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RELATIONSHIP BETWEEN ANTHROPOGENIC REFLECTIVE SURFACES AND GLOBAL TEMPERATURES: AN UNEXPECTED COMBINATION FOR THE FUTURE OF CLIMATE

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Introduction

Global warming and climate change is, without a doubt, one of the most debated scientific topics of the 21st century.

Beyond the prejudices shown by the different factions of the scientific community on these issues, it is believed that, in addition to the acclaimed global policies implemented, considered the only valid ones for the reduction of global temperatures related to the emission of greenhouse gases, it is important to expand scientific research in order to consider new and different approaches, probably less vexing for the world population and easier to apply, which can intervene on the increase in temperatures and the consequent energy balance of the planet Earth.

Among these possibilities, a strategy that has mobilized, in recent years, a growing interest from a minority of the scientific community is that of the positive effect induced by artificial reflective surfaces on the global temperatures of the planet and on the possibility of being able to use such interactions/consequences, through a targeted increase in reflective surfaces, to control the growth of global temperatures.

In other words, artificially increasing the Earth's albedo, i.e. the Earth's ability to reflect sunlight tout court, could contribute to reducing the overall energy absorbed by the lithosphere and hydrosphere and the consequent emission of infrared radiation, notoriously responsible for the excitation of molecules belonging to the natural "greenhouse blanket", without which the Earth would be a glacial planet (-22° C) and substantially hostile to all humanity.

In particular, we evaluate how surfaces such as solar panels, agricultural greenhouses or white-painted roofs of buildings produce an increase in albedo in the areas where they are present, through the increase in additional reflectivity that could actually help limit global warming. It is as if we were providing the Earth with a reflective barrier, capable of rejecting part of the solar radiation and, consequently, alleviating climate pressure.

The aim of this article is to examine, on a local and global scale, what is the incidence, in orders of magnitude, of the presence of reflective surfaces and what is the action of a possible expansion of these surfaces and their consequent impact on the climate system. In particular, attention has been paid to how these surfaces influence phenomena such as cloud formation and atmospheric circulation, two key factors for regulating the climate and the alarming increases in temperatures.

Development of global reflective surfaces

Over the last twenty years, we have witnessed a remarkable expansion of artificial reflective surfaces distributed on the surface of the Earth, which, in various ways, affect different areas of interest, including that of photovoltaics with the installation of solar panels, the agronomic one, with the presence of increasingly high-performance greenhouses and that of reflective building materials.

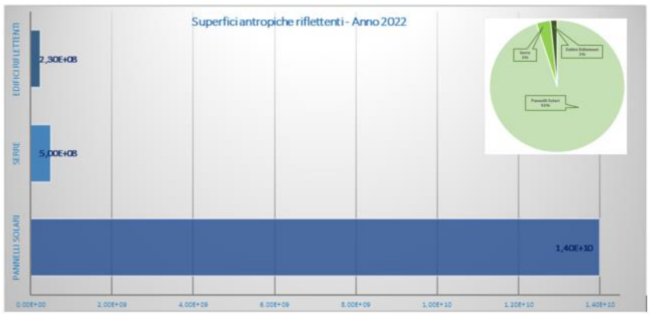
In relation to the analyses conducted to evaluate the possible benefits on the interference between these structures and global temperatures, the results of the analyses conducted on the growth rates, in the last twenty years, are proposed below, providing the representative value of the coverage of the earth's surface in 2022 and its forecast for 2030.

It should be noted that, for the purposes of this article, no site measurements were conducted, as they were not necessary for the objectives set. Instead, the data present in specialized literature were assumed as true, with reference to the order of magnitude of the parameters sought. Systematically, we have:

a. **Photovoltaic systems**. The adoption of photovoltaic solar panels has seen an exponential expansion in the last twenty years, with a coverage of over 1.4 ^1010 m2 achieved in 2022. The installation of these systems was carried out to generate electricity, without taking into account the reflective power of a fraction of the solar radiation absorbed by them. This mechanism, however, appears to be of considerable interest as it directly influences the value of the Earth's albedo, with consequences that may vary based on the region where they have been installed. Specifically, their reflectance effect on solar radiation may contribute to reducing heat accumulation in the lithosphere and hydrosphere, producing microclimatic consequences that are believed to be of particular scientific interest and therefore should be carefully considered.

b. **Protected cultivation facilities**. Greenhouses, which are in fact protected cultivation facilities designed to create a controlled and optimal environment for plant growth, regardless of external weather conditions, have reached an estimated total surface area of approximately 5^108 m2 in 2022.
Such systems help to reflect a significant part of the solar radiation even if their impact on the albedo is certainly lower than that produced by photovoltaic systems.
However, from the analyses conducted, their diffusion, with an annual growth rate of about 5%, represents a considerable contribution to the global energy balance.
Unlike photovoltaic systems, greenhouses, designed to maintain a comfortable environment for cultivation, contribute to the climatic effects by modulating the amount of reflected radiation, producing clear effects on local climatic conditions.

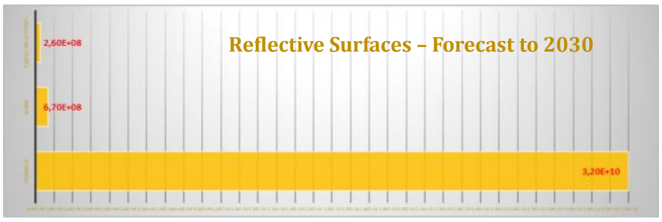
c. **Reflective Buildings** Reflective materials increasingly used in the definition of modern architectural works, such as white building roofs (cool roofs), play a key role in mitigating the "heat island" effect in cities, contributing to the regulation of urban temperatures.
With a total surface area of 2.3^108 m2, these structures, in fact, in addition to directly reflecting part of the solar radiation, help to reduce the internal temperature of buildings, decreasing the need for artificial cooling and, consequently, the energy consumed for this process, producing an indirect contribution to global temperature in both environmental and economic terms.



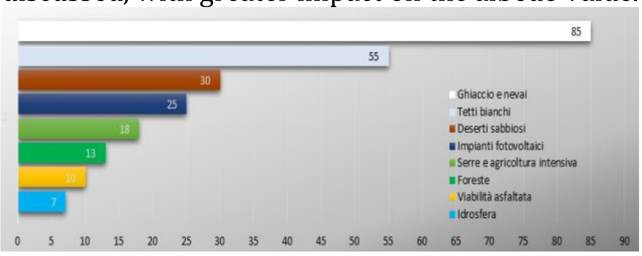
Based on the data presented above, a forecast of development and growth for the different areas up to the year 2030 has been hypothesized. This estimate has been defined solely on a “constant average annual growth” derived from the limited historical growth data obtained in the last ten years, considering such projections more plausible than speculations linked to the application of different mathematical laws and conditioned by exclusively objective analysis parameters.

Specifically, a percentage increase of 15% was estimated for photovoltaic systems, 5% for protected cultivation areas and only 2% for reflective buildings.

This average annual growth percentage rate was subsequently applied to the surfaces surveyed in 2022, obtaining a forecast increase, by category, as shown below:



Below, for completeness of information and for appropriate comparison and consecutive objective evaluation, a representation is proposed, in percentage orders of magnitude, of the natural and anthropogenic reflecting classes, previously discussed, with greater impact on the albedo value.



The influence of reflective surfaces on the origin of clouds

Reflective surfaces not only directly influence the Earth's albedo, but also play an indirect role in regulating cloud formation and atmospheric circulation.

By modifying the thermal gradients and heat flow between the Earth's surface and the atmosphere, these surfaces reduce the heat available for evaporation and evapotranspiration, decreasing the amount of water vapor and, consequently, the formation of clouds.

As surface temperatures rise, the atmosphere's capacity to hold water vapor increases, amplifying global warming.

However, increasing reflective surfaces tends to reduce ground temperatures, thereby lowering evaporation rates and the amount of water vapor available to clouds.

This process, therefore, can limit cloud cover in some areas, also influencing atmospheric cooling. In some cases, however, the increase in the Earth's albedo can strengthen thermal inversions, retaining moisture close to the ground and thus favoring the formation of low clouds that act as a protective shield against solar radiation.

This dual effect highlights the complexity of the climate dynamics induced by the expansion of reflective surfaces and suggests that their widespread adoption should be carefully considered in the context of integrated climate strategies.

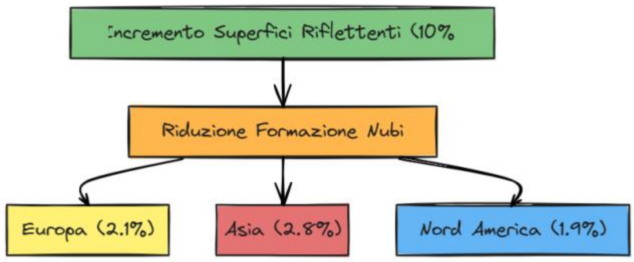
The study conducted by J. Smith et al. (2022) estimated that a 10% increase in reflective surfaces distributed in urban areas would induce a reduction, at a local scale, in cloud formation of between 2 and 3%. This data is largely influenced by the geographical region and the local climate to which it refers.

Below is a summary table that summarises the average results indicated in the study cited:

Region	Increase Reflective Surfaces (%)	Reduction Cloud Formation (%)
Urban Areas Europe	10	2.1
Urban Areas Asia	10	2.8
North America Urban Areas	10	1.9

Estimated reduction of clouds in relation to the increase of reflective surfaces

These values suggest the relationship between reflective surfaces and clouds.



Specifically, the increase in reflective surfaces can significantly influence cloud formation, with effects that vary depending on local conditions.

The study conducted defined the relationship between clouds and urban contexts; specifically, it was observed that the effect of cloud reduction in urban contexts can have implications both on the availability of rainfall and on atmospheric cooling, making further research necessary to fully understand the aforementioned dynamics.

An intuitive example that is presented to support what has been stated is based on the assumption that all urban roof surfaces in metropolitan areas, located in hot climates, are made reflective.

This idea, which is actually possible to implement compared to the “castrating” initiatives implemented today, would produce an increase in global albedo that would offset the effect of global warming equivalent to 24 Gt of greenhouse gas emissions. Essentially, it would be equivalent to eliminating about 300 million cars from circulation every 20 years.

Interference between reflective surfaces and wind circulation

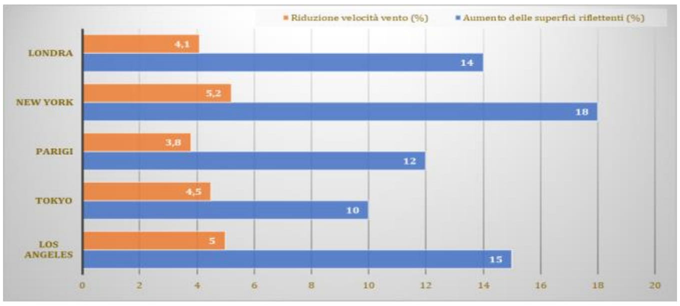
The basic elements of climatology show us that, as is well known, the cooling of surfaces in contact with air masses has as a direct consequence a reduction in pressure gradients, effectively generating a significant disturbance in the speed of local winds.
This consequence, also in this case, produces a direct interference with the reflective surfaces, considering that their increase interferes significantly with the circulation of local atmospheric currents.
Specifically, the reflection of more solar energy alters the distribution of heat, significantly influencing the movement of air.

A particularly significant effect is observed in the so-called "heat islands" (on the side), in which temperature increases (mustard line) are observed, even very significant ones, in relation to the density of human presence.
However, the analysis of data present in the literature allows us to state that the presence of reflective surfaces such as white roofs and building cladding contribute to reducing urban heating on average by about 35% (blue line), with peaks even above 50%, causing a weakening of the ascending currents and reducing the wind speed.
The alteration of wind circulation not only affects local conditions in terms of temperature but can have indirect effects on other climatological parameters, cooperating to reduce or increase localized manifestations such as cloud formation.
These alterations are closely connected, in a notable manner, with the geographical location of the site in terms of latitude and the presence of large masses of water.

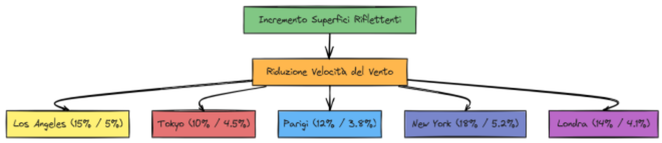
For example, reduced updraft from cooler surfaces triggers changes in ventilation patterns that limit the atmosphere's ability to disperse pollutants in some regions, creating localized conditions of high pollution.
A study conducted in California on the relationship between the reduction of wind speed and the increase in reflective surfaces revealed that the diffusion of reflective roofs in urban areas of large cities can produce a reduction in the average wind speed varying between 5 and 8% in the central hours of the day.

City	Reflective Surfaces Increase (%)	Wind Speed Reduction (%)
Los Angeles	15	5
Tokyo	10	4.5
Paris	12	3.8
New York	18	5.2
London	14	4.1

Effect of increasing reflective surfaces on wind speed in different urban areas



Reduction of wind speed in relation to the increase of reflective surfaces



The reduction of wind speed, therefore, significantly affects the urban microclimate, as a reduction in speed can reduce heat dispersion, contributing, in fact, to keeping urban areas cooler.
This interference is intensified when there are areas with artificial shading and vegetation of urban parks.
However, the reduction of wind can also have a negative effect, as a reduced air circulation can reduce the dispersion of air pollutants, allowing, if no specific mitigation measures are foreseen, such as the limitation of vehicular traffic, the accumulation of pollutants and worsening the air quality in the city.

Effects of the increase in reflective surfaces on a global scale

While local overlaps and effects can, as seen, be significant and determinant of peculiar climatic conditions, the global effect of reflecting surfaces on atmospheric circulation and cloud formation appeared more complex, showing the need to define more sophisticated, multi-variable models that are not easy to predict.
Although climate simulations suggest that albedo increases in specific areas influence large-scale local wind patterns, this is not the case on a global scale, where such changes, resulting from movements of huge air masses that interfere with ocean expanses, mountain ranges, and large desert and steppe areas, are difficult to quantify, also due to the absence of long and complete time series of data that would allow statistical treatments of complex models and consequent forecasts.
However, some hypotheses of global climate models present in the literature show that a 20% growth of reflective surfaces on the entire planet could reduce the circulation of winds at a global level by about 1-2%, with potential secondary effects on precipitation. Specifically, there would be reductions in precipitation due to the decrease in transport resulting from the decrease in the circulation of winds, of the humid critical masses, especially in those terrestrial areas where such phenomena are linked precisely to the relevance of circulations in the atmosphere, such as the monsoon zones that determine the two seasonal cycles characterized by humidity and rain when the winds blow towards the land and dry otherwise.

Climate models and future projections

Current climate models, such as those used by the Intergovernmental Panel on Climate Change (IPCC), are beginning to integrate the role of reflective surfaces in simulating future climate projections, recognizing that the presence of such surfaces impacts regional climate change predictions, with a particular impact on urban areas and dry climates, where the effect of reflective surfaces is most pronounced.
In fact, starting in 2016, the sixth phase of the Coupled Model Intercomparison Project (CMIP6) was launched with the aim of optimizing the representation of reflective surfaces and their impact on climate, with particular attention to urban areas and arid climates, where the effect of reflective surfaces is more pronounced.

At this stage, the importance of reflective surfaces, such as white roofs and changes in land use, in modulating the Earth's energy balance was recognized.
All this allows us to assert how important it is to strengthen research in this direction, since a demonstration of the interference of reflective surfaces on a planetary scale could lead to innovative measures to mitigate the rise in global temperature.

Simulating the effect of increasing albedo on global atmospheric circulation

The graph above illustrates, on a global scale, the areas where the increase in reflective surfaces has a significant impact on wind speed and air mass circulation.
The analyses conducted to simulate the variations in wind following the increase in reflective surfaces are based on a “simplified mathematical relationship” that describes how an increase in albedo in specific regions can influence the reduction in wind speed.
This relationship is based on the principle that an increase in albedo reduces the amount of solar energy absorbed by the Earth's surface, causing local cooling which, in turn, modifies temperature gradients and thus wind circulation.
Experiments show that increases in albedo can reduce wind speed by up to 2-3% in urban areas with high reflectivity rates, meaning that when albedo increases, the amount of heat absorbed by the Earth's surface decreases and this cooling reduces the temperature gradients that affect the strength of the winds and, consequently, their circulation.
However, it has been found that on large scales, the effect of albedo on atmospheric circulation is not linear and depends on multiple factors, including surface type, latitude, regional climate patterns, and topography.
Simulations in the literature propose complex modeling performed through the use of complex differential equations and numerical simulations based on the physical laws governing fluid dynamics, radiation and energy.

Conclusion

The increase in anthropogenic reflective surfaces affects the Earth's albedo, contributing to reduce global warming and, in fact, modifying the local atmospheric dynamics. However, even if this strategy could be seen as a useful component for climate mitigation, the increase of such surfaces must be considered with caution due to the potential secondary effects and their real long-term impact.

As we have presented, the increase in reflective surfaces has a significant impact not only on the Earth's albedo and global energy balance, but also on cloud formation and wind circulation. These effects manifest themselves at local and/or regional levels and are now recognizable through complex meteorological consequences, which require further studies and advanced climate models to be fully understood.

Therefore, evaluating the integration of reflective surfaces into global climate strategies could offer an opportunity to mitigate global warming, even if the long-term unwanted side effects are not yet known.

It seems important to consider the increase in reflective surfaces as a complement within a broader climate adaptation and mitigation strategy.

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