Part One
Living on Spaceship Earth

Energy for a Sustainable World: From the Oil Age to a Sun-Powered Future. Nicola Armaroli and Vincenzo Balzani

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The Energy Challenge

> "Pay attention to the whispers,
> so you won't have to listen to the screams."
>
> Cherokee Proverb

1.1
Our Spaceship Earth

On Christmas Eve 1968, the astronauts of the Apollo 8 spacecraft, while in orbit around the Moon, had the astonishment to contemplate the Earthrise. William Anders, the crewmember who took what is considered one of the most influential photographs ever taken, commented: "We came all this way to explore the Moon, and the most important thing is that we discovered the Earth" [1] (Figure 1.1).

The image taken by the Cassini Orbiter spacecraft on September 15, 2006, at a distance of 1.5 billion kilometers (930 million miles) shows the Earth as a pale blue dot in the cosmic dark (Figure 1.2). There is no evidence of being in a privileged position in the Universe, no sign of our imagined self-importance. There is no hint that we can receive help from somewhere, no suggestion about places to which our species could migrate. Like it or not, Earth is a spaceship. It's the only home where we can live.

Spaceship Earth moves at the speed of $29\,\mathrm{km\,s^{-1}}$, apparently without any destination. It does not consume its own energy to travel, but it requires a huge amount of energy to make up for the needs of its 6.8 billion passengers who increase at a rate of 227 000 per day (the population of a medium-sized town), almost 83 million per year (the population of a large nation) [2]. Spaceship Earth cannot land and cannot dock anywhere to be refueled or repaired. Any damage has to be fixed and any problem has to be solved by us passengers, without disembarking. We travel alone in the Universe, and we can only rely on the energy coming from the Sun and on the resources available on the surface or stored in the hold of our spaceship.

Earth's civilization has always depended on the incessant flow of solar energy that sustains the biosphere and powers the photosynthetic production of food. Until a few centuries ago societies obtained their energy from sources that were almost immediate transformations of solar radiation (flowing water and wind) or that took relatively short periods of time to become available (wood) [3]. The feature

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Figure 1.1 Earthrise: a photograph of the Earth taken by astronaut William Anders on December 24, 1968, during the Apollo 8 mission while in orbit around the Moon. This picture is one of the *Life*'s 100 Photographs that Changed the World. Credit: NASA.

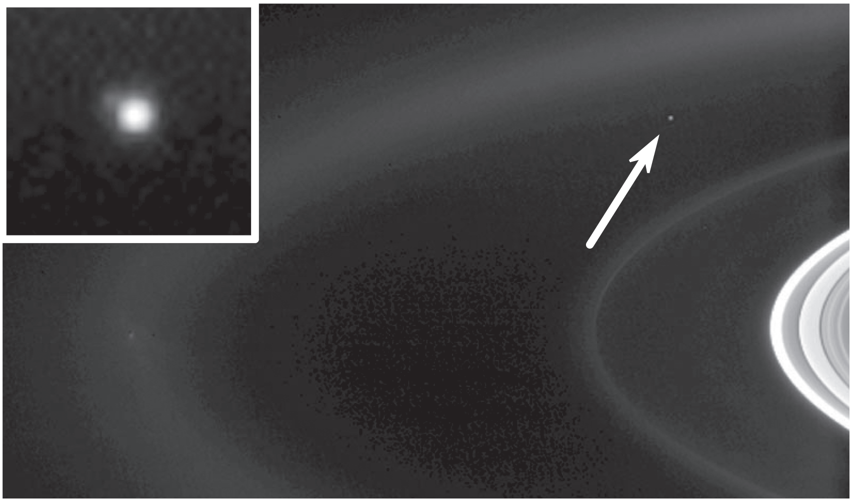

Figure 1.2 Photograph taken by the Cassini Orbiter spacecraft on September 15, 2006, at a distance of 1.5 billion kilometers from Earth. The dot to the upper left of Saturn's rings, indicated by the arrow, is the Earth. Saturn was used to block the direct light from the Sun, otherwise the Earth could not have been imaged. Inset: expanded image of the Earth which shows a dim extension (the Moon). Credit: NASA.

that distinguishes modern industrial society from all previous epochs is the exploitation of fossil fuel energy. Currently over 80% of the energy used by mankind comes from fossil fuels [4]. Harnessing coal, oil, and gas, the energy resources contained in the store of our spaceship, has prompted a dramatic expansion in energy use. Powering our spaceship Earth with fossil fuels has been very convenient, but now we know that this entails severe consequences [5, 6].

Firstly, fossil fuels are a nonrenewable resource that is going to exhaust. We have consumed 1 trillion barrels of oil in the last 140 years, and currently the world's growing thirst for energy amounts to almost 1000 barrels of oil, 93 000 cubic meters of natural gas, and 221 tons of coal per second [7]. How long can we keep running this road? Secondly, the use of fossil fuels causes severe damage to human health and the environment. It has been pointed out [8] that the energy challenge we face relates to "the tragedy of the commons" [9]: we treat fossil fuels as a resource that anyone anywhere can extract and use in any fashion, and Earth's atmosphere and oceans as a dump for their waste products, including more than 30 Gt per year of CO_2. A third critical aspect concerning fossil fuels is that their uneven allocation, coupled with the unfair distribution of wealth, leads to strong disparities in the quality of life among the Earth's passengers.

1.2
An Unsustainable Growth in an Unequal World

1.2.1
Population Growth and Carrying Capacity

In the last 100 years there has been a rapid population growth due to medical advances and massive increases in agricultural productivity. In 1950, the world population was 2.6 billion, with an increase of 1.5% per year [10]. In 2010, it was more than 6.8 billion, but with a lower rate of annual increase (1.1%), that is expected to decline further until 2050, when the Earth will be populated by about 9.2 billion people. At that time, the median age of the world population will be 37.3 years, up from 26.6 in 2000 [11].

The population size of a biological species that a given environment can sustain indefinitely is termed carrying capacity. Overpopulation may result from growth in population or reduction in capacity. The resources to be considered when assessing the carrying capacity of a given ecological system include clean water, clean air, food, shelter, warmth and other resources necessary to sustain life. In the case of humans, several additional resources must be considered, including medical care, education, sewage treatment, waste disposal, and, of course, energy.

Clearly, spaceship Earth has a limited carrying capacity, but it is quite difficult to assess the maximum number of humans who can live on it in satisfactory welfare conditions, also because "satisfactory welfare" is a somewhat subjective concept. An alarm bell, however, comes from the estimation of the ecological footprint, defined as the amount of biologically productive land and sea area needed to regenerate the resources a human population consumes and to absorb and render harmless the corresponding waste [12]. In global hectares per person, in 2006 the Earth's biocapacity was 1.8, while the average footprint was 2.5. In 2009, the Earth Overshoot Day, that is, the day when humanity begins living beyond its ecological means, was September 25 [13]. In other words, mankind uses biological services faster than the Earth can renew them.

1.2.2 Economic Growth and Ecologic Degradation

The expansion of the human enterprise in the twentieth century was phenomenal, particularly because of the availability of low-cost energy. Unfortunately, however, it has caused bad consequences that we have now to face. Ecologists emphasize that dominant patterns of production and consumption are causing environmental devastation and a massive extinction of species [14]. Climatologists warn about anthropogenic climate change [15]. Geologists point out that we will soon reach, or maybe we have already surpassed, the peak of oil production [16]. Seismologists wonder whether natural disasters, like the devastating earthquake which in May 2008 killed 80 000 people in China, are triggered by exaggerated human constructions [17]. International agencies inform us that about 6 million hectares of primary forest are lost each year [18]. People are worried about nuclear waste [19], and in affluent countries even disposal of electronic waste causes domestic and international problems [20, 21]. Last but not least, food security is a growing concern worldwide [22, 23].

Some scientists have pointed out that global effects of human activities, directly or indirectly related to the use of fossil fuels, are producing distinctive global signals. Accordingly it has been proposed that, since the beginning of the Industrial Revolution, we have entered a new epoch that can be called Anthropocene [24], in which the Earth has endured changes sufficient to leave a global stratigraphic signature distinct from that of the Holocene or of previous Pleistocene interglacial phases [25].

In spite of these alarm bells, growth remains the magic word of narrow-minded economists and politicians. They believe that the economic growth must continue indefinitely, and therefore they incessantly press for increasing production and consumption. In affluent countries, we live in societies where the concepts of "enough" and "too much" have been removed [26]. We do not take into account that the larger the rates of resource consumption and waste disposal, the more difficult it will be to reach sustainability and guarantee the survival of human civilization.

1.2.3 Inequalities

The goal of ecological sustainability is even more imperative if we consider the problem of disparity [27]: the passengers of spaceship Earth travel, indeed, in very different "classes." As an average, an American consumes about 7.11 toe of energy per year, a quantity approximately equal to that consumed by two Europeans, 4 Chinese, 17 Indians and 240 Ethiopians [28]. The uneven consumption of fossil fuels and the related generation of waste products are accompanied by uneven consumption and consequent uneven waste generation of any kind of nonrenewable store, for example, metals [29, 30].

Disparity is indeed the most worrying feature of our society. The poorest 40% of the world's population account for 5% of global income, and the richest 20% account for three-quarters of global income. According to the World Bank [31], the Gross Domestic Product (GDP) at purchasing power parity per capita is higher than \$30 000 in at least 25 countries (\$46 400 in the US), but it is below \$3000 in more than 50 countries and less than \$1000 in 15 African nations [32]. The three richest persons in the world have assets that exceed the combined GDP of the poorest 47 countries.

Income inequality is vast and is reflected in all aspects of life: health, education, food, energy, and so on. Life expectancy at birth is higher than 79 years in most of the affluent countries with a peak of 83 years in Japan, but in several African nations it is below 50 years, for example, 47 years in Nigeria [2]. The adult literacy rate is close to 100% in many countries, but it is below 50% for at least 15 nations, mostly African. In more than 45 nations at least 20% inhabitants do not have access to a reliable water source. Large differences are also found in the ecological footprint, that is 9.0 ha per capita in the US, 11 times higher than that in India [33]. It has been calculated that if all the world's 6.8 billion inhabitants were to live at current American ecological standards, we should look around for another four Earths to accommodate them [33].

There are also strong inequalities among citizens within each nation. The gap between rich and poor is larger in developing nations, but is increasing in almost all the affluent countries. The ratio between the household incomes of the richest 10% to the poorest 10% is 168 in Bolivia, 51 in Brazil, 16 in the US, and 11 in Italy [34]. In spite of the presence numerous billionaires (356 in 2009), poverty in the US is endemic, with roughly 13–17% of the people living below the federal poverty line [35]. In 2008, 11% of American households were food insecure, with 30% of African American minors living below the poverty threshold [36]. Health disparity is a big problem in several countries including the US [37]. Domestic disparity is a difficult problem to solve in a society where the way of life is based on consumerism, and international disparity is a problem set aside by politicians of affluent countries to please their supporters. In the long run, however, both problems have to be tackled because disparities destabilize human society. If things do not improve, sooner or later the poor will rise up against the rich. The boost of "illegal" immigration in affluent countries that lie at the boundary between the North and the South of the world (e.g., United States, Italy, Spain) is indeed a forewarning of what will happen in the international scene. Any action to restore equity should likely pass through lowering resource consumption (in particular, energy) by the rich while attempting to raise that of the poor.

Our time is characterized by an unsustainable growth in an unequal world. We should try to decrease disparity, while being aware that growth based on consumption of nonrenewable resources is poised to be an ephemeral illusion.

1.3
Energy and Climate Crisis

In the last 100 years the strong increase in population and the availability of large amounts of fossil fuels have led to an average primary energy consumption rate of almost 15 trillion watts (i.e., 15 TW) of power worldwide [7]. Current global trends in energy supply and consumption are environmentally, economically, and socially unsustainable. We need more energy to fill the gap between the industrialized and the developing countries, but at the same time we will not be able or allowed to consume more fossil fuels for several reasons: their limited amount, their increasing cost, and, above all, the need to reduce CO_2 emissions.

According to the fourth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) [15], an increase in carbon dioxide concentration leads to an increase in the greenhouse effect that, in turn, causes climate change. This will impact food security [38], water availability [39], fish production [40], and global forests [18]. Other not less dangerous effects will be ocean acidification [41] and permafrost melting [42]. Indeed, climate change caused by an increase in the CO_2 concentration in the atmosphere might result in much more than a simple stratigraphic signature of the Anthropocene epoch: it could lead to devastating effects on humanity.

Recently, two important steps in the right direction have been made: Europe signed its own climate agreement committing the region to a 20% cut in emissions by 2020 as well as a doubling of use of renewable energy and boosting energy efficiency by 20% over the same period, and US President Obama decided that combating climate change is a priority of his administration. These positive signals are counterbalanced by the great difficulties encountered when trying to set global and concerted policies to curb atmospheric carbon pollution [43].

1.4
Dealing with Change

In the last few decades we have become aware that we live in a fragile spaceship, with limited resources. We realize that we are in danger and that risks derive from two main features: too much consumption and too much disparity. In a restricted and perhaps overpopulated system like spaceship Earth, opportunities discovered and exploited by a generation can cause challenges to the subsequent ones. Fossil fuels have offered outstanding opportunities during the twentieth century in the rich countries of the western world, but now mankind has to face the challenges arising from fossil-fuel overexploitation. We need to reduce progressively the production of CO_2, while providing a suitable energy supply to allow a decent standard of life to all of the people around the world. This means that we have to learn to save energy, to find more intelligent ways of exploiting traditional energy sources and to develop new ones. From the supply side, there are several options, including (i) the use of fossil fuels (in particular, coal) with carbon capture and sequestration, (ii) expansion of nuclear energy with third- and fourth-generation power plants, and (iii) development of a variety of unexploited or underexploited renewable sources like solar energy, wind energy, geothermal energy, ocean energy, and biofuels. On the demand side, the opportunities include (i) saving energy in every action of our life, (ii) limiting energy wastage in heating and cooling buildings, (iii) increasing the efficiency of internal combustion engines and electric motors, (iv) moving from fossil fuel-powered automobiles to electric vehicles, and perhaps (v) developing a hydrogen economy. But energy supply and demand have implications that go far beyond technical features. In developing countries billions of people work hard to improve their standard of living and need much energy to succeed. They look forward to reaching a welfare level comparable to that enjoyed by the citizens of the countries that developed in the past century. To reach this goal, they constantly increase energy consumption and CO_2 production, but these parameters continue to increase also in affluent countries, where people falsely believe that the quality of life increases linearly with energy consumption.

In the last few decades the world has undergone big changes, and we should deal with them. We need new thinking and new ways of perceiving the world's problems.

1.5 Unavoidable Questions

For several reasons, we are deeply interested in finding solutions to the climate and energy crisis. As passengers of spaceship Earth, we need energy for satisfying our fundamental needs while living in a pleasant environment. As parents, we wish to leave our planet in a good shape for the benefit of future generations. As passengers traveling in the first class, we feel obliged to help passengers living in much worse compartments to find a better accommodation. As members of mankind, we have the moral duty of contributing to solving the energy problem as a decisive step towards creating a more peaceful world. And if we are scientists, we have a great responsibility that comes from our knowledge and educational duty [44].

We are at a crossroads, and decision on the path to be taken lies with policy makers who, unfortunately, usually look only at the interest of their own nation and at the next election. What we would need are politicians capable of looking far-off in space and time, statesmen thinking over the whole planet and the future generations. To play as statesmen, politicians need to be counseled; this is particularly true in the case of important and complex problems like energy that need to be tackled globally, with the wisdom deriving from an interdisciplinary approach. Advice should come from scientists of the various scientific and humanistic disciplines, who are less conditioned and better informed than politicians on the present state of spaceship Earth and on what will likely happen in the next few decades. It is indeed their duty to find answers to several entangled, fundamental questions like the following:

- Can we afford to stop burning fossil fuels or at least reduce their consumption?
- How long can we continue to treat the atmosphere and the oceans as a carbon dioxide sewer?
- Can scientists find any new energy source capable of replacing fossil fuels?
- Is it wise to develop nuclear energy?
- Can renewable energies supply us with all the energy we need?
- How can people living in poor countries improve their quality of life?
- Will it be possible for all Earth's inhabitants to reach the standard of living of developed countries without devastating the planet?
- Should the citizens of the affluent countries change their lifestyle and look for innovative social and economic paradigms?
- Is it possible to reach the goal of ecological sustainability?
- Will decreasing resources lead to a destructive collapse of economy or can we manage to descend without too much damage?
- To what extent is well-being, or even happiness, related to energy consumption?
- Is it possible to do more with less?
- Can we afford to wait for the end of the crises, that follow one after the other, before addressing the energy problem and the related climate change?
- Will science and technology alone take us to where we need to be in the next few decades?

These are, indeed, hard questions. History teaches that the pressures of the great, hard questions can bend and even break well-established principles, thereby transforming difficult challenges into unexpected, astonishing opportunities [45]. But we should not forget that the challenge of saving spaceship Earth and its passengers needs the engagement of all of us.

And we have to start right now.