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# Albedo control as an effective strategy to tackle Global Warming: A case study

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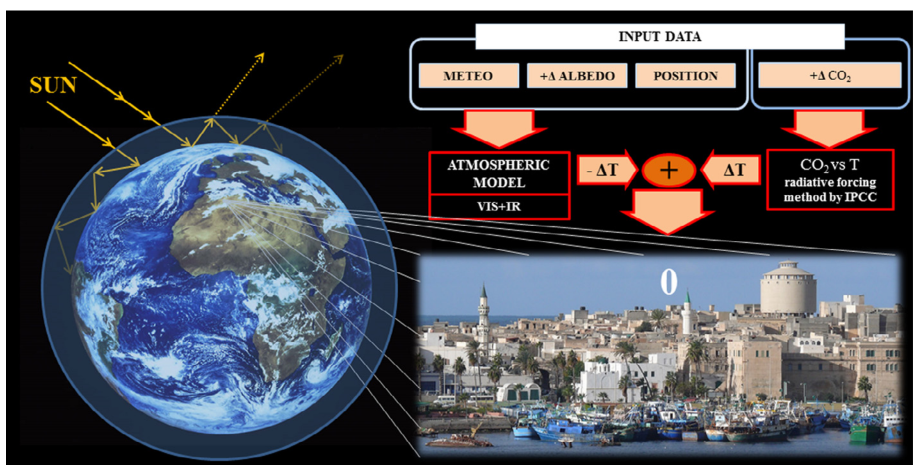
## HIGHLIGHTS

- We modeled the energy exchanges for the system Earth–Atmosphere–Outer space.
- We proposed a method quantifying the $CO_{2eq}$ offset potential of high-albedo surfaces.
- We presented the application of the method to a case study in Tunis.
- The $CO_{2eq}$ offsetting potential depends on the geometry-orientation of the surfaces.
- An economic value was attributed to the Albedo control compensation mechanism.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Recent research developments focused on Climate Change issue aimed at achieving Kyoto targets. In this context, an innovative methodology (officially recognized by WEC in 2009) is proposed to mitigate Global Warming by artificially enhancing earth's Albedo. Such a methodology allows to quantify the maximum environmental benefit achievable through the installation of Albedo control technologies, as a function of the geographical features of the installation site, local meteorological conditions, radiative properties, tilt angle, and orientation of the surfaces. This benefit is directly quantified in terms of $CO_{2eq}$ offset. Albedo control can be an effective mitigation strategy by means of three synergistic effects: a direct contribution towards Global Warming mitigation produced by an enhanced reflection to the space of the shortwave incident radiation; the indirect contribution from energy saving in buildings with high Albedo envelopes; the indirect contribution from the mitigation of Urban Heat Island phenomenon. Since the effectiveness of Albedo control is mostly relevant in Mediterranean area, for both climate conditions and historical-architectural heritage, this work presents procedures and findings of the ABCD project (Albedo, Building green, Control of Global Warming and Desertification) concluded in 2012, funded by the Italian Ministry for the Environment. A description of the analytic model is also presented. The paper focuses on the appli-

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cation of the methodology to a Tunisian factory site, showing that approximately 16,000 $tCO_{2eq}$ could be offset in 30 years with the installation of about 115,000 $m^2$ of high-reflective surfaces. Finally, a tradable value (ETS carbon credits) for Albedo control technologies is proposed.



**Nomenclature**

*Abbreviations*

| | |
|---|---|
| IPCC | Intergovernmental Panel on Climate Change |
| RF | radiative forcing |
| ETS | emission trading system |
| CIRIAF | Interuniversity Research Center on Pollution and Environment "Mauro Felli" |
| UHI | Urban Heat Island |

*Symbols*

| | |
|---|---|
| $r$ | coefficient of reflection |
| $L$ | latitude |
| $\beta$ | tilt angle |
| $\gamma$ | azimuth angle |
| $\theta$ | incident angle of the sun's rays |

## 1. Introduction

European Directives (following the Kyoto Protocol) reserve a particular focus to the improvement of environmental policies and strategies for Member States in order to cope with Climate Change [1]. According to this common task, several technologies (both innovative and conventional ones) have to be combined and further investigated to tackle Global Warming [1]. Over the period 1880–2012 the globally averaged combined land and ocean temperature increased by 0.85 K [2]: polar and continental glaciers have been melting and the ocean level has been increasing (1.8 mm/year in the period of 1961–2003). The high rate of frequent and intense extreme weather phenomena (hurricanes, floods, drought, etc.) represents a direct consequence of this trend.

Climate Change effects are evident (e.g. Mauna Loa Observatory data [3]) in this historical phase and almost the entire scientific community agrees that human activities are responsible for the heating of the earth surface [4]. Also the IPCC [2] Intergovernmental Panel on Climate Change, in its Fifth Assessment Report, Technical summary, states that "very likely[1]" the cause of Climate Change has to be attributed to anthropogenic activities. The rapid and continuous increase in concentration of greenhouse gases and the lack of policies and technical instruments to counteract the phenomenon requires to propose sustainable, technically-simple, and relatively cheap solutions to be applied in countries with limited economic resources to control the global average temperature increase. Until today, the Kyoto Protocol has been the only significant instrument to control $CO_2$ emissions. It required the 38 signatory states to reduce their emissions by 5% (with respect to 1990 levels) during the 2008-2012 commitment period.

Recent studies showed that the Global Warming reduction would have been very low (3–10% in a century) even if all involved countries fulfilled the Kyoto goals. Moreover many nations, including the United States (responsible for 36.1% of the total $CO_2$ emissions), refused to ratify the agreement and no limitation has been required for developing countries (that contribute to half of the world total greenhouse gas emissions). On the other hand, the same greenhouse gas emission control policies adopted by industrialized countries could have negative consequences for reducing countries development. Therefore, the Protocol itself can be considered as the first step towards the Global Warming mitigation but further improvements are strongly required. With respect to the available technologies to mitigate Global Warming, a major place is occupied by the renewable energies (e.g. wind, solar, hydrogen and biomass [5–9]) together with the improvement of energy efficiency and energy saving strategies [10,11]. Carbon capture and storage systems (CCS) are also important strategies against Global Warming [12–14] with promising future improvements in terms of costs-efficacy.

In this context, the earth surface reflectance increased through the implementation of cool roofs and other high-albedo techniques [11]. The reduction of the amount of energy that contributes to the earth warming could represent an effective solution in order to reduce the Global Warming and compensate the effect produced by the emission of greenhouse gases into the atmosphere. In order to quantify such a positive effect (in terms of $CO_{2eq}$ offset), CIRIAF developed an innovative methodology for the evaluation of the $CO_{2eq}$ abatement potential of high reflective surfaces as a function of the geographical features of the installation site (e.g. latitude), local weather conditions, tilt angle and orientation of the covered areas [15]. This methodology could be applied in order to estimate the further global environment benefit of cool roofs and high Albedo surfaces when they are exposed to direct solar radiation, in terms of their $CO_2$ offset potential. Such a benefit could be added to the energy savings produced by cool roof technologies via the reduction of the building energy demand for cooling [16–18]. Further research efforts also focused on the development of new cost effective materials, e.g. retro-reflective materials, that are able to reflect the incoming radiation into space, without contributing to the overheating of very dense urban areas and to the Urban Heat Island phenomenon [19–21]. Focusing on a planetary perspective, the Global Warming can be counteracted using marine aerosols [22–24].

To this aim, high-reflective materials (e.g. cool roofs), can be also used to achieve energy savings and energy efficiency in buildings. Cool roofs are those techniques aimed at achieving high solar reflectance and high thermal emissivity of the building roof [11]. These properties lead to a clear and strong tendency of cool roofs materials to stay cooler than the materials conventionally used in traditional roofing constructions, when subjected to continuous solar irradiation [25]. The benefits generated by cool roofs technologies are currently mainly related to the indoor microclimate and the corresponding reduction of electricity demand for cooling. In fact, the installation of a cool roof can result in energy savings, increased human thermal comfort (both indoors and outdoors) and significant positive impacts on urban environmental quality [26–31].

[1] 95% probability level.