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Research Article

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A simulative and multi-agent study for balancing the quantity of CO_2 in an urban area by fixing the sources of emissions and absorptions

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Abstract The magnitude of the quantitative evolution of emissions from the main greenhouse gas, carbon dioxide (CO_2), is an undeniable evidence. The need to have technological tools that can predict the possible counterbalance of its quantity released and stored in the atmosphere is a good opportunity for mankind. This work illustrates a paradigm of simulating CO_2 offsets across a city using a system based on reactive, dynamic, open and distributed agents that is built on a multi-agent architecture of emitting and absorbing sources.

Keywords Simulation, multi-agent system, counterbalance, paradigm, greenhouse gas, Sustainable development

1. Introduction

Climate, environmental and other talented scientists have been alerting of the serious rise in time of the storage of greenhouse gases (GHG) including CO_2. They have warned about the imperative need to perpetuate GHG emission attenuation efforts to circumscribe the dimension of climate change over the next coming centuries. There is an urgent need to anticipate the mitigation of these emissions for sustainable development [1]. Moreover, in our cities, the quest for energy generated by human activities continually causes an exponential consumption of fossil fuels [2], which are the main sources of emissions of GHG [3]. These anthropogenic emissions deserve a particular attention given the alarming proportions they are taking. In this struggle against the rising quantity of CO_2, innovation and creativity of technological tools are necessary for the purpose of prediction. Furthermore, multi-agent systems are nowadays used to solve complex problems in several areas such as financial systems, leisure, telecommunications, control-command, embedded systems, and many others [3-13]. Through a multi-agent system, this paper presents a paradigm to simulate a time-offset of the amount of CO_2 that would be released into the atmosphere at the scale of an urban center in view of possible mitigation. Built on a multi-agent architecture of emitting and absorbing sources, the system operates on the basis of reactive, dynamic, open and distributed agents.

Worrying and alarming situation of CO_2

The consequences of massive and continual GHG releases constitute an obvious reality that is experienced daily. Across the planet, the population is experiencing the effects of these emissions through the manifestation of natural cataclysms such as torrential rains [14], hurricanes [15], cyclic droughts [16], rising oceans [17], rainfall variability and its impact on agricultural yields [18], etc. According to the Intergovernmental Panel on Climate Change (IPCC), it is almost likely that the anthropogenic GHG emissions are the leading cause of global warming observed since the mid XXth century [19]. These emissions are mainly from the combustion of fossil fuels [20]. All these unpredictable and disastrous situations for mankind are therefore generated by anthropogenic emissions emitted mainly as a result of the search for energy during the consumption of fossil fuels. These activities are mainly related to energy production (generators, power plants, etc.), burning and incineration of waste (solids or liquids), etc. The following figure summarizes the contributions of the different groups of CO_2 emitters and absorbers [21-23] where ρ,V, PCI, FE_a, activity, purity represent respectively the density, the volume, the net calorific value, the emission factor of type a fuel, the quantity of urea-based additives and the mass fraction of urea in urea-based additives. For air flights, these parameters are all calculated at the landing and take-off (LTO) phases.

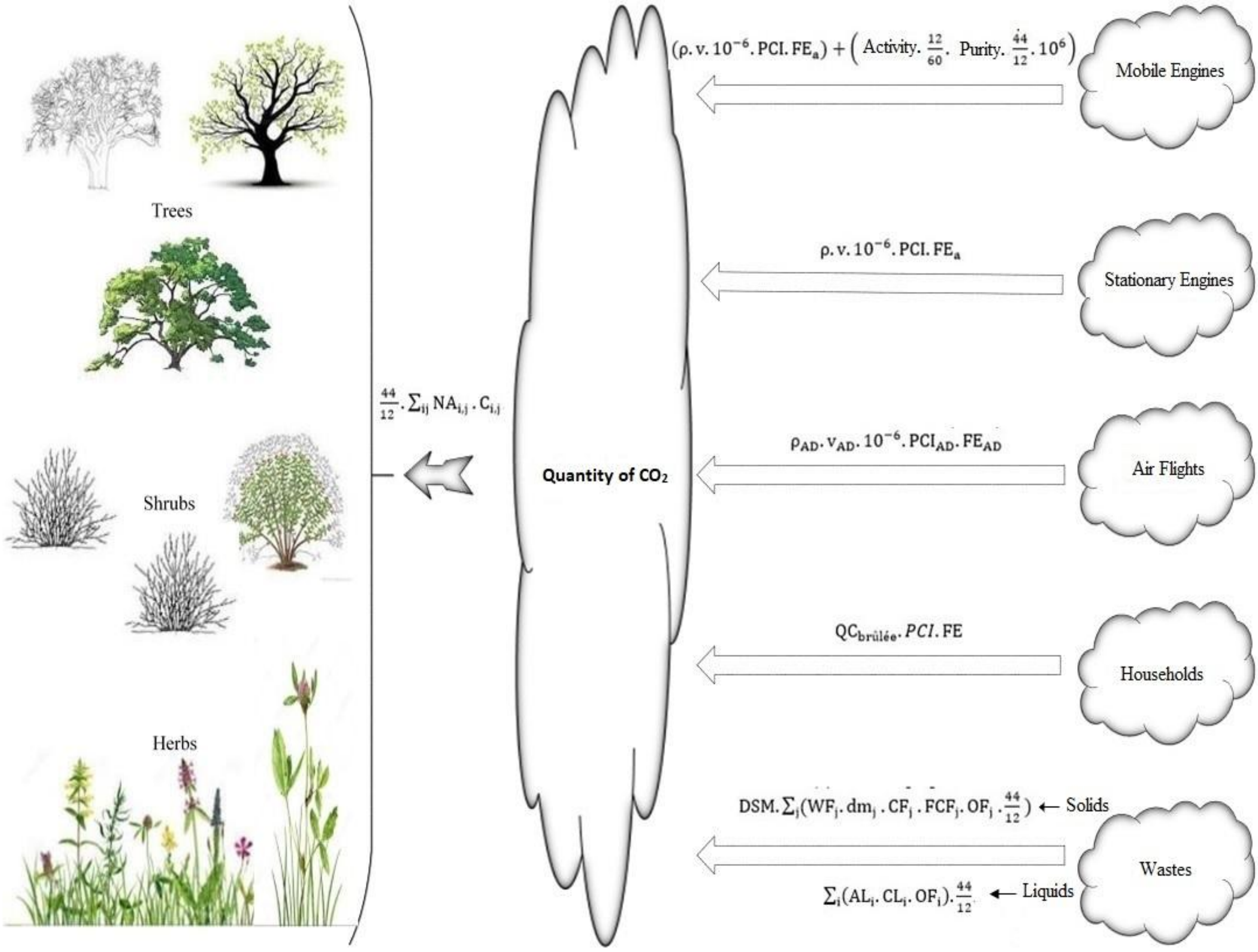


Figure 1: The main groups of CO_2emittersand absorbers in an urban center

3. Agents description

The agents of the multi-agent simulator called "SMAGCO" are of two categories: temporary and permanent. However, all agents interact with the main coordinator, which is the central node of the platform called SMAGCO Main Interface (IPS). The various states (Figure 2) of this central agent are illustrated below.

All emitting agents (mobile engine, stationary engine, air transport, household, solid waste and liquid waste) and absorbers (trees, shrubs and herbs) are considered temporary. Each temporary agent changes state according to its usage context. The following figure describes the variability in the status of temporary agents based on exchanged messages.

All management agents, analytical and processing agents, and authentication and access agents are permanent. The following class diagram (Figure 4) describes the internal structure of the simulator. However, the use of certain objects as resources requested for the operation of the platform imposes the coexistence of agents and objects in the proposed diagram.

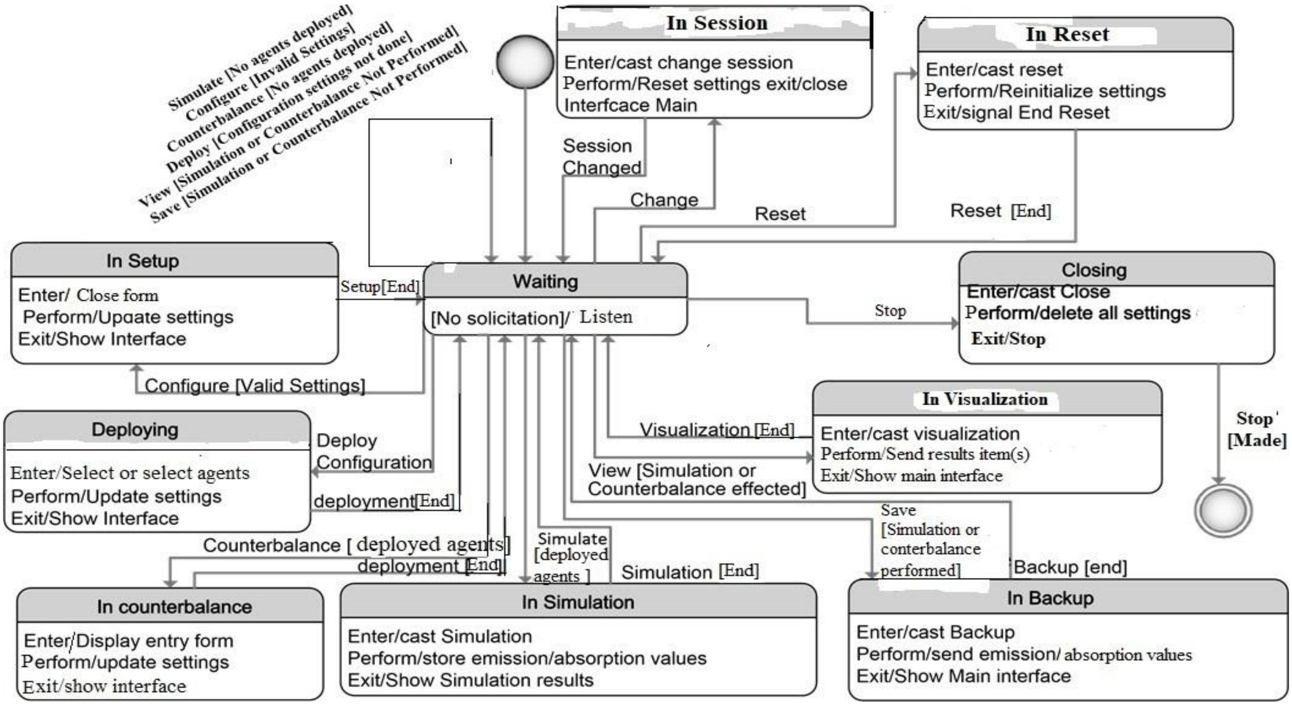


Figure 2: State diagram of the Interface agent

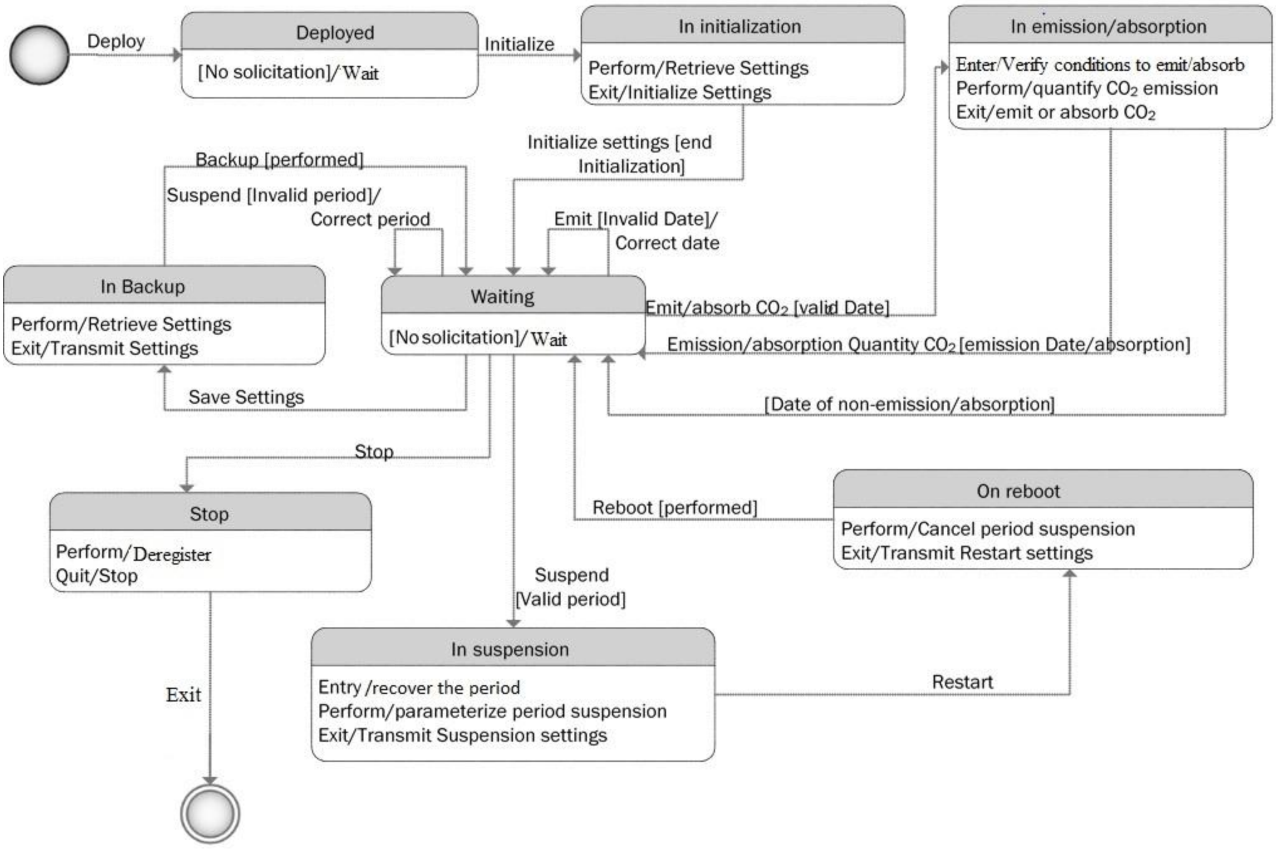


Figure 3: State diagram of a temporary agent

The *Interface* class is the primary class that allows to manage the entire system. It brings together all the simulation parameters such as dates (start and end), emission factors, absorption factors, emission and absorption values, etc. Its methods or services model the various requests of the IPS agent. The *Temporary*, *Emitter*, *Absorber* and *Waste* classes are abstract classes bound by a hierarchical relationship. The *Temporary* class is the base class that includes properties and methods common to CO_2 emitters and absorbers.

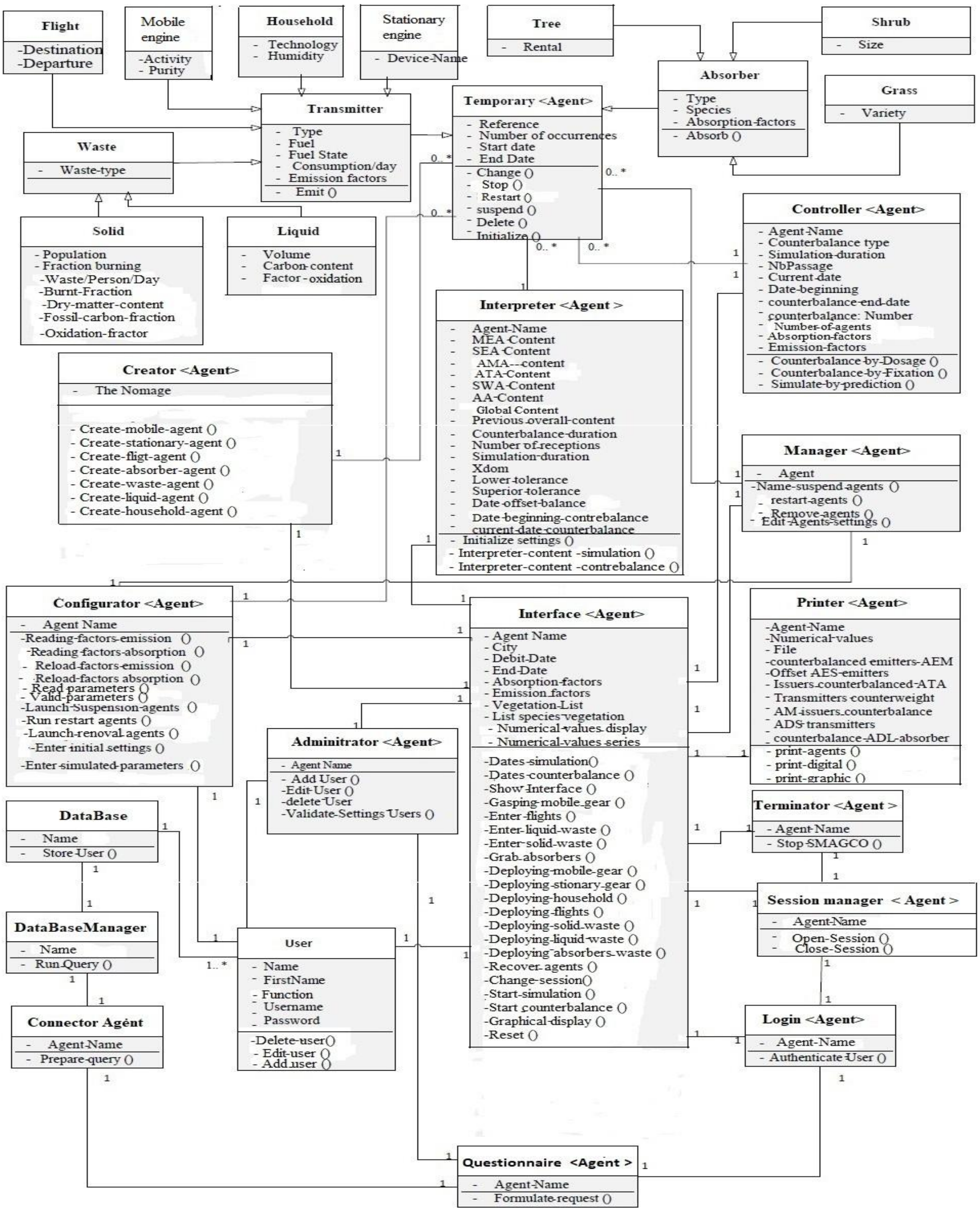


Figure 4: Class diagram of the simulator

The *Interpreter* class includes all backup properties of different emissions and consumptions, counterbalance control properties, dates (start and end), and many other control and computation properties. These methods or services describe the involvement of the interpreting agent in the operation of the system. The *Controller* class includes the emission control or absorption properties of temporary agents, and its methods or services illustrate the control options of the controller as per system usage. The *Manager*, *Creator*, and *Configurator* classes describe the methods or services of the manager, creator, and configurator agents, respectively, depending on how the multi-agent system is used. The *Printer*, *Login*, *Session*, and *Administrator* classes describe the services and properties that are related to print, system login and shutdown, session open and close, and other administrative tasks. The *Login* class describes the methods and services for accessing objects in the *User* class by querying the questionnaire agent modelled by the *Questionnaire* class. The *Connector* class models the connector agent that prepares the request received from the questionnaire agent. This agent calls the object of the *DataBaseManager* class which executes the query by using the *DataBase* class object that stores the objects in the *User* class.

4.Counterbalance Coordination Protocol

The search for a balance between emissions and absorptions goes through the counterbalance protocol. The approach adopted is to coordinate in a reactive manner between processing agents (IPS, CONTROLLER, INTERPRETER, TERMINATOR) and temporary agents: MEA (mobile engine), HA (household), ATA (air transport), SEA (stationary engine), SWA (solid waste), LWA (liquid waste), AA (absorber). This coordination has been possible through the exchange of messages between reactive agents (stimulus/response). The coordination procedure to search for a counterbalance of CO_2 in a context of emissions and absorptions takes place according to the following message exchange sequence:

Algorithm Counterbalance ()

```
input: Temporary agents (MEA, HA, ATA, SEA, SWA, LWA, AA) deployed, a city, tolerance,
           start and limit dates of the search for the counterbalance.
output:    The date or not of the counterbalance and the values of emissions and absorptions.
known: emission factors, absorption factors.
variables:
        globalValue, valueMEA, valueMA, valueATA, valueSEA, valueSWA, valueLWA,
        valueAA, Tolerance, precedingValue: real;
        counterbalanceBeginningDate, counterbalanceEndDate, currentDate: date
        agentsList: array;
        ctrlCounterbalanceEnd, emissionAbsorptionSaveEnd, ctrlAuthorizationEmissionAbsorptionEnd: bool;
        receptionWaitingNumber: int;
begin
        USER launches counterbalance from the main interface;
        IPS displays the form for entering counterbalance parameters;
        while  (invalid counterbalanceBeginningDate   or invalid counterbalanceEndDate
                or invalid counterbalanceTolerance)
                 USER captures the settings;
                (counterbalanceBeginningDate, counterbalanceEndDate, counterbalanceTolerance) ←
                parameters entered and validated;
        endWhile
        IPS sends validated parameters to CONTROLLER;
        CONTROLLER receives the parameters;
        CONTROLLER executes agentsList ← List of deployed agents;
        if (size (agentsList) = 0) then
                 CONTROLLER sends a notification message to IPS;
              IPS displays to USER the message "No agent has been deployed in SMAGCO";
        else
              CONTROLLER sends an initialization message to all temporary agents; CONTROLLER
              updates the counterbalance settings;
                 for each temporary agent of agentsList        do
                    receive the initialization request;
                    get initialized;
                    calculate its quantity $CO_2$ to be emitted or absorbed;
           endFor
           currentDate: ← counterbalanceBeginningDate;
           ctrlCounterbalanceEnd ← false
           ctrlAuthorizationEmissionAbsorptionEnd ← false;
          emissionAbsorptionSaveEnd← true;
         while   ((not ctrlCounterbalanceEnd) and (emissionAbsorptionSaveEnd))
                         IPS sends control permission to CONTROLLER;
```

```
                CONTROLLER receives control permission;
            CONTROLLER sends size (agentsList) to INTERPRETER;
            CONTROLLER   sends authorization to all temporary agents to emit or absorb;
            CONTROLLER sends end of authorization to INTERPRETER;
            for Each temporary agent of agentsList do
                receive authorization to transmit or absorb;
                    quantify the amount of $CO_2$ to be emitted or absorbed;
                    send quantity $CO_2$ to INTERPRETER;
            endFor
            INTERPRETER gets the size of the list;
                INTERPRETER sets receptionWaitingNumber to size (agentsList);
            INTERPRETER receives notification of end of authorization;
                INTERPRETER sets ctrlAuthorizationEmissionAbsorptionEnd to true;
              while (receptionWaitingNumber > 0)
                  INTERPRETER receives an emission or an absorption;
                          INTERPRETER processes quantity of $CO_2$;
                          INTERPRETER decrements receptionWaitingNumber;
            endWhile
                if ((receptionWaitingNumber = 0) and (ctrlAuthorizationEmissionAbsorptionEnd))
                then
                        if (  (currentDate < counterbalanceEndDate) and (
                         (globalValue <- counterbalanceTolerance and preceedingValue < 0) or
                           (globalValue > counterbalanceTolerance and preceedingValue > 0) ) )
                           then
                                INTERPRETER sends to IPS globalValue, valueMEA, valueMA,
                                valueATA, valueSEA, valueSWA, valueLWA, valueAA,
                                currentDate;
                                currentDate ← currentDate + (1 day);
                                ctrlAuthorizationEmissionAbsorptionEnd ← false;
                                emissionAbsorptionSaveEnd ← false;
                                preceedingValue ← globalValue ;
                    else
                                INTERPRETER sends to IPS globalValue, MEAvalue, valueMA,
                                valueATA, valueSEA, valueSWA, valueLWA, valueAA,
                                currentDate and the end notification of counterbalance;
                                ctrlCounterbalanceEnd ← true;
                  endIf
              endIf
                if IPS receives a message that contains only emission and absorption values
                (globalValue, MEAvalue, valueMA, valueATA, valueSEA, valueSWA,
                valueLWA, valueAA, currentDate) then
                        IPS saves all emission and absorption values with their current date;
                        IPS sends the end of backup message to CONTROLLER;
                endIf
                if IPS receives emission and absorption values (globalValue, MEAvalue,
                valueMA, valueATA, valueSEA, valueSWA, valueLWA, valueAA, currentDate)
                and the end notification of counterbalance then
                        IPS saves all emission and absorption values with their current date;
                        IPS informs USER of the counterbalance end while specifying the
                        context (normal end or balance date reached);
              endIf
                  CONTROLLER receives end of backup notification;
              CONTROLLER sets emissionAbsorptionSaveEnd to true;
      endWhile
    endIf
end
```

The following sequence (Figure 5) and activity (Figure 6) diagrams further explain the counterbalance coordination protocol process.

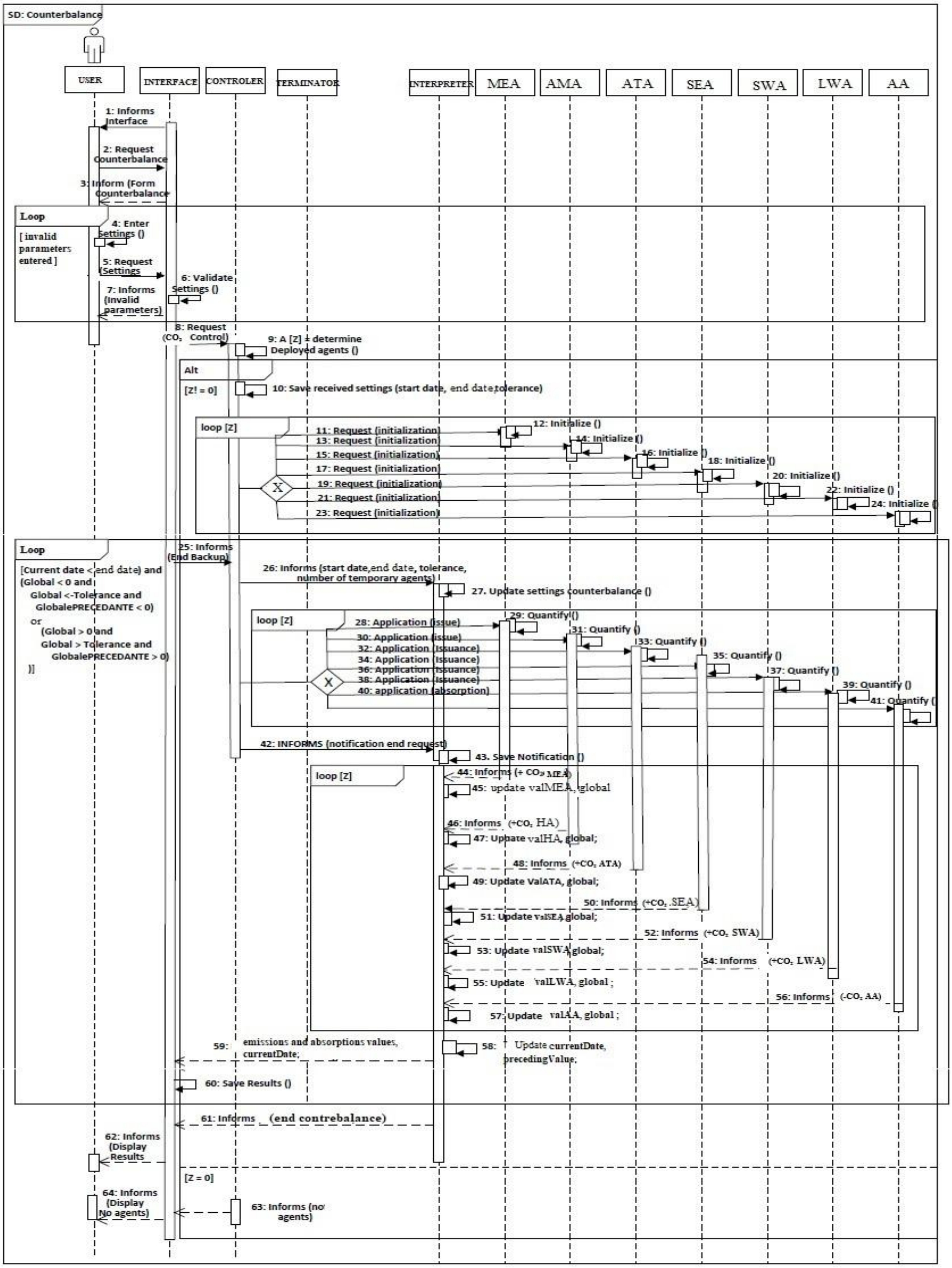


Figure 5: Counter balances equence diagram

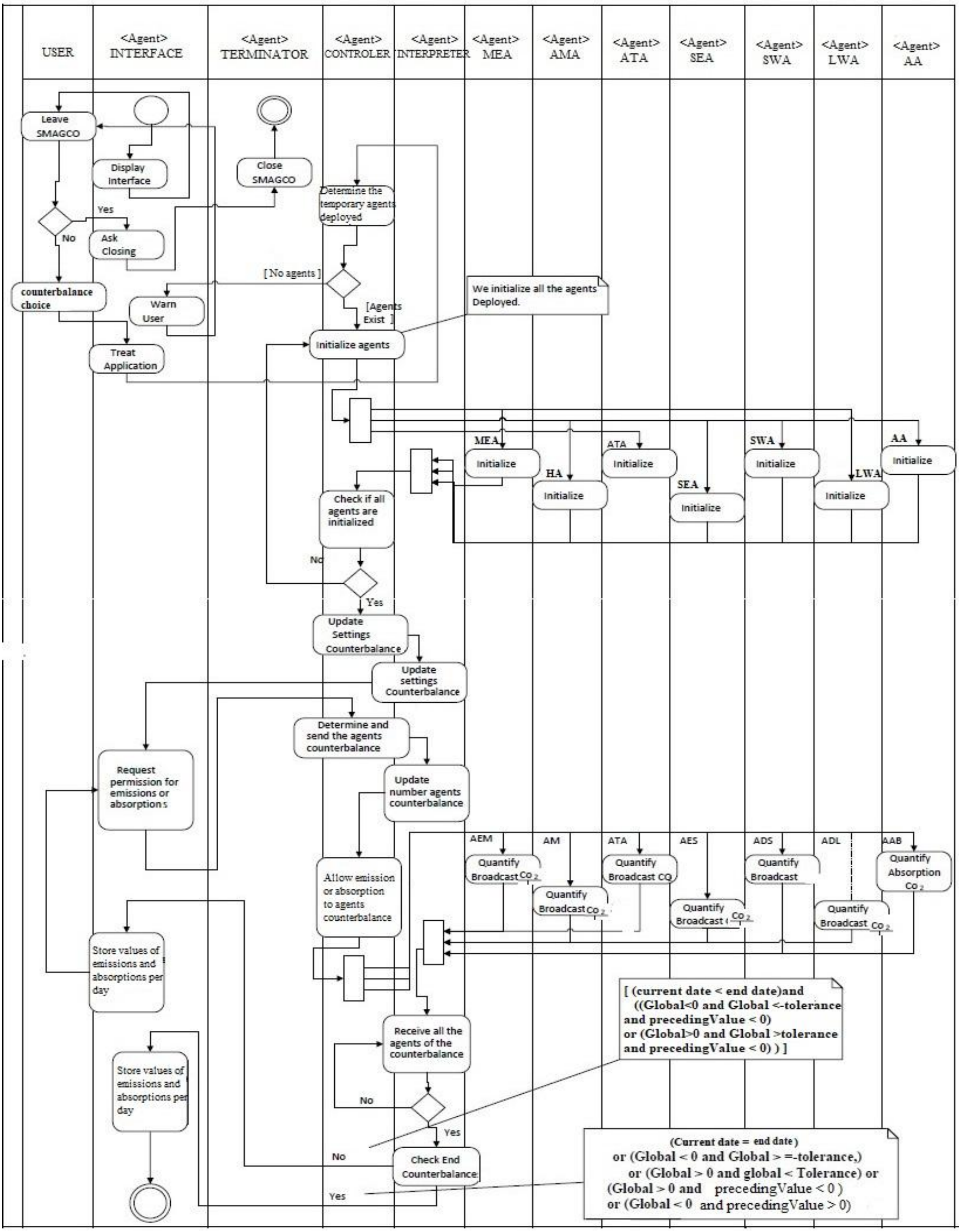


Figure 6: Counter balance activity diagram

Results and Discussion

The search for an equilibrium between emissions and absorptions of CO_2 was carried out using the multi-agent simulation system based on the following characteristics of temporary agents.

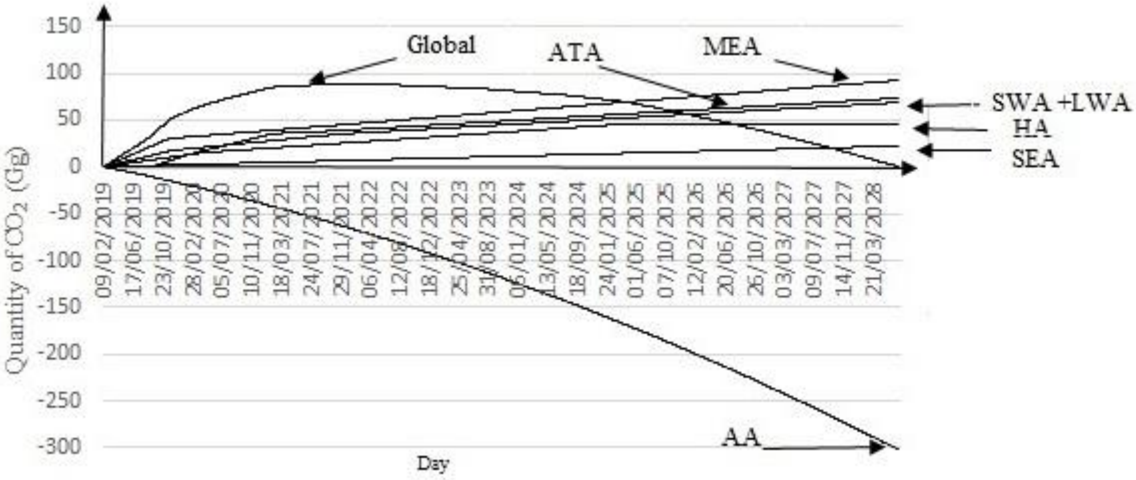
Table 1: Characteristics of temporary agents

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 Take Off), 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, Technology, Humidity, 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.

The deployed temporary agents operate on the basis of their daily emissions or absorptions depending on their period of operation. The search parameters are the start date of simulation, the end date of simulation, and the tolerance. Figure 7 illustrates an example of results for the search of an equilibrium between emissions and absorptions of CO_2. It is noted from this simulation that the context of the simulated environment makes it possible to reach an equilibrium.

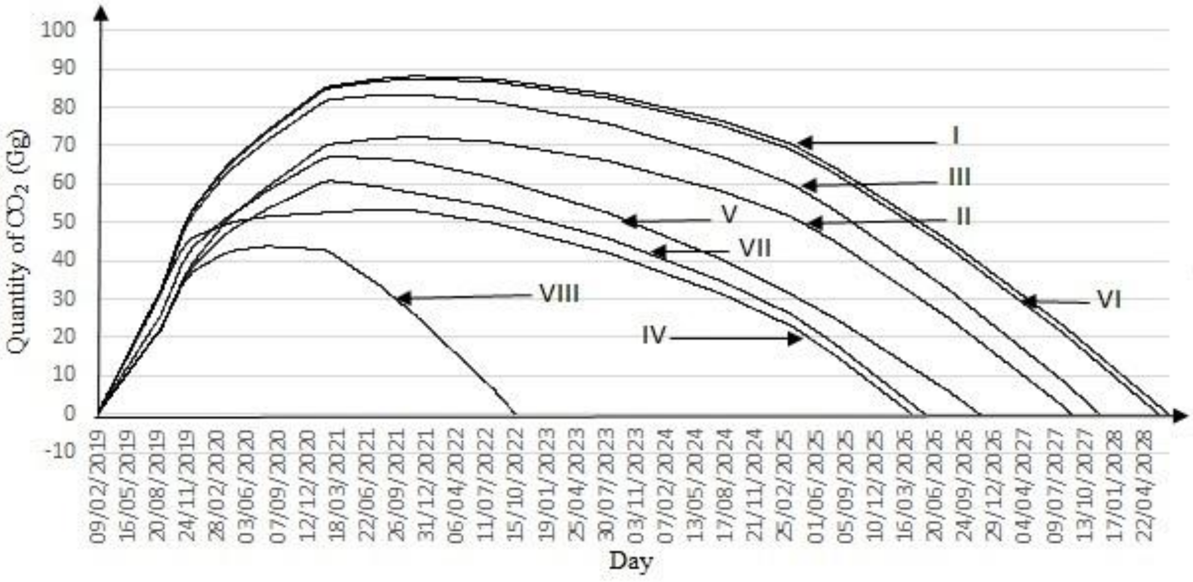
Figure 8 illustrates a balance search based on a decrease of emitting agents and an increase in absorbers. Although the final configuration is a function of several parameters such as the number of agents of each type, the duration of operation of emitting agents, the period of existence of absorbers, the time interval of search, we observe that:

- The time to search for a balance decreases with a decrease in the number of each emitting agent;
- The decrease in time is less significant with a decrease in the number of solid wastes;
- The decrease in time is very significant with a decrease in the number of stationary engines, the number of mobile engines, the number of households, the number of liquid wastes and the number of air flights. Thus, the decrease in the massive combustion of fossil fuels (coal, oil, natural gas) leads to a decrease in the amount of CO_2, which is in agreement with Van and John [24];
- A significant increase in the number of absorbers significantly decreases the time to search for abalance. This shows the need for planting trees, landscaping the green areas and especially their maintenance. These results are in agreement with Jürgen and Oliver [25] on global climate policy strategies [26]: <<Each cut tree reduces the capacity of agroforestry parks to sequester atmospheric CO_2while the burning of the cut tree wood increases the atmospheric CO_2 >>;
- Mitigating the CO_2 greenhouse effect must include measures for reduction, absorption and sequestration of emissions in agreement with Peters et al. [27].



Series	MEA	SEA	ATA	HA	SWA	LWA	AA
I	10 000	50 000	200	5 000	500	50 000	20 000 000

Figure 7: Example of simulation results



Series	MEA	SEA	ATA	HA	SWA	LWA	AA
I	10 000	50 000	200	5 000	500	50 000	20 000 000
II	**5 000**	50 000	200	5 000	500	50 000	20 000 000
III	10 000	**10 000**	200	5 000	500	50 000	20 000 000
IV	10 000	50 000	**50**	5 000	500	50 000	20 000 000
V	10 000	50 000	200	**1 000**	500	50 000	20 000 000
VI	10 000	50 000	200	5 000	**300**	50 000	20 000 000
VII	10 000	50 000	200	5 000	500	**10 000**	20 000 000
VIII	10 000	50 000	200	5 000	500	50 000	**30 000 000**

Figure 8: Balance search

Conclusion

In this article, simulations have been carried out in order to search for an equilibrium between emissions and absorptions of CO_2 in an urban environment. The proposed model is multi-agent and implemented on the basis of a protocol of interactions designed to better coordinate the search process. It was concluded that a counterbalance of CO_2in an urban environment largely depends on the number of emitters, absorbers and the period of the search. It was also concluded that multi-agent systems are important tools capable of greatly contributing to the global mobilization to mitigate greenhouse effects.

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