The ethics of terraforming Mars: a review

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Introduction

Terraforming of a planetary body (planet or moon) or *planetary ecosynthesis* is the hypothetical process of deliberately modifying its atmosphere composition, temperature, topography, or ecology to be similar to those of Earth to make it habitable for Terran organism, including humans. Terraforming is a common concept in science fiction. In fact, Jack Williamson, a science fiction writer, coined the term in 1942. But the first to use the concept was H.G. Wells in his *The War of the Worlds* (1898), where the martian invaders start a terraforming-reverse process in order to change our planet for their own benefit. But since the publication of *The Sands of Mars* in 1951 by Arthur C. Clarke, the great majority of stories regarding terraforming were settled on Mars. One recent example is the wonderful *Mars Trilogy* by Kim Stanley Robinson that has filled our dreams about the red planet with astonishing details.

In the scientific field, the first one who talk about terraforming of Mars was the ever-inspirational planetary astronomer Carl Sagan in *The Long Winter Model of Martian Biology: A Speculation* (1971) and in *Planetary engineering on Mars* (1973) both published in *Icarus*. In *Blues for the Red Planet*, the fifth episode of his mythical television series *Cosmos: A personal Voyage* (1980), he exposes his ideas to the public. Sagan's plan for terraforming of Mars implies seeding its polar caps with dark plants. These plants will be artificially selected or genetically modified to resist and "survive" the harsh conditions of Mars climate. The positive point gained with this seeding will be releasing oxygen and darkening the martian surface, melting down the polar caps and liberating the ancient martian atmosphere trapped in there. This fusion water could be transported to the equator by the construction of a network of channels, similarly to the one Percival Lowell believed an inexistent Martian civilization had constructed. Sagan's opinion about the ethics of this terraforming process, in the case the planet result not sterile is categorical: *"If there is life on Mars, then I believe we should do nothing to disturb that life. Mars, then, belongs to the Martians, even if they are microbes."*

But why is Mars, the planet of our Solar System, which has received so many attentions concerning the creation of a biosphere in there? In the current conditions of Mars there is no organism able to survive and in no way grow. However, increasing evidences are revealing a different and biologically interesting ancient history (McKay, 2010). This early wetter and warmer martian conditions together with its closeness are the primary basis for carry out a planetary ecosynthesis on Mars.

In the last years several review works about the concept of terraforming have appeared in the scientific literature. McKay and Marinova (2001) review the general aspects regarding the planetary ecosynthesis in the red planet. Graham (2004) has focused in the biological aspects of the creation of a biosphere on Mars and has delineated the stages of such a process. Finally Beech has written a book *Terraforming: The Creation of Habitable Worlds* (2009) in which the terraforming process is exhaustively analyzed. To delve deeper into the technical aspects of this exciting process, we recommend the reading of such works.

The purpose of this paper is to review the ethical questions that terraforming the red planet raises and thereby we pretend provide a conceptual setting for future iGEM projects regarding terraforming. First, we review the concepts developed in the field of environmental ethics beyond Earth. Then the possibility that current Mars would not be a sterile planet and the nature of its eventual biota with the ethical issues that raises the extermination of that life in a terraforming process. We finish evaluating the cost and the benefits of such a process.

Environmental ethics beyond Earth

Environmental ethics is a field of philosophy focused on the natural environment. Its expansion started in 20th century, when disastrous consequences of human activity started to arise. In the academic arena, famous scientists like Aldo Leopold with his book *A Sand County Almanac* (1949), or Rachel Carson with her *Silent Spring* (1962), were one of the first that started to claim about the ecological crisis and the necessity to consider it from a philosophical point of view. The papers published in *Science* by Lynn White (1967) and Garrett Hardin (1968) were also milestones in the field. The first specific academic journals were the American *Environmental Ethics*, the Canadian *The Trumpeter: Journal of Ecosophy* and the British *Environmental Values*.

But until a few years ago, environmental ethics has been only limited to a geocentric context. This field began to have an extra planetary importance when humans started to launch space junk in the Earth orbit. Publication of *Beyond Spaceship Earth: Environmental Ethics and the Solar System* edited in 1986 by Eugene C. Hargrove settled a landmark in ethical concepts related to extra planetary environment, such as social and economic implications of space exploration for human life, Earth orbital pollution and ecological problems related to possible future colonies. Scientists such as Robert Haynes, who coined the term ecopoiesis in 1990 and Cristopher McKay have been key personalities in the development of this field. Thus, cosmocentric view of environmental ethics tries to elucidate questions about legitimity of terraforming Mars, including possible rights it may have as an overall system (Fogg, 2000).

McKay (1990) proposes that any system of environmental ethics is based on three elemental axioms:

> *Anti-humanism*. Humans do not have the right to change the environment using their technology. According to McKay (1990), this axiom is linked to the principles of humility and “original sin”. Our species, in comparison to others, would not have special rights or needs. Thus, anti-humanism argues against Mars terraforming (McKay and Marinova, 2001).
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> *Wise stewardship*. Humans are responsible of using the nature in an intelligent way in order to benefit our present and future generations. This axiom is linked to the principle of utility and seems to be consistent with Mars terraforming, which may help us on science development (McKay, 1990).
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> *Intrinsic worth*. It states that human use is not the ultimate value and that living systems have intrinsic worth independent of human utility (McKay, 2001). This axiom is linked to the principle of the value of life (McKay, 1990).

Fogg exposed in 2000 four central environmental ethic perspectives, which have their own opinion about terraforming legitimacy:

Antropocentrism. It states that humans must have a higher value than other things or beings in nature. It holds that be basis of the humans intrinsic value is the individual capacity to think rationally and act morally. As it considers that the rest of nature has only amoral acts, our species would be the only one with rights (Murdy, 1975). Rights of other living forms are limited to those that humans decide to grant them on instrumental grounds (Fogg, 2000). This doctrine has evolved along the time. Until publication of *The Origin of Species* it was generally thought nature was created to benefit man. Humanity has been progressively being aware of that any person is both a hierarchical system and a component of hierarchical systems. Thus our existence depends on the proper functioning Earth's present biosphere: we have to think in our future generations and treat our environment in a wisely way (Murdy, 1975). According to this anthropocentric doctrine, there is not moral objection against planetary colonization or terraforming if benefits which humanity can get with such processes exceed those that can be got without them (Fogg, 2000).

Zoocentrism. It proposes that animals have similar rights to humans, mainly the right to live, as they have an intrinsic value based on their consciousness that must be respected (Fogg, 2000). Tom Reagan's book *The case for an animal right*, published in 1985, is considered a key work about animal rights. According to zoocentrist opinion, sentient animals must be treated as humans, *illegitimating* their exploitation for food, biomedical research, or any other degrading purpose. Zoocentrist doctrine does not ague against Mars terraforming because it does not assign any intrinsic value to non-sentient microorganisms and inert objects (Fogg, 2000).

Ecocentrism (or biocentrism). It is based on holistic principles: everything is interconnected, forming part of a whole. According to it, the whole living world has an intrinsic value and its integrity, stability and beauty must be respected (Leopold, 1977). None species is considered superior to others, nor inferior. Ecocentrism supporters claim for a radical change in our current civilization, reducing our population and energy and resources expense (Fogg, 2000). These holistic ideals were critizised by Reagan (1983, p.362), who named them as totalitarians. As ecocentrism only assigns intrinsic value to living forms, space settlements and terraforming is not inmoral for it, unless the, planet to terraform hosted life (Fogg, 2000).

Cosmic preservationism. It assigns intrinsic value to uniqueness and defends that the cosmos has the right of being preserved from any change caused by human activity (Fogg, 2000). Thus, preservationists argue against planetary settlement and terraforming. Alan Marsall, one of the major exponents in preservationism, proposes strict measures in order to protect planets of changing from their natural state (Marsall, 1993).

Life on Mars?

How probable is the existence of life on Mars? Would it be legitimate to invade the red planet with terrestrial life forms that would outcompete the eventual martian ones? We know for sure that there is not a technological civilization or sentient organisms, so if there is life on Mars it would be at microbial stage.

If we assume life is linked to the existence of water (Pace, 2001), we must describe the hydrogeologic history of Mars in order to find life or its signatures. Reconstruction of this history has been carried out by mean of image analysis of *Viking* probes, combined with topographic data obtained from Mars Orbital Laser Altimeter (MOLA) and the pictures (MOL) from the *Mars Global Surveyor*, spectral data from the *Mars Odyssey* and with geological analysis of the *Mars Exploration Rovers Spirit* and *Opportunity*.

During the firsts ~800 Ma a vast ocean called *Oceanus Borealis* could have been settled over Northern hemisphere. Its liquid water may be maintained by a hydrogeologic cycle, a magnetic field and a possible dynamic lithosphere that would allow carbonate recycling. This scenario is very similar to the early Earth, and life might have arisen there. The presence of life on Mars during the existence of this ocean has been suggested with the found of the meteorite ALH84001, discovered in 1984 in the glacier *Far Western* in the antartic region of Alan Hills. It is a volcanic rock formed 4,500-500 Ma ago with 3,190 Ma old carbonate globules and polycyclic aromatic hydrocarbons (PAHs). Ovoid and tubulars microscopic structures and magnetite crystals are also present. With these findings, McKay and colleges published in 1996 a study in which they proposed four evidences supporting microbial life on Mars:

1- Carbonate globules are similar to those originated on Earth by bacterial activity.
2- PAHs might derive from biomolecules.
3- Microscopic structures might be microfossils.
4- Magnetite crystals are very similar to those formed by terrestrial magnetotactic bacteria.

But these supposed evidences have lost strength after numerous studies (Knoll, 2003). Carbonate formation and PAH presence does not require the action of living organisms: carbonate precipitation could be produced by high temperature reactions, conditions incompatible with life. PAHs synthesis can take place by catalytic inorganic processes (Fairén, 2004). Microscopic structures seem to be too simple to discard a non-biotic origin. Similar structures can be obtained from chemical mixes (García-Ruiz, 2003). Thus, they cannot be considered as evidences of life on Mars. The presence of magnetite crystals is the only evidence that cannot be discarded. They are considered biomarkers as it is impossible to distinguish them from the crystals that magnetotactic bacteria (such as MV-1, a marine bacterium) form (Thomas-Keprta *et al*., 2001). However, some experiments that have managed to obtain similar magnetite crystals (Golden *et al*., 2002) weaken this hypothesis (Knoll, 2003).

When the internal dynamo and the cortical renovation ceased, this hypothetical ocean will be frozen, gradually disappearing by sublimation, infiltration and hydrogen fugue to the space. Certain chemolithotrophic microorganisms might have survived in underground waters during this process of inhabitability of Mars, thanks to the protective effects of the ground layer against radiation. (Fairén, 2004). After this first ocean disappeared, Mars suffered for 300 Ma a dry and cold period that finished due to a massive volcanic activity in the magmatic complex of Tharsis (Luque y Márquez, 2004). The CO_2 release maybe allowed a second ocean to be formed in the Northern lower lands. Although this mass of water was smaller and shorter in time than the first one, it is possible that it promoted the creation of a second biosphere (Fairén, 2004).

But Mars is currently assailed by solar wind, UV radiation and X-rays. There is not liquid water on its surface due to its weak atmosphere (~10 mbars). However, water might be abundant underground, as the *Mars Odyssey* probe evidenced (Luque y Márquez, 2004). Thus, a martian biosphere formed by metabolic active living forms inhabiting underground caves where water might be liquid is possible (Fairén, 2004).

Another evidence that can point out the existence of current martian life could be the recent detection of methane. In 2003 and 2004 three different research groups announced methane detection at Mars atmosphere (Atreya et al., 2007). But these results were controversial until the publication of a recent study that compiles the last observations (Mumma et al. 2009). Methane is unstable there (average life 300-600 yrs), due to the different photochemical, oxidative and electrochemical reactions it suffers. Although it remains at the atmosphere for enough time as to be uniformly spread by winds and diffusion (Atreya *et al*., 2007), methane is concentrated both in space and time in form of gas plumes during summer at the north hemisphere, and is dissipated in less than one year (Mumma *et al*., 2009). Methane reaches there 33ppbv on summer, when approximately 0,6 Kg of methane per second are released. Mumma and colleges proposed in 2009 that this gas is continuously being produced underground, but it is released to the atmosphere only when high temperatures of summer break the ice layer which covers the surface.

At the Earth, the 90 to 95% of methane has a biological origin. But at Mars, it may have either a geological or biological origin (Atreya, 2007). But a martian origin of this methane does not seem probable because volcanoes produce high quantities of SO_2, which has not been detected, and because martian volcanoes are inactive since hundreds of millions of years ago. So geological origin of methane does not seem probable. The most plausible sources of methane at Mars seem to be from hydrogeochemical or microbial activity (Atreya *et al*., 2007). At hydrothermal vents from oceanic dorsals, ultramaphic silicates (rich in Fe or Mg, such as olivine and pyroxene) produce H_2 by mean of a process called serpentinization. Subsequently, H_2 reacts with carbon grains, carbonaceous minerals, CO_2 and CO and finally generates methane. Serpentinization can take place at high (350-400 ^{o}C) or intermediate (30-90 ^{o}C) temperatures. It is thought that the temperature of the hypothetical martian aquifers may lay at the second interval (Atreya *et al*., 2007). However, biologic activity cannot be discarded. Methanogens from the Earth require H_2, CO_2 and CO. If these organisms lived in the Martian underwater they would have the H_2, CO_2 and CO required for their life (Atreya, 2007). Once produced either by serpentinization or biological activity, methane would be accumulated in a stable clathrate to be finally released to the atmosphere through fissures (Atreya *et al*., 2007). The *Mars Express* probe has obtained some data, which suggest methane is present in higher concentrations in those regions with permafrost (Atreya, 2007). Both the geologic and biologic hypothesis can explain this correlation. By now they seem equally probable (Atreya, 2007).

Data exposed above suggest that current life on Mars seems unlikely, although we cannot discard the existence of a remanent martian biosphere. If life on the red planet were finally discovered, scientists would face with the dilemma of the ethical legitimacy of invading an alive planet. Mckay (2001) states that we must differentiate between the case in which martian life is genetically related to life on Earth as results of the same abiogenetic event and a subsequent exchange between worlds by means of panspermia, and the case in which life on Mars represents a form of life which is not related to terrestrial living forms. In the first case the ethical problems seem to be of minor importance in the opinion of McKay (1982). Terraforming would be supported by all environmental ethics axioms and perspectives, but anti-humanism, ecocentrism and cosmic preservationism. Although martian living forms would help us to understand origin of life, invading Mars would not be more illegitimate than colonising terrestrial ecosystems uninhabited by humans. It would be more ethically troublesome the founding of martian living forms which were not part of our tree of life. It would mean that origin of life in both planets would be independent. In such case, McKay (2001) propose three possibilities:

- Leave Mars alone, not altering life that inhabits it.
- Alter Mars in order to allow its own biota to become a global biological system that controls the biogeochemical cycles on this planet.
- Take samples of the whole biodiversity of Mars and store them at biobanks before invading this planet with terrestrial living forms.

Firsts two options seem to have a greater ethical support than third one but they imply to do not terraforming Mars. In the second option the necessary conditions to the spreading on the martian surface of its biota would be no the same than the necessary to the earth biota, so the term terraforming is not accurate. It should not be a problem if humanity never needs to. The advantage of the second option respect first and third ones is that it would have an enormous scientific interest, as it would allow us to observe and study the creation and development of a second biosphere. McKay (2001) thinks third option, the only one which supports terraforming, is not fair because in his opinion it is inconsistent with ethical standards and it would make impossible the obtainment of optimal knowledge about a second type of life, loosing the opportunity of profiting the benefits in research (e.g medical) that it may have otherwise. He states it would be disrespecting a second type of life.

We personally think second option would be the best one in the case humans had the necessary resources to bloom a martian biosphere and we did not need to terraform Mars (the most probable option). Scientific study of martian life would have invaluable applications in fields such as drug discovery or industry. But if we needed to terraform Mars, third option would be the only one which could save our species. In such case, Mars invasion would not be more unethical than interspecies competition for resources. It is clear we were destroying a remanent biosphere based on a different type of life, but we could manage to keep it not only in biobanks but also building nature reserves where martian biodiversity would be protected and studied. Thus, terraforming would be ethically compatible with the existence of martian native organisms.

Relation cost-benefits. Is it worth?

Terraforming Mars would imply a great economic, time and social investment. Technology needed for it is neither yet available nor affordable. But in the case humanity had the required elements for starting a planetary ecosynthesis, would it be worth?

Warming up the planet from its current mean temperature -60 ºC to at least 0 ºC in order to reach habitable conditions for the firsts microbial colonizers might be carried out both by blackening Mars surface (which would decrease its albedo) with plants or lichens (Sagan, 1971) and using super greenhouse gases such as perflourocarbons (PFCs) (Lovelock and Allaby, 1984). McKay (2009) estimated in 100 years the time necessary for doing so. But this would be just the first and easiest step. Producing an oxygen-rich, breathable atmosphere would take around 100,000 years (McKay, 2009).

Mckay's proposal for atmospheric conditions required for habitability is shown on Table 1. More than 1000 human generations would be necessary in order to complete this task. Economical costs should cover all the space journeys, materials, salaries/maintenance of high-qualified workers and their medical and psychological care during millenniums. Being very optimistic, we could expect that the only way of funding terraforming would require a global consensus and coordination. Colonizing Mars may be the origin of enmities between countries, related to sharing out the new land, which might doom the project.

Table 1: McKay's proposal for limit levels of different important parameters for habitability. Source: McKay *et al.*, 1991.

Parameter	Limits	Note
Global temperature	0–30 °C	Earth = 15 °C
Composition for plants, algae, microorganisms		
Total pressure	>1 kPa	Water vapor pressure plus O_2, N_2, CO_2
CO_2	>0.015 kPa	Lower limit set by photosynthesis No clear upper limit
N_2	>0.1–1 kPa	Nitrogen fixation
O_2	>0.1 kPa	Plant respiration
Composition for breathable air		
Total pressure:		
Pure O_2	>25 kPa	Lung water vapor plus CO_2, O_2
Air mixture	>50 kPa	Based upon high elevation
	<500 kPa	Buffer gas narcosis
CO_2	<1 kPa	Set by toxicity
N_2	>30 kPa	Buffer gas
O_2	>13 kPa	Lower limit set by hypoxia
	<30 kPa	Upper limit set by flammability

There are growing evidences which suggest that Mars used to have an ancient carbon dioxide atmosphere which was thick enough to maintain liquid water during the two firsts martian geological eons: Noachian and Hesperian (McKay, 2010). Noachian erosion rates are consistent with erosion by running water (Golombek and Bridges, 2000). But nowadays Mars has a dry and cold surface, probably caused by a progressive process of atmospheric loss due to its small size (1/10 of mass of Earth) (Manning *et al*. 2005). The absence of plate tectonics prevents gases such as carbonates being recycled by their ejection through volcanoes formed by the subduction of one plate under to another. Also, as there is not a magnetic field on Mars, solar winds impact directly on the upper atmosphere of this planet, promoting atmospheric erosion (Jakosky *et al*, 1994). As these physical features cannot be changed, Mars ecosynthesis would be ephemeral, with a habitable lifetime subjected to carbonate formation. McKay (2009) proposed that Mars could be habitable for humans about 10 to 100 million years before its new atmosphere were lost.

Mars terraforming would be a way to combat overpopulation, due to its proximity with the Earth. But we do not know how human demographics will behave in a time scale of such a magnitude. Overpopulation might not be a problem in the future if human global population is decimated after suffering some disaster. In that case, the colossal investment would be wasted and humanity would become completely vulnerable to extinction. The approach of using Mars as a merely ecosynthesis model and extrapolate or replicate terraforming results to other possible planets seems to be unfeasible due to the named costs and time required.

Conclusion

If we stay on the Earth and do not colonize the space we will be keeping all the eggs in one basket. We think that humanity must protect itself and the Earth's biosphere by establishing new homes in space and other planets. In the Solar System there are not others suitable worlds for human habitation without the need for extensive terraforming. At the moment, terraforming is so far a merely hypothesis. For example, in the case of Mars, that has been the focus of this review, we ignore so far many crucial aspects like the amount of CO_2 buried into the regolith or present at the South Polar Cap; or the location, amount and state of the underground water (McKay and Marinova, 2001). However thanks to our accelerated technological progress we hope it might be feasible in the future centuries.

We consider that terraforming is licit in case humanity depends on it for its survival. Even in the case there were life on Mars, and it was independent to Earth's we could try to protect that life in biobanks or reserves. We judge that it would be legitimate as probably there would not be a developed biosphere on Mars but only a hypothetical remnant frozen biosphere. It is suppose that the benefits of this process would be to solve the problem of overpopulation and/or to offer a second planet where to live after the Earth's habitability arrives to an end with the increasing luminosity of the Sun (Caldeira and Kasting, 1992). Unknown physical obstacles may appear in the process of planetary ecosynthesis together with economical and political ones. For those reasons Mars may sustain small populations of scientist (a kind of Utopia), but perhaps big colonies on Mars may not be feasible. If that were the case, human colonization of the Solar System would involve sealed cities in orbit or in the Lagrange points of the Earth-Moon system as the ones imagined by the physicist and space activist Gerard O'Neill (1974).

Acknowledgments:

We thank to everybody who participated in our Human Practice Interview (it can be read at the *Ethics in terraforming* webpage): Daniel-Roberto Altschuler, Francisco Anguita-Virella, Peter Austin, Fernando J. Ballesteros-Roselló, Alberto González-Fairén, Michael López- Alegría, Christopher P. McKay, Amelia Ortiz-Gil, Mariano Ruiz, and Milton Wainwright.

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