ANALYSIS OF GLOBAL WARMING MITIGATION BY WHITE REFLECTING SURFACES

Federico Rossi, Andrea Nicolini
University of Perugia, CIRIAF
Via G.Duranti 67
06125 Perugia, Italy
T: +39-075-5853846; F: +39-075-5848470; E: frossi@unipg.it

The rapid increase in greenhouse gas (GHG) concentration over the last 50 years has produced approximately 0,64 Celsius degrees rise in global mean temperature. The most worrisome effects of global warming include severe weather and related hydro-geologic events, many of which have been already occurring. Earth's global surface temperature strongly depends on its surface radiative properties. Solar radiation absorbed by surface, together with a natural atmospheric greenhouse effect, represents the mechanism regulating Earth's temperature. Therefore, Earth's albedo modification by proper surfaces would reduce the portion of solar radiation absorbed by the Earth, and consequently decreased average global temperature. Quantification of reflecting surface effectiveness has been accomplished through mathematical relations, based on the energy balance among sky, atmosphere and earth surface. The correlation between the temperature reduction and the greenhouse gases decrease in the atmosphere has been calculated on the hypothesis that the temperature increase in the last century has been caused exclusively by the GHG concentration variation occurred in the same period. It has been estimated by a specific model that the reflecting surface area which is required to offset the effect, in terms of global mean temperature, of introducing in the atmosphere of 1 ton of CO_{2eq} is equal to 8 square meters. In terms of Radiative Forcing, a drop of 0.28 W/m^2 is obtained for each 10^6 km^2 of surfaces with reflection coefficient of 0.9. Furthermore, greenhouse gas "abatement" cost through reflecting surfaces has been compared to the one obtained by the main renewable energy sources (see Tables 1 and 2).

Table 1: CO_{2eq} avoided emissions using energy renewable sources.

Technology	***Avoided emissions***
	gCO_{2eq}/kWh
Ribbon silicon	365
Photovoltaic mono/multicrystalline silicon	355
Thermal solar (flat collector)	210
Wind generator	394
Hydroelectrical	385

Table 2: CO_{2eq} avoided emissions using white reflecting technology.

Technology	***Avoided emissions***
	$kgCO_{2eq}/m^2$
Reflecting surfaces	130

In the hypothesis of producing white "reflecting" surfaces through simple laying of one or more coats of paint, greenhouse gases (GHG) emissions strictly depend on

paint type. A surface coated with water based paint emits about 3 $kgCO_{2eq}/m^2$ over a period of 10 years. When the coating is made of solvent based paint, the GHG emissions double. However, such a contribution can be neglected: a surface with a 0.9 solar light reflection coefficient compensates, during its life cycle, for the introduction in the atmosphere of approximately 130 $kgCO_{2eq}/m^2$ (see Table 1). The above tables do not immediately allow a comparison of renewable energy sources with white reflecting technology in terms of avoided CO_2, as the former are systems to produce energy whereas the latter is a system to mitigate Earth average global temperature. A comparison method is proposed, based on the cost necessary to avoid the same amount of emitted CO_{2eq}:

$$C_{CO2} = \frac{CP_{FR} - CP_{FF}}{E_{FF} - E_{FR}}$$

where CP_{FR} is the energy unit production cost in c€/kWh for renewable sources, CP_{FF} is the energy unit production cost in c€/kWh for traditional sources, E_{FR} are CO_{2eq} emissions ($kgCO_{2eq}$/kWh) with renewable energy sources, E_{FF} are CO_{2eq} ($kgCO_{2eq}$/kWh) emissions with traditional energy sources. The reference price for white reflecting surfaces is the cost of paint, marked up of 20% to include the labour cost necessary to produce and efficiently operate the surfaces. The comparison is shown in Table 3.

Table 3: Comparison of avoided CO_{2eq} emission costs between different renewable sources and the white reflecting technology.

Technology	**Avoided CO_{2eq} costs**
	c€/$KgCO_{2eq}$
Ribbon silicon	59.0
Photovoltaic mono/multicrystalline silicon	60.5
Thermal solar (flat collector)	30.0
Wind generator	3.8
Hydroelectrical	2.6
Reflecting surface made by lime paint	4.0
Reflecting surface made by vinyl acrylic paint	5.0

Thus, the use of reflecting surfaces can be an important alternative to compensate for greenhouse gas introduction in the atmosphere. With a price ranging from 5.0 c€/$KgCO_{2eq}$ down to 4.0 c€/$KgCO_{2eq}$ such a technology shows reduction costs in line with the most affordable renewable sources, with the added advantage of simplicity reduced installation time. Such features makes this technology particularly suitable for countries where higher levels of insolation make the system even more effective and valuable in terms of avoided CO_2. A surface installed in a Saharan desert area is expected to have an effectiveness 3-4 times higher than an equivalent surface elsewhere. Therefore, a cooperation research project is going to start among Italian research centers (CIRIAF – Interuniversitary Center on Pollution from Physical Agents, CRC – Climate Research Center, CRB – Biomass Research Center, IPASS – Consortium for Environmental Engineering and Sustainable Development, CETMA – Center for Design and Technologies of Materials) and Tunisian scientific and operative agencies in order to test the suitability of the proposed technology.

International Conference
CO2 Summit: Technology and Opportunity
Vail, Colorado
June 6-10 2010

ANALYSIS OF GLOBAL WARMING MITIGATION BY WHITE REFLECTING SURFACES

Federico Rossi*, *Andrea Nicolini
University of Perugia, CIRIAF
Via G.Duranti, 67 – 06125 Perugia, Italy

BACKGROUND

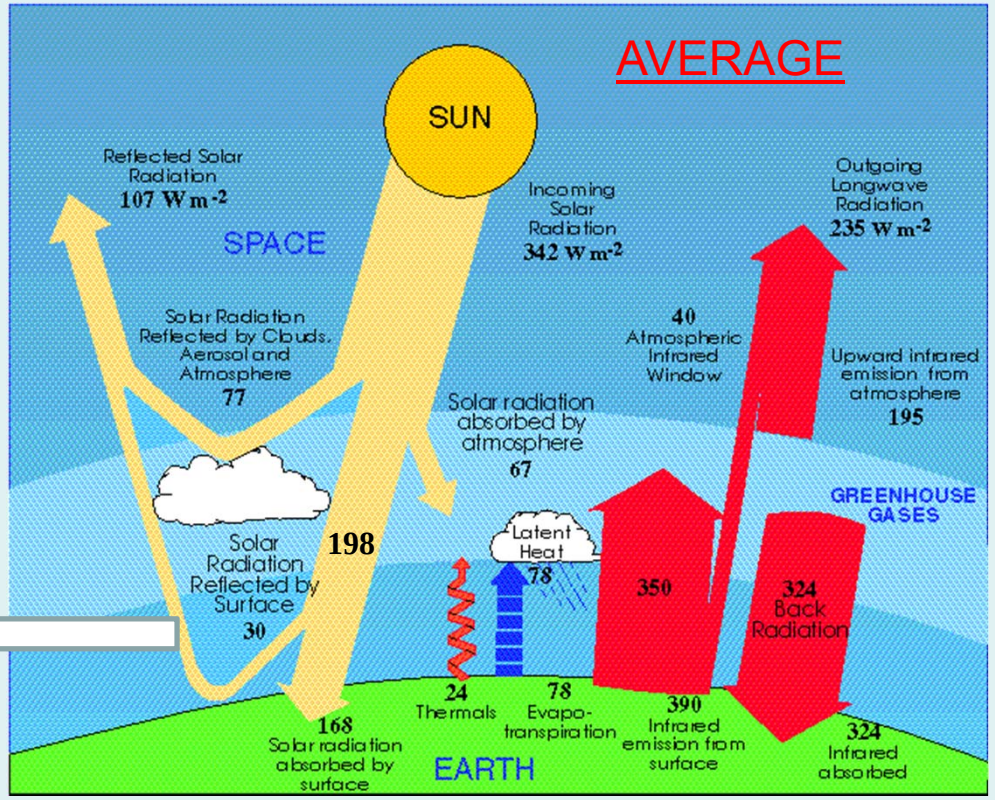
IPCC Fourth Assessment Report say that Earth's average temperature increase is due to anthropogenic causes.

Approaches to tackle Global Warming are aimed to prevent CO_2 release into atmosphere

These methods are also supported by recent policies as:
- Emission Trading Scheme (ETS)
- Kyoto Protocol
- European 20-20-20 Programme

Are there complementary approaches to tackle Global Warming?

The answer may be found in the Earth thermal balance.



AVERAGE

$$\frac{30}{198} = 15.2\%$$

An important role is played by Earth Albedo = shortwave energy reflected by the Earth towards outer space.

• An increase on Earth albedo corresponds on Earth temperature decrease.

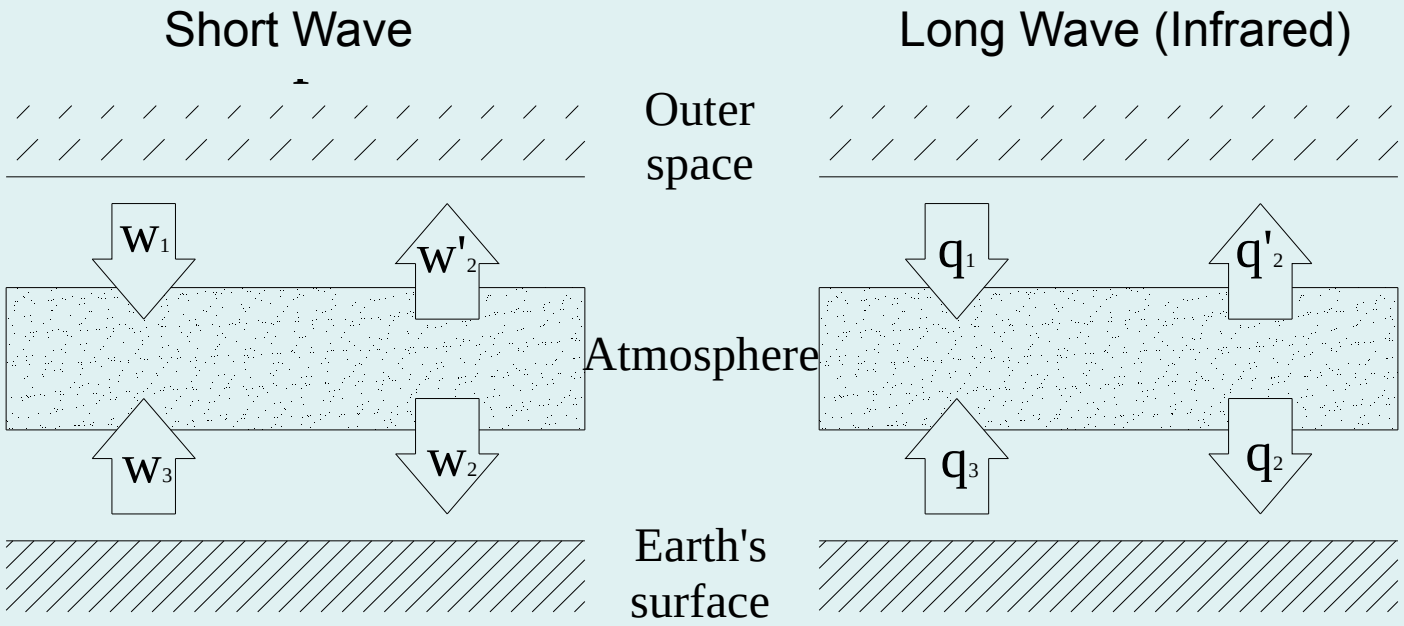
•The proposal is to artificially slightly modify Earth albedo in order to compensate Earth temperature increase due to Global Warming

To make it viable and controllable

1. A proper thermal balance model has been formulated which links Earth albedo to Earth temperature

2. A proper relation has been also proposed which links Earth albedo to CO_2 concentration variation

MODEL SCHEME



Energy balance (both in short and long wave spectrum) is governed by:

$$w_3 + w_1 + q_3 + q_1 - w_2 - w'_2 - q_2 - q'_2 = C_{atm} \cdot \frac{dT_{atm}(\tau)}{d\tau}$$ (Atmosphere)

$$w_2 + q_2 - w_3 - q_3 = C_{Earth} \cdot \frac{dT_{Earth}(\tau)}{d\tau}$$ (Earth)

MODEL MOTHER RELATIONS

$$w_3 + w_1 + q_3 + q_1 - w_2 - w_2' - q_2 - q_2' = C_{atm} \cdot \frac{dT_{atm}(\tau)}{d\tau}$$ (Atmosphere)

$$w_2 + q_2 - w_3 - q_3 = C_{Earth} \cdot \frac{dT_{Earth}(\tau)}{d\tau}$$ (Earth)

Earth surface (C_{Earth}) and atmosphere (C_{atm}) "heat capacities" represent equivalent heat capacities because only a portion of each body takes part to energy balance. Determination of C_{Earth} and C_{atm} has been carried out by calibrating the model with the climatic data reported by the Fourth Assessment Report by IPCC.

MODEL OUTPUT

By considering a steady state condition:
T_{Earth} (Earth temperature) may be attained by the following relation:

$$T_{Earth} = \frac{-1}{\sigma_0\alpha_3(-1-\rho_2+\rho_2 r_3 r_2 - r_3 r_2 - \tau_2 r_3 r_2 + \tau_2)}[-\sigma_0\alpha_3\cdot(\rho_2-\tau_2-1)\cdot[-\sigma_0\alpha_3\cdot(\rho_2-\tau_2-1)\cdot\omega_1\cdot(r_3 r_2-1)\cdot$$
$$(t_2\rho_2\rho_3 - t_2 r_3\rho_2\rho_3 + \tau_2\rho_3 t_2 r_3 - t_2^2 r_3\rho_3 - \rho_3 r_2 - \rho_3 r_3 r_2 + r_2^2\rho_3 r_3 + \rho_3 - \tau_2\rho_3 t_2 + r_3 r_2 + t_2 - 1 + r_2 +$$
$$- r_2^2 r_3 + t_2^2 r_3 + t_2 r_3)]^{\frac{1}{2}}\cdot(r_3 r_2 - 1)]^{\frac{1}{2}}$$

- α_3 infrared Earth's surface absorption coefficient
- ρ_2 infrared atmosphere reflection coefficient
- ρ_3 infrared Earth's surface reflection coefficient
- σ_0 Stefan-Boltzmann constant
- τ_2 infrared atmosphere transmission coefficient
- ω_1 incoming solar flux (342 W/m^2)
- r_2 atmosphere reflection coefficient in the solar spectrum
- r_3 Earth's surface albedo in the solar spectrum
- t_2 atmosphere transmission coefficient in the solar spectrum

As you can see, T_{Earth} depends on r_3 (Earth Albedo) which is artificially and impactless modifiable.

$$\left(\frac{dT_{Earth}}{dr_3}\right) = \text{Sensibility of } T_{Earth} \text{ to albedo}$$

Earth temperature average increase since preindustrial era to the present day is 0.67 °C (IPCC Fourth Assessment Report).

Albedo modification can produce a 0.67 °C reduction
in Earth average temperature

The proposed model shows that the average absorption coefficient of Earth surface a_3 (= 1-r_3) in shortwave spectrum is to be reduced from:

0.848 to 0.834 (a_3').

If albedo modification is achieved by artificial "laying high albedo surfaces (albedo r = 0.9)", the required area S_r is given:

$$S_r = \frac{(a'_3 - a_3) \cdot S_T}{1 - r - a_3}$$

- a_3 Earth's surface absorption coefficient in the visible spectrum
- a_3' Earth's surface absorption coefficient in the visible spectrum modified by laying white reflecting surfaces
- r artificial surface albedo
- S_T extent of Earth's surface

S_r is $9.36 \cdot 10^6$ km^2 @ r = 0.9

(This is roughly the area of USA)

To relate temperature increase to CO_2 concentration variation, the following hypothesis has been considered:

CO_2 concentration increase since preindustrial to the present day is the only cause which yielded the Earth temperature increase.

$+1.23 \cdot 10^{12}$ tCO_{2eq} → + 0.67 °C ± 0.18 °C

(CO_{2eq} total mass increase) (Earth temperature increase)

(By IPCC Fourth Assessment Report data)

CO_2 concentration increase

280 ppm → > 380 ppm
(pre-industrial era) (today)

The High Albedo Surface area S_{eq} required to offset the effect of introducing in the atmosphere 1 ton of CO_{2eq} has been obtained as follows:

$$S_{eq} = \frac{S_r}{\Delta CO_{2eq}} = \frac{9.36 \cdot 10^{12}\ m^2}{1.23 \cdot 10^{12}\ tCO_{2eq}} = 7.6\ \frac{m^2}{tCO_{2eq}}$$

S_r = High Albedo Surface area required to offset a 0.67 °C Earth temperature increase.

ΔCO_{2eq} = CO_{2eq} total mass increase from preindustrial to the present day

In terms of Radiative Forcing, a drop of 0.28 W/m^2 is obtained for each 10^6 km^2 of surfaces with 0.9 albedo.

HOW TO ARTIFICIALLY MODIFY ALBEDO?

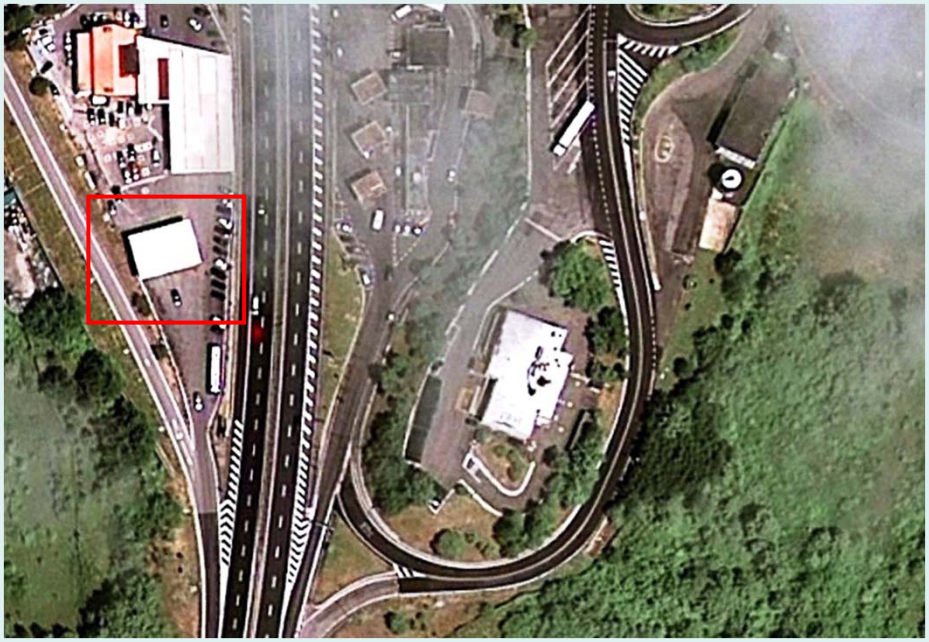
SOLUTIONS AND APPLICATIONS

1. Whitening treatment of industrial building roofs
2. Whitening treatment of highways and parking areas
3. Reactivation of unused salt lakes
4. Installation of new saltworks in low value areas (industrial areas or petrochemical sites on the coasts
5. Plantings of species with particular chromatic properties
6. Artificial white reflecting floating islands

(Italian patents PG2006A0086 and PG2007A0009)

ALREADY CERTIFIED EXAMPLES

A typical reflecting painting realized on silos (Perugia, Italy)



Reflecting covering of a Total Service station (Fiorenzuola, motorway A1, Italy)

AVOIDED CO_2 EMISSIONS (COMPARISON WITH RENEWABLE SOURCES)

Technology (CO_{2eq} Emissions)	*Reference Technology (CO_{2eq} Emissions)*	*Avoided emissions*
		gCO_{2eq}/kWh
Ribbon silicon ($35\ gCO_{2eq}/kWh_e$)	**Combined cycle gas turbine** ($400\ gCO_{2eq}/kWh_e$)	365
Photovoltaic mono/multicrystalline silicon ($45\ gCO_{2eq}/kWh_e$)		355
Wind generator ($6\ gCO_{2eq}/kWh_e$)		394
Hydroelectrical ($15\ gCO_{2eq}/kWh_e$)		385
Thermal solar (flat collector) ($20\ gCO_{2eq}/kWh_t$)	**Boiler stoked with natural gas** ($230\ gCO_{2eq}/kWh_t$)	210

Technology	*Avoided emissions*
	$kgCO_{2eq}/m^2$
White Reflecting Surfaces (0.9 albedo)	130

TECHNICAL ECONOMICAL EFFECTIVENESS

The mentioned tables do not immediately allow comparison of renewable energy sources with white reflecting technology in terms of avoided CO_2, as the former are systems to produce energy whereas the latter is a system to mitigate Earth average global temperature.

A comparison method is proposed, based on the cost required to avoid the same amount of released CO_{2eq}.

$$C_{CO2} = \frac{CP_{FR} - CP_{FF}}{E_{FF} - E_{FR}} \quad \left[\frac{c€}{kgCO_{2eq}}\right]$$

CP_{FR}	Energy unit production cost for renewable sources [c€/kWh]
CP_{FF}	Energy unit production cost for traditional sources [c€/kWh]
E_{FR}	CO_{2eq} emissions with renewable energy sources [$kgCO_{2eq}$/kWh]
E_{FF}	CO_{2eq} emissions with traditional energy sources [$kgCO_{2eq}$/kWh]

TECHNICAL ECONOMICAL EFFECTIVENESS

Technology	*Avoided CO_{2eq} costs*
	c€/KgCO_{2eq}
Ribbon silicon	59.0
Photovoltaic mono/multicrystalline silicon	60.5
Thermal solar (flat collector)	30.0
Wind generator	3.8
Hydroelectrical	2.6
Reflecting surface made by lime paint	4.0
Reflecting surface made by vinyl acrylic paint	5.0

CONCLUSIONS

Albedo Control can be an important complementary method to compensate greenhouse gases effect on Earth temperature because of:
- Lower costs (4-5 c€/KgCO_{2eq}) than renewable energy sources for avoiding the same CO_2 effect;
- Easiness and short time for installation;
- Opportunity for countries where higher levels of insulation make the system even more effective and valuable in terms of avoided CO_2

ABCD RESEARCH PROJECT
(Albedo – Building green – Control of global warming – Desertification)

A cooperation research project is going to start among Italian research centers and Tunisian scientific and operative agencies. The project main purpose are:
-verify and certify the performances of the proposed technology;
- include Albedo Control method into ETS system

FOR MORE INFO

albedocontrol.com