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CARBON OFFSET CALCULATORS

BY

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Abstract. The nowadays climate warming trend is of significance because it is related with the human activities starting from the mid-18th century. This climate warming coincides with the increasing of the greenhouse gases concentration in the atmosphere, especially carbon dioxide. Some solutions, like urban agriculture, are aimied to oppose this phenomenon. We are studying a solution to increase the carbon sequestration in urban environments – the rooftop greenhouse buildings - and this work introduces an useful tool for assessing the efficiency of projects of this kind, respectively a fuzzy expert application, made in MATLAB, for real-time estimating the carbon sequestration capacity.

Keywords: Carbon offset; carbon sequestration; fuzzy system; neural network; modeling and simulation.

1. Introduction

The Earth's climate has often changed along history. When the solar energy is reflected by the earth surface and oceans (snow, ice) or by the atmosphere (clouds, volcanic eruptions) the earth's atmosphere and the whole planet's

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surface cools. When the earth absorbs the sun's energy or when atmospheric gases prevent earth's heat to radiate into space by greenhouse effect, the planet warms. A variety of factors, natural (small variations in Earth's orbit for instance) and human (fossil fuels burning and deforestation), can influence the earth's climate system. In the last 650,000 years we had seven cycles of glacial advances and retreats, with the abrupt end of the last ice age about 11,700 years ago, which produced the modern climate that favorized the development of our civilization.

The nowadays global heating is particularly strong and alarming, since during the last three centuries humans intensified their industrial activities based on burning fossil fuels and have expanded their inhabited areas at the expenses of the surrounding environment (forests, fields, etc.). Our technologies are essentially based on oxidations, creating a chain reaction: increased CO_2 footprint => O_2 depletion => increased global greenhouse effect => global warming.

Although this anthropomorphic global heating is still debated, a convincing proof of its validity was provided by the spectacular effects over the atmosphere produced in 2020 after the economy slowing down caused by the COVID pandemic (Helm, 2020). "There has been a very significant reduction in economic activity, very large falls in transport by air, road and railways, and with these have come large falls in air pollution and greenhouse gas emissions, as well as reduced pressure on nature" (Balas *et al*., 2018).

When measuring the CO_2 emissions in the atmosphere, it is essential to to be able to distinguish between fresh emissions and those accumulated over time. The major source of nitrogen dioxide NO_2 in the atmosphere is from the burning of fossil fuels. While CO_2 emissions last for decades NO_2 has a relatively short lifetime that can be measured in hours. That is why one uses NO_2 as a tracer to detect recent emissions of CO_2 into the atmosphere. The researchers use a spatial high-pass filtering method to separate out man-made sources of carbon dioxide from those resulting from the release and uptake by vegetation (Dempsey, 2022). Fig. 1 is illustrating the above considerations.

A complementary natural phenomenon, able to oppose the dramatic CO_2 chain reaction is the photosynthesis. Our metabolism and comfort require the presence of plants, we need to inhale plant produced O_2. At the same time, because of our complementary metabolisms, plants benefit from the CO_2 we are exhaling. Our main goal is to fund a lasting symbiosis with plants.

A strategic response to global warming is the urban agriculture (UA): cultivating plants, at large scale, into cities, since most of the agricultural terrains outside cities are already exploited (Goldstein *et al*., 2016; Nwosisi and Nandwani, 2018; Stefani *et al*., 2018). There are several UA versions, the most promising seeming to be the building-integrated agriculture (BIA), because our typical cities have not enough spare surfaces for proper agriculture. BIA means cultivating plants into or onto buildings. Wasting the inside buildings' space for agriculture, except decoration, is equally unfeasible, so we embraced the onto building version, by means of a well-known item: the rooftop Greenhouse (RTG).

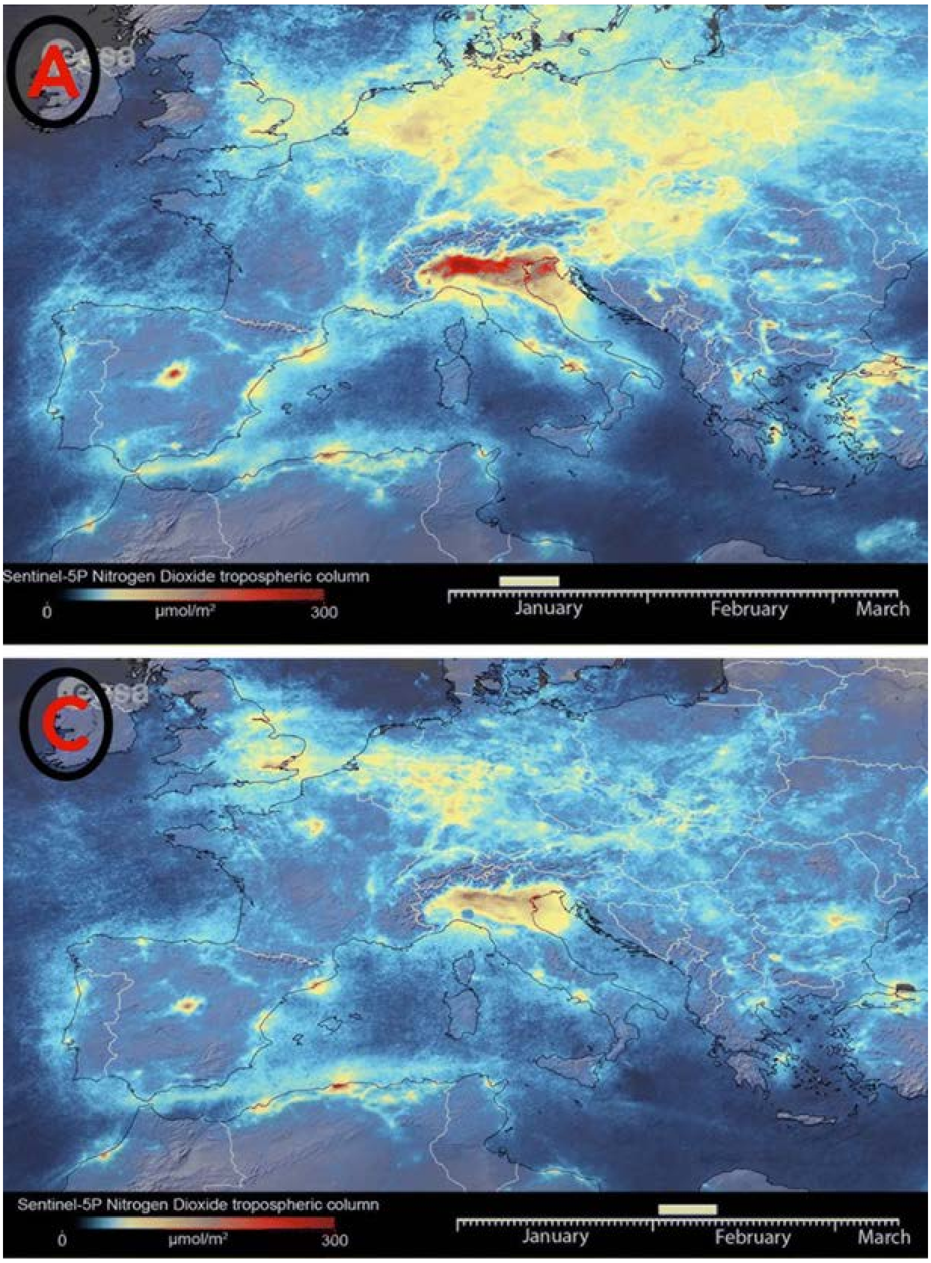


Fig. 1 – Satellite views of nitrogen dioxide emissions, before and during the COVID pandemic, by ESA2020 (Cárcel-Carrasco *et al*., 2021).

Known from decades, RTGs have failed to overcome the demonstrative stage, due to a poor economic efficiency. A solution to this issue is the integrated rooftop greenhouse (IRTG), which means to connect the RTG with the building by natural bidirectional air flows: O_2 enriched air from roof to building and CO_2 enriched air from building to roof (Pons *et al*., 2015; Sanjuan-Delmás *et al*., 2018). One can such way introduce the concept of building metabolism and create a sustainable indoor humans-plants symbiosis. The first IRTG is featured for the Mediterranean climate.

2. The Intelligent Rooftop Greenhouses

The intelligent rooftop greenhouse (iRTG), introduced in (Balas *et al*., 2018), aim to achieve an advanced management of energy, water, and gases, at the expense of the available renewable energy resources. Our objectives are to extend the iRTGs' applicability to all climates, to connect them to the smart cities, and not least, to maximize its carbon dioxide offset. If applied at large scale, the iRTGs will increase the CO_2 offset of our cities, opposing global heating.

The technical solutions that are particularizing iRTG from IRTG are:

- The active control of the iRTG ventilation system, namely of the bidirectional air flows between RTG and building and of the air flows between RTG, building and environment.
- The use of water-to-water and air-to-air heat pumps, to harvest geothermal and eolian energies.
- The intelligent management of temperatures, water, and gas concentrations (CO_2 and O_2).
- The iRTG implementation as an internet of things (IoT) subject.

The iRTGs are intended to value a huge space resource, available virtually in any building: the roof. Either conventional or flat, the roof is usually the most unused part of a house. Its role is to protect the building against the undesirable meteorologic phenomena. If set as iRTG, the roof is receiving new and important functions:

- Isolating the plants to obtain the integrated space with the underneath building.
- Harvesting the solar energy by greenhouse effect or by photovoltaic devices.
- Harvesting the eolian energy by air-to-air heat pumps, windmills, or other devices.
- Collecting rain waters.

3. The Carbon Offset Calculators

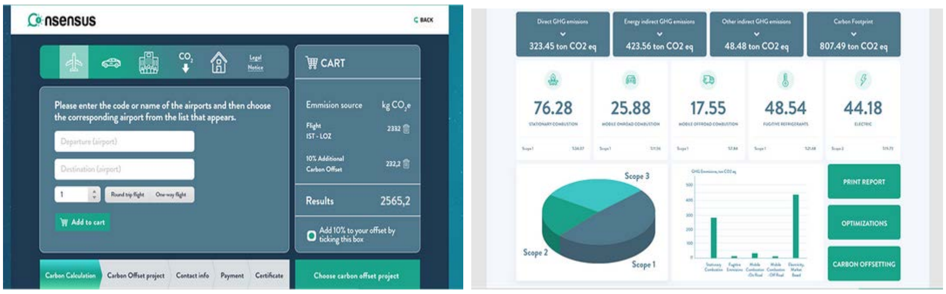
Regarding the reversing of the atmospheric CO_2 pollution and the mitigation of the global warming, some concepts are beginning to be intensively applied:

- *Carbon offset* (COFF): a reduction in emissions of carbon dioxide or other greenhouse gases, opposing the emissions made elsewhere. Offsets are measured in tons of carbon dioxide equivalent (CO_2e).
- *Carbon sequestration* (CSEQ): the long-term sequestration of carbon dioxide from the atmosphere, performed for instance by plants, through photosynthesis. Other CSEQ mechanisms are also possible due to the carbon sinks (soil, water, etc.) The usual carbon sequestration unit is $t_{CO2}{\cdot}ha^{-1}{\cdot}year^{-1}$.
- *The carbon neutrality*: the compensation of the greenhouse gas emissions by climate-positive actions. We are now beginning to talk about the *carbon neutral buildings*. Carbon neutrality is a major aim for iRTGs.
- *Decarbonizing cities*: investigating practical solutions for urban development to minimize natural resource depletion and climate change.

iRTGs are aimed to decarbonize our cities by turning most of buildings towards carbon neutral. The previously chosen technical solutions are clear: using renewable energies to reduce the buildings' carbon footprints and increasing the presence of the plants to improve the carbon offset.

Building IRTGs or iRTGs is attractive, but if we want to encourage their large-scale dissemination, we must find ways to assess the carbon offset they can produce, to offer a reliable base for the design of great projects.

The difficulty of this assessment lies in the lack of direct measurement tools for carbon offset and in its extreme variability. On-line calculators/estimators represent the leading solution for the time being (https://www.carbonfootprint.com/). In addition to the daily variations caused by the plants' inspiration-expiration, CO_2 consumption varies with lighting, humidity, temperature, stage of development and health of plants, season, and many other factors.



a) Co2nnector b) Co2nnectorPro

Fig. 2 – Commercial Carbon offset calculators (Co2nsensus, 2021).

To create an accessible and effective tool, able to facilitate carbon offset estimation, we assume the next interpretation of the COFF-CSEQ relationship:

$$\mathrm{CSEQ} = \int_0^T \mathrm{COFF} \cdot \mathrm{dt} \tag{1}$$

$$\mathrm{COFF} = \mathrm{dCSEQ}/\mathrm{dt} \quad (2)$$

The period T for which CSEQ is usually calculated is one year, compensating most of the short-term variations and the seasonal variation of COFF.

This approach assumes a slow variable COFF, neglecting its daily and weather variations, with a focus on weekly-monthly variations caused by the choice of the species of plants, their configuration, and their development.

Carbon footprint/offset calculators are available on the software market, being used in the project assessments and CO_2 certifications: (Co2nsensus, 2021; Climatecare, 2021), etc.

4. The Fuzzy-Expert Offset Calculator

The commercial carbon offset calculators are useful in building scale applications, but they do not offer insights of the calculus algorithms. We aim to conceive a real-time transparent carbon offset calculator suited for iRTGs, easily tunable with continuously acquired knowledge about iRTGs. We are inspired by an approach from the real time measurement of urban air quality parameters: fusion systems composed of low-cost geostatic sensor networks and computer models, instead of expensive standard equipment, (Schneider *et al*., 2017).

Measuring CO_2 concentrations in buildings' apartments and in rooftop greenhouse would be obviously the most accurate source of data for a proper assessment of the COFF, but for the moment no proper equipment and no iRTG prototype are built. That is why we will rely on the CSEQ to estimate COFF and we will use an expert like computer model.

The plants' CSEQ can be directly measured, but in a laborious manner:

a) Determine the total green weight of the plant.

b) Determine the dry weight of the plant.

c) Determine the weight of carbon in the plant.

d) Determine the weight of CO_2 sequestered in the plant.

We are introducing a software tool, able to roughly estimate CSEQ and COFF using linguistically shaped information acquired by visual analyze of the crop: a *fuzzy expert calculator of the carbon offset*.

The fuzzy expert calculator is a decision system emulating the human reasonings, on behalf of a fuzzy expert rule base and of an inference algorithm. The bases of control/decision rules of IF-THEN type are designed by specialists in the application's domain (not necessarily and in computer science).

We initiated our investigations with the following configuration:

- Inputs:

a) V_P the percentage of the total greenhouse volume occupied by plants [%].

b) D_P the development stage of the plants, measured by percentage of the final development.

c) *CS_P* the carbon sequestration capacity of the species grown in RTG.

- Output: *Cseq*

In the following example we use for all the three input variables (V_p, D_p and CS_p) the usual linguistic terms: *small*, *medium*, and *great*. The output variable has four terms: *zero*, *small*, *medium*, and *great*. The resulting control surface is nonlinear and can be adjusted by tuning the rules.

The technical realization of such expert systems is remarkably simple in most software environments, but the configuration and the tuning of the rule base demands sound experimental results, we expect to acquire in the close future.

5. A Fuzzy Inference System Implementation

A Matlab-FIS (*Fuzzy Inference System*) implementation of the above calculator configuration is presented into the following figures.

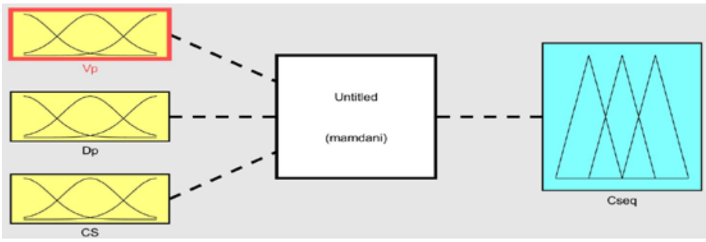


Fig. 3 – The main window of the FIS application.

The input variables' membership functions are identical to the Fig. 4 one.

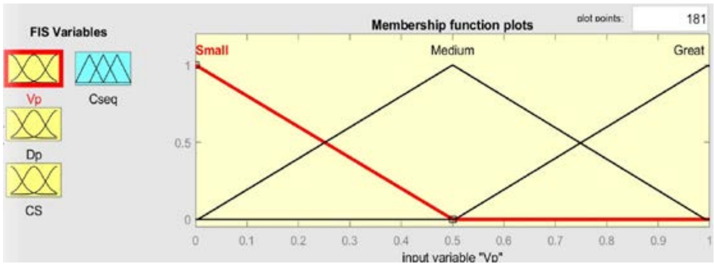


Fig. 4 – One of the input variables - V_p.

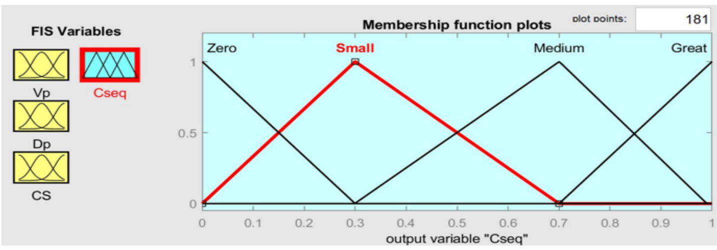


Fig. 5 – The output variable *Cseq*.

The output variable Cseq with four fuzzy labels (*Zero*, *Small*, *Medium* and *Great*) is shown in Fig. 5.

The eleven fuzzy control rules base is shown in Fig. 6.

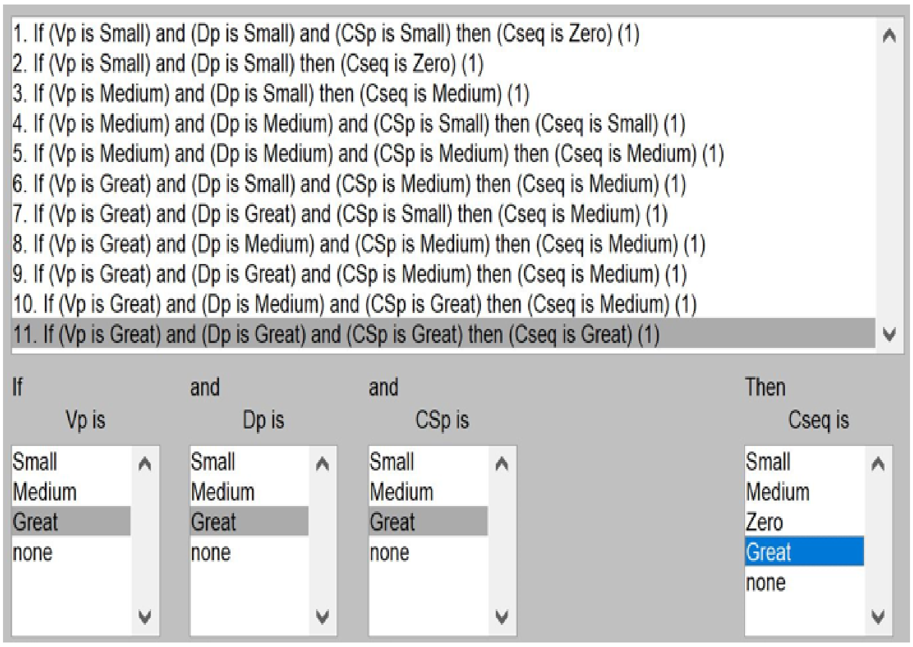


Fig. 6 – An eleven rules base.

The resulting control surface is bounded down and up by rules 1 and 11 (see Fig. 6):

1. **If** V_P is Small **and** D_p is Small **and** CS_p is Small **than** *Cseq* is *Zero*

% This is the worst situation

11. **If** V_P is *Great* **and** D_p is *Great* **and** CS_p is *Great* **than** *Cseq* is *Great*

% This is the best situation

The 3-D nonlinear input-output dependence generated by the carbon offset calculator is illustrated by the Fig. 7 family of control surfaces.

The above inference rule base is generic, intended only to present the structure we propose for the carbon offset calculator. Its validation may be achieved only on the base of validation data issued out of a RTG prototype and a precise *Cseq* laboratory measurement.

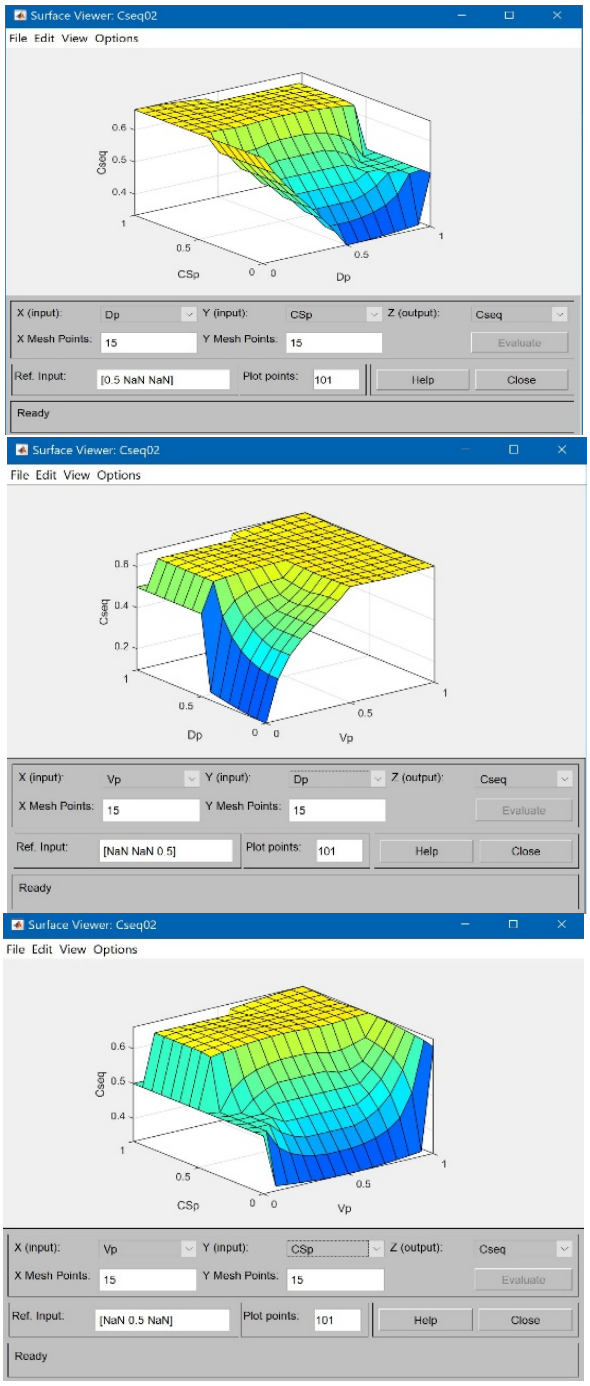


Fig. 7 – Carbon offset control surfaces for different values of the variables.

It is to remarq that the output variable which is for the moment *Cseq*, which can be precisely measured, will be replaced in the final product by *Coff*, the carbon offset.

The final implementation is intended to be built according to the *Fuzzy-Interpolative Methodology* (Balas, 2009), meaning a look-up-table with linear interpolation version of the FIS, which is further more efficient, in any possible software environment.

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5. Conclusions

The paper presents a fuzzy expert version of a software product, highly demanded by the carbon offsetting projects: the carbon offset calculator. We are applying it for a novel concept, the intelligent rooftop greenhouse, and instead of directly measuring the carbon offset, which is virtually inaccessible, we work with the carbon sequestration, assumed as the integral of the carbon offset.

Comparing to the commercial carbon offset/footprint calculators, the fuzzy expert solution is representing the knowledge in a transparent manner, which is facilitating the research on the atmosphere's decarbonizing projects.

The future work concerning this subject will be the validation of the rule base on behalf of experimental data and the fuzzy-interpolative implementation.

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CALCULATOARE PENTRU OFFSETUL DE CARBON

(Rezumat)

Tendința actuală de încălzire globală este semnificativă, deoarece este legată de activitățile umane începând de la mijlocul secolului al XVIII-lea. Încălzirea climatică din zilele noastre coincide cu creșterea concentrației de gaze cu efect de seră din atmosferă, în special a bioxidului de carbon. Unele soluții, cum ar fi agricultura urbană, sunt dezvoltate cu scopul de a le opune acestui fenomen. Ne propunem să studiem o soluție de creștere a fixării carbonului în mediile urbane - clădirile cu acoperiș seră - și această lucrare introduce un instrument util pentru estimarea eficienței proiectelor de acest fel, respectiv o aplicație de tip fuzzy expert, realizată în MATLAB, pentru estimarea în timp real a capacității de fixare a carbonului. Continuarea acestei lucrări va consta validarea bazei de reguli pe baza datelor experimentale și implementarea fuzzy-interpolativă.