, etc.;
- Solid Waste Agent (SWA): CO_2 emitting agents during incineration or open burning of solid waste;
- Liquid Waste Agent (LWA): CO_2 emitting agents during incineration or open burning of liquid waste.

These agents, whose structure is illustrated in Figure-2, emit CO_2 when they are in operation. Their internal structure is described as a three-component entity: start-up control, operation, and combustion. The start-up control module allows the agent to receive power on or off while the operation module ensures the operation of the agent and the combustion module represents the action performed by the agent. It is also necessary to note the refueling sub-module which controls the fuel level of the agent.

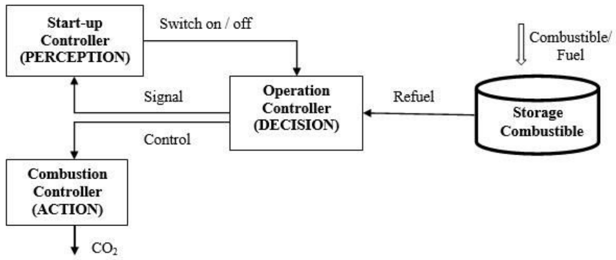

Figure-2. Internal structure of an emitting agent.

The absorbers are represented by a single type of agent, Absorber Agent (AA). The structure of these agents is illustrated in Figure-3. Consisting mainly of trees, shrubs and herbaceous plants, they depend on CO_2 to survive through the phenomenon of photosynthesis. For their survival, they also need resources such as water, air, and heat.

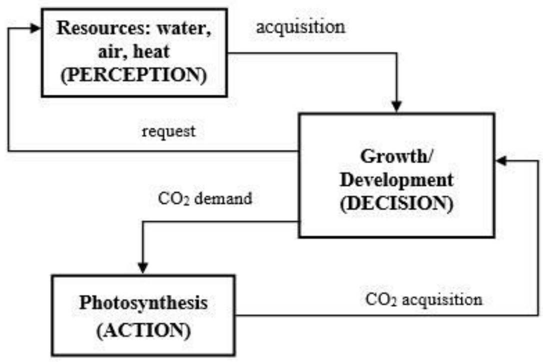

Figure-3. Internal structure of an absorber agent.

There are three types of permanent agents: management agents, analysis and processing agents, and authentication and access agents. Four permanent agents are responsible for the management of temporary agents as follows:

- Creator Agent (CA): responsible for the creation and deletion of temporary agents;
- Agent manager (AMA): responsible for the management of the activities of all agents;
- Controller Agent (CTRA): responsible for the control and reception of emissions and absorptions of temporary agents;
- Configurator Agent (CONFA): responsible for the configuration of temporary agents.

For the analysis and processing, there are four agents:

- Interpreter Agent (IA): responsible for interpreting emissions and absorptions of the gas at a given time;
- Printer Agent (PRINTA): responsible for printing the statistics as well as the numerical and graphical results of the simulation;

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- Questionnaire Agent (QA): responsible for receiving the parameters and translating them into a request for processing;
- Connector Agent (CNTA): responsible for receiving and processing the request using the database object.

The authentication and access agents control and allow access to the platform. There are four of them involved in this mechanism:

- Login Agent (LOGA): responsible for authenticating the user in the platform;
- Session manager Agent (SEMA): responsible for changing the sessions of the users of the platform;
- Terminator Agent (TERMA): responsible for closing the platform;
- Administrator Agent (ADMINA): responsible for registering and managing the users of the platform.

For the implementation of the simulator, the functional architecture of Figure-4 is used. The agents described above are deployed to exchange messages in order to estimate the quantity of CO_2 at a given moment.

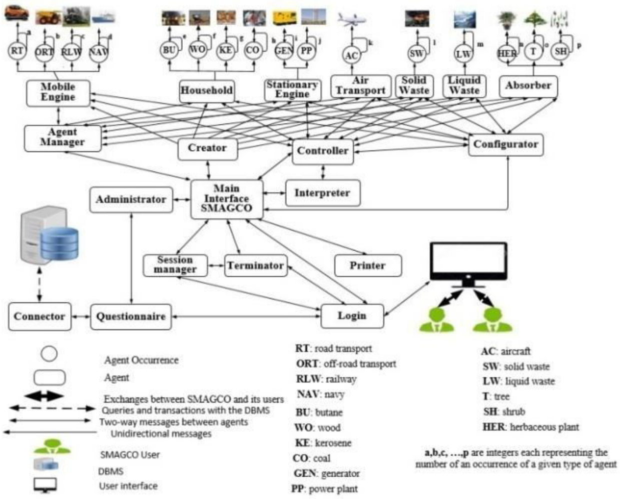

Figure-4. Functional structure of the simulator.

DISCUSSION OF RESULTS

For the sake of application of the simulator, several series of simulations have been performed over various time intervals. Different agent configurations have been involved. For the purpose of this investigation, we have assumed an experimental city with CO_2 emitting and absorbing agents whose characteristics are given in Table-1.

Table-1. Characteristics of the agents used for simulation.

Agents	Characteristics
MEA	Reference, Type, Owner, Fuel used, Consumption / day, Activity, Purity, Number of occurrences, Start date, Stop date.
ATA	Reference, Type, Owner, Consumption / LTO (Landing or Takeoff), Number of occurrences, Start date, Stop date.
SEA	Reference, Type, Owner, Fuel used, Consumption / day, Number of occurrences, Start date, Stop date.
HA	Reference, Type, Household Head, Fuel used, Consumption / day, Number of occurrences, Start date, Stop date.
SWA	Reference, Population, Burning waste fraction, Waste volume / habitant / day, Burned waste volume / habitant / day, Number of occurrences, Waste components, Fraction of type / material, Dry matter content, Total carbon content , Fossil carbon fraction, Oxidation factor, Burning start date, Burning stop date.
LWA	Reference, Volume, Carbon Content, Oxidation factor, Number of occurrences, Burning start date, Burning stop date.
AA	Reference, Type, Species, Age, Number of occurrences, Date of beginning of existence, Date of end of life.

Given the impossibility of representing all possible agent configurations, we limited ourselves to a few agent samples with well-defined characteristics representing a categorical average. Surely, there exists a lot of differences between and within categories of agents such as terrestrial transport agents where for example two different vehicles consume different quantities or types of fuel but also operate at different times. Though it will reflect only the average behavior of the system, we believe that a simulation based on average values can make an important contribution. Another important issue is that the average values alone are not sufficient because they will limit the global evolutions to simple linear values (see Figure-5), which is far from reflecting the reality. We must therefore find a mechanism to get closer to the reality, taking into account the possibility of agents to start and stop operation at any time. Thus, we assume that for each category, agents are born and die over time. Furthermore, in order to reduce the number of agents to deploy (which may be exponential), a set of n agents operating under the same conditions is considered to be a single agent with n occurrences. The results of the simulations performed on the basis of the experimental city are shown in Figures 5-13.

Figure-5 illustrates the simulation results per unit agent of each category and we observe that:

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- Individually, air transport (ATA) produces more CO_2 than all other sectors;
- In the order of their emission capacities, the agents are classified as follows: ATA, Waste (LWA + SWA), SEA, MEA, HA;
- The absorption of carbon dioxide from a tree is very low;
- The Global curve (the sum of all emissions from which the absorptions are subtracted) grows rapidly. Therefore, a very large number of trees is needed in order to balance CO_2 emissions in an urban area.

From Figure-6, we observe the basic simulation for all agents. From the results of the series of simulations performed (Figures 6-13), we observe that:

- The overall quantity of gas emission is proportional to the quantity of emitting agents, all categories combined;
- The overall quantity of gas emission depends on the nature of the emitting agents;
- Despite of the individual aircraft pollution capacity, air pollution due to air transport (represented by ATA) remains insignificant in a city because of the limited number of landings and take-offs;
- The large numbers of stationary engines (SEA), mobile engines (MEA), households (HA) and waste (LWA + SWA) make their contributions very significant in the pollution of urban areas.

Moreover, an increase in the number of absorbers greatly decreases the quantity of CO_2 released. (Figure-13). However, this absorption remains limited compared to the emissions. Indeed, we have limited the absorbers to trees that are the main consumers of CO_2.

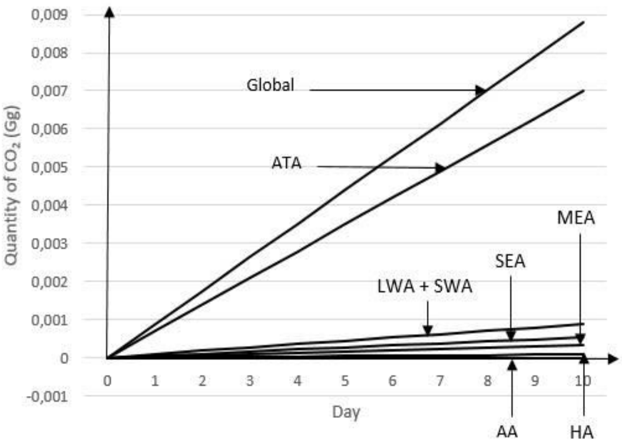
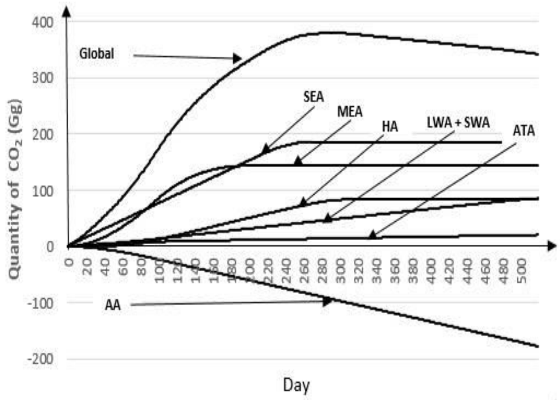
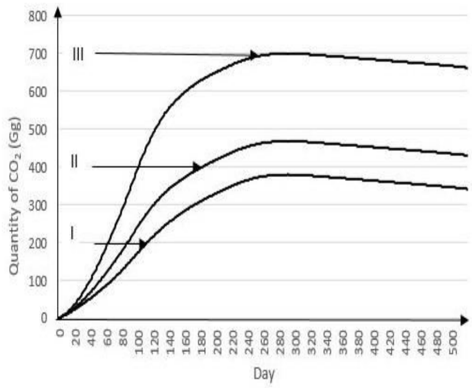


Figure-5. Emission and absorption of CO_2 per unit agent.



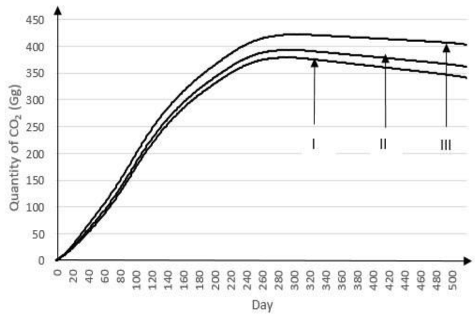
MEA	ATA	SEA	HA	SWA	LWA	AA
100 000	250	100 000	1 000 000	1 000	100 000	20 000 000

Figure-6. Example of simulation results.



Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	150 000	250	100 000	1 000 000	1 000	100 000	20 000 000
III	300 000	250	100 000	1 000 000	1 000	100 000	20 000 000

Figure-7. Evolution of the quantity of CO_2 according toMEA.



Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	500	100 000	1 000 000	1 000	100 000	20 000 000
III	100 000	1000	100 000	1 000 000	1 000	100 000	20 000 000

Figure-8. Evolution of the quantity of CO_2 according to ATA.

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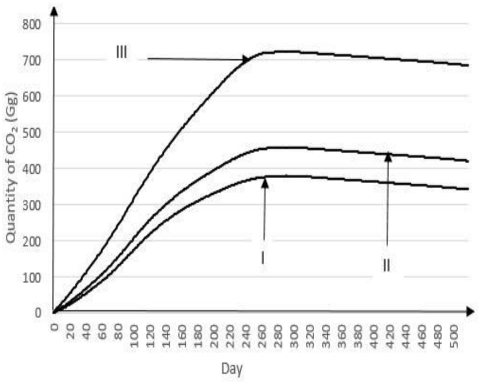
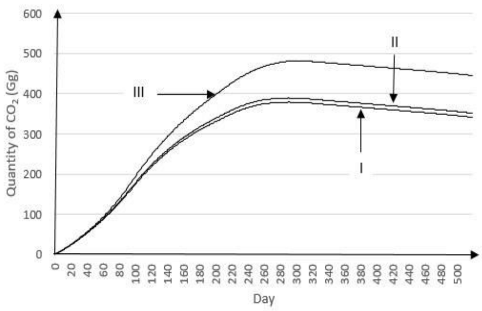


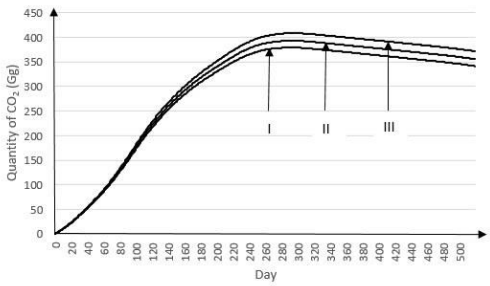
Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	250	150 000	1 000 000	1 000	100 000	20 000 000
III	100 000	250	300 000	1 000 000	1 000	100 000	20 000 000

Figure-9. Evolution of the quantity of CO_2 according to the SEA.



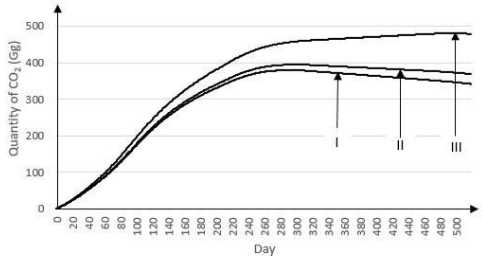
Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	250	100 000	1 500 000	1 000	100 000	20 000 000
III	100 000	250	100 000	3 000 000	1 000	100 000	20 000 000

Figure-10. Evolution of the quantity of CO_2 according to HA.



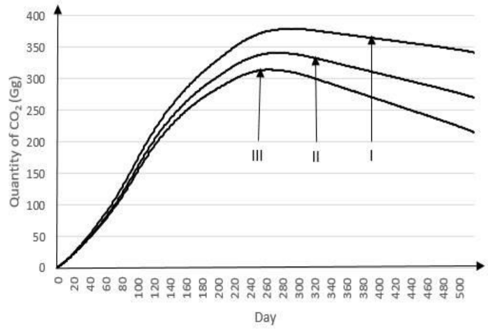
Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	250	100 000	1 000 000	1 500	100 000	20 000 000
III	100 000	250	100 000	1 000 000	3 000	100 000	20 000 000

Figure-11. Evolution of the quantity of CO_2 according to SWA.



Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	250	100 000	1 000 000	1 000	150 000	20 000 000
III	100 000	250	100 000	1 000 000	1 000	300 000	20 000 000

Figure-12. Evolution of the quantity of CO_2 according to the LWA.



Series	MEA	ATA	SEA	HA	SWA	LWA	AA
I	100 000	250	100 000	1 000 000	1 000	100 000	20 000 000
II	100 000	250	100 000	1 000 000	1 000	100 000	20500 000
III	100 000	250	100 000	1 000 000	1 000	100 000	21 000 000

Figure-13. Evolution of the quantity of CO_2 according to AA.

CONCLUSIONS

In this article, a multi-agent simulator has been designed and implemented in order to compute the quantity of CO_2 in urban areas. The results show that multi-agent systems are important forecasting tools for sustainable development. It is also shown that the dynamics of the forecast and quantitative evolution of CO_2 is characterized by the variability of the number of emitters / absorbers and their nature. However, absorption remains limited compared to emissions.

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