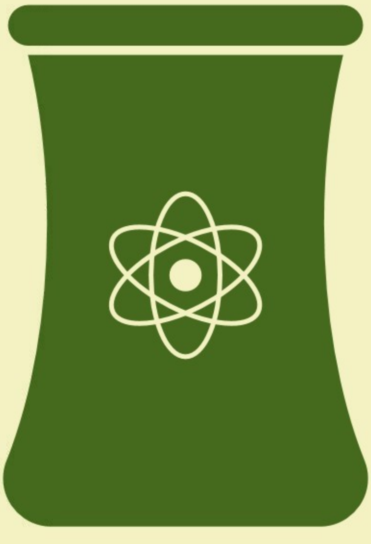
Juan José Gomez Cadenas



The Nuclear Environmentalist

Is There a Green Road to Nuclear Energy?

Springer

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It's a black and white photograph, but it captures the light of a summer afternoon in 1959.
The man has a plucky nose, an honest chin, and a moustache in the style of Clark Gable.
The girl is a very beautiful brunette. Her smile is ecstatic; his, incredulous. Both of them, in love.
This year we're celebrating their golden wedding.
To my parents

Acknowledgments

Every book is a voyage.

Without my wife Pilar and my children Irene and Hector, it would not have been a voyage but a wreckage.

Without the help of numerous friends and colleagues, it would have been much more difficult to find a safe harbor. The list is long and the memory of the old sailor weak. Thus, I prefer to extend here my acknowledgment to all of them without spelling their names. You all know.

I am grateful for the kindness of the Spanish Nuclear Council and the Foro Nuclear, who have supplied information concerning Spanish nuclear power stations.

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Chapter 1
All that Glitters is not Green

Oxymoron (from Greek oxymoros, "pointedly foolish"). A combination of contradictory or incongruous words, as cruel kindness. *(Merriam-Webster).*
Oxymoron (from Greek "sharp dull"). A figure of speech that combines contradictory terms. (Wikipedia).

The painter, carrying his easel, walks leisurely across the meadow that extends up to the limits of the summer sky. Under a chestnut tree he prepares his palette and his colors, then stretches and smiles. He is wearing a cotton shirt and slacks; a straw hat covers his curly hair. He walks barefoot because he likes the feel of the grass under his feet. This painter loves nature; he loves nature as an artist and as a scientist. This painter is a nuclear physicist, and his job consists in harnessing the elementary power of the atom, the one that makes the stars glow, in order to generate the power and hydrogen his town uses.

The town where the painter lives extends on both sides of a wide river, a few kilometers from this meadow. Today is the summer's solstice of the year 2050, and also the tenth anniversary of the Day of Change, the historic date when the last coal-fired power station was closed down. To celebrate this, a lot of families have gone on cycling tours along the car-free road lined by wind turbines that leads to the great reservoir, all of which, together with the nuclear power station, provide electricity for the homes and industries in town. Others, like the painter, practice their hobbies.

The town and its people reject excesses, detest wasting and believe in solidarity. They know it is necessary in order to improve a world which now, halfway into the century, already houses nine billion people. The people who live here consume less energy than they used to waste at the beginning of the 21st century: they live in highly efficient buildings, travel on high-speed trains, drive little hybrid cars. The sheer mention of the monstrous SUVs that used to cram the highways some decades ago sends shivers down their spines. However, more energy is consumed on the planet than ever before, as for the first time, all of its inhabitants have the right to a reasonable minimum.

Generating all this energy without the resort to the fossil fuels whose threat still lingers over the future like a Nazgul's shadow—the CO_2 concentration has stabilized at 450 ppm, and scientists hold the hope that a catastrophe has been averted—requires a momentous effort. The painter is proud of his work because he knows that it is an important part of this effort. Without him and many others like

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him, this meadow where he is strolling might be a bleak wasteland stricken by draught.

Today, the painter feels inspired. He fixes his gaze on the twin towers that dominate the horizon and gets to work. A while later, the giant chimneys of the nuclear power plant start to become visible on his canvas, but he has transformed them into huge trees, covered with green leaves.

Gaia

Gaia. During my first years at university, that was all we talked about. Gaia was Mother Earth, the living planet, the Earth Goddess made divine through science. And James Lovelock was her prophet.

Lovelock was working for NASA in 1965, engaged in a project that tried to find life on the Red Planet, when he realized that the atmosphere of Mars and Venus, like the one of the primitive Earth, was almost completely made up of CO_2. What had happened on our planet that had turned its atmosphere into something so different from its neighbors? The audacious scientist dared to postulate the hypothesis that life itself was responsible for these deep changes.

Lovelock liked to talk about Gaia as if it were an intelligent being, capable of globally controlling its own temperature, atmosphere composition and ocean salinity through, and in benefit of, living organisms. It is a beautiful and not quite accurate metaphor that has been very controversial in scientific circles, where poetic license is frowned upon, but which has also won him myriads of supporters. For all my generation, James Lovelock was not just an ecologist, but the incarnation of ecologism.

Few could compare to him in the shrine of our admiration. One of these was Carl Sagan, author of wonderful books dealing with the solar system, supernovae, the search for extraterrestrial intelligence, quasars, black holes and all the other prodigies the sky is teeming with. And then Isaac Asimov's novels were our gospels. Lovelock inflamed our spirit with the idea of a living planet. Sagan bewitched us with the beauty of the cosmos. But Asimov persuaded us that one day our ships would navigate this infinite sea, the universe.

Asimov's spaceships, needless to say, were powered by nuclear energy. There was no other way to reach the high acceleration which is necessary in order to travel at near-light speed. There was no other way to generate the electricity, the hydrogen, the food and synthetic materials needed by those oversized spacecraft which mankind boarded en route to the stars. There was no other way to feed the formidable magnetic shields protecting the fleet from high-energy cosmic rays. Like on Captain Nemo's Nautilus, those space vessels were driven by just one reliable, powerful agent. The atom.

The Threat of Climate Change

Three decades have passed since then. Asimov and Sagan are no longer with us, but 90-year old James Lovelock is as energetic as ever and still fond of metaphors, as shown in the title of his latest work.

In *The Revenge of Gaia* (Lovelock 2007) the old ecologist argues that humankind's lack of respect for the planet—which can be seen in the destruction of rainforests and biodiversity, together with the inordinate consumption of fossil fuels—is driving the Earth's capacity to counter the effects of greenhouse gases to the limit. The result can be frightening:

> "The planet we live on has merely to shrug to take some fraction of a million people to their deaths (referring to the December 2004 tsunami). But that is nothing compared with what may soon happen; we are now so abusing the Earth that it may rise and move back to the hot state it was in 55 million years ago, and if it does, most of us, and our descendants, will die."

Venus, whose size and distance from the sun are not very different from the Earth's, is a near example of how this announced revenge can strike. The enormous build-up of CO_2 in its atmosphere causes an extremely strong greenhouse effect, and surface temperatures rise to nearly 460°C. Venus is an inferno drowned in darkness. Light cannot pierce the thick layer of toxic clouds, composed of sulphur dioxide and sulphuric acid.

What forces hold the greenhouse effect at bay and spare us the fate of our ruined stellar twin? Lovelock maintains it is above all the biomass, forests, plankton and algae we are hurrying to destroy while we increase the CO_2 concentration in a suicidal way by burning coal, oil and natural gas. In his view, consequences will be devastating.

The IPCC's Forecasts

Lovelock is not the only scientist to hold this opinion . The recent report by the Intergovernmental Panel on Climate Change (IPCC 2008)[1] uses a more moderate and quantitative language, but reaches essentially the same conclusions, to wit:

- The concentration of greenhouse gases has increased exponentially since the beginning of the industrial age, particularly along the 20th century (Fig. 1.1).
- The release of greenhouse gases into the atmosphere has caused the average global temperature to rise by around one degree in the last one hundred years.

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[1] The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body created by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). It is made up of hundreds of scientists from all the world, with the goal of studying climate change and its consequences.

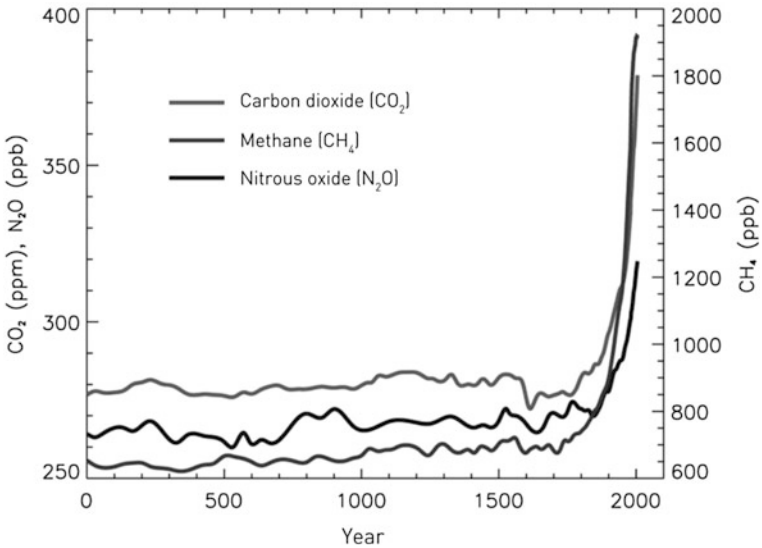

Fig. 1.1 Atmospheric concentrations of several greenhouse gases in the last 2,000 years (parts per million on the *left*, parts per billion on the *right*). The exponential increase of CO_2 is due to the human effect since the beginning of the industrial age. *Source* (IPCC 2008)

More specifically, since the middle of the last century, it has risen by half a degree, coincidentally with the increased concentration of greenhouse gases.

- At the end of the present century, the Earth may have increased by between one and three degrees. In the last case, consequences can be dramatic for our civilization: rise of sea levels flooding coastal cities, expansion of subtropical deserts, etc.

When Crocodiles Swam in the Arctic

Ours is not the first warm period in the history of Gaia. There was a similar one about 55 million years ago, at the beginning of the geological epoch known as Eocene, brought about by the release, in a brief lapse of time (between a few decades and two or three centuries), of billions of tons of CO_2 into the atmosphere.

What natural phenomenon could have given rise to such an increase in gases which under normal conditions are kept at constant concentrations on Earth? A possible explanation, due to the Norwegian physicist Henrik Svensen and his team (Svensen et al. 2004), points to the dissociation of methane hydrates, triggered by underwater eruptions in the North Atlantic, a region active at the time.

Methane hydrates are formed by compounding water and methane under high pressure and relatively low temperature, conditions which are prevalent in the deep sea. There are huge amounts of this compound, formed from decay of plankton and other organic matter. In a sense, this is one of the many mechanisms by which Gaia regulates herself; we can describe them as gigantic carbon deposits sequestered by living creatures in the sea.

We should not forget that the dreaded greenhouse gases are essential for life. One third of the solar radiation that hits the Earth is reflected back into space (by clouds, snow layers, oceans, etc.), the rest is absorbed and emitted back as infrared radiation and then again partially absorbed by gases which are present in the atmosphere in low concentrations, among them CO_2, methane (CH_4) and water vapor. However, the gases which make up most of the atmosphere, oxygen and nitrogen, do not absorb infrared radiation. Were it not for the CO_2, methane and water vapor, among others, the mean temperature on Earth would be about $-20°C$ instead of the cozy $15°C$ we enjoy on the surface of our planet.

In the words of Lovelock, Gaia "knows" how to keep the concentrations of greenhouse gases in the optimal range for life. At an average temperature of fifteen degrees, the sea is a good habitat for algae and other sea organisms that synthesize chlorophyll, sequestering any excess CO_2 from the atmosphere and taking it down to the sea floor when they die. If the concentration of CO_2 increases, so does the capacity of the algae to synthesize chlorophyll, making them thrive, and this in turn regulates the CO_2 levels by storage in the sea, for example in the form of methane hydrates.

But even the Earth can suffer from fever occasionally. At the beginning of the Eocene, this fever was caused by an escalating volcanic activity which made the ocean temperature soar and reversed the CO_2 capture cycle through methane hydrates. When these compounds decay, huge amounts of carbon are released to the atmosphere, which in turn increases the ocean temperature and breaks down more and more hydrates. This is akin to a disease, but our planet is very tough and soon after it found a new stable state (or rather a "metastable" one, in the sense that it is one among many possible states). During this new state, which in fact lasted for only a blink of the eye in geological terms, just one or two hundred thousand years, the temperature of the Arctic Ocean was 23 degrees, turning it into a comfortable habitat for species such as the crocodiles.

Being a good mother, Gaia loves all her children equally. Geological studies suggest that in those times there were tropical rainforests reaching up to a latitude that today corresponds to the north of France or the state of Maine in the USA. A lot of species would undoubtedly thrive in such a warm climate. Others would go extinct. In the words of Lovelock:

> By 2040, parts of the Sahara desert will have moved into middle Europe. We are talking about Paris. As far north as Berlin […]. If you take the IPCC predictions, then by 2040 every summer in Europe will be torrid. It is not the death of people that is the main problem; it is the fact that the plants can't grow. There will be almost no food grown in Europe […]. We are about to take an evolutionary step and my hope is that the species will emerge stronger. It would be hubris to think humans are God's chosen race.

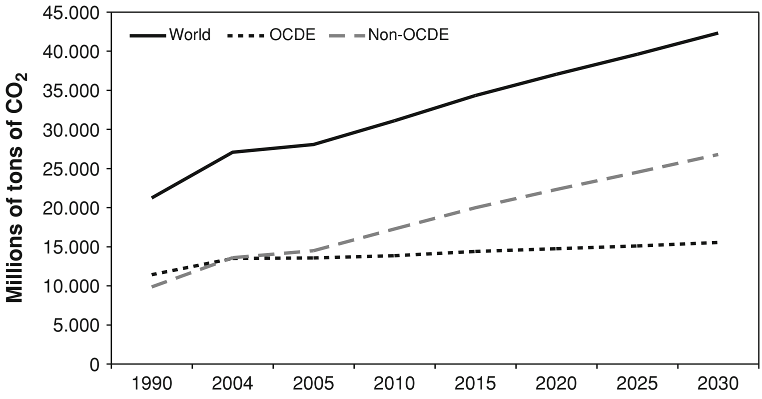

Fig. 1.2 CO_2 emissions into the atmosphere (historical and foreseen by EIA). *Source* (EIA 2008)

CO_2 and Fossil Fuels

In contrast to what happened in the Eocene, the current increase in the levels of greenhouse gases is not due to natural causes but to a strange bipedal, hairless, big-headed species which appeared recently on our planet and has even more recently started to burn fossil fuels in such huge quantities that the effect is comparable to the volcanoes of the Eocene. Figure 1.2 shows the global CO_2 emissions in millions of metric tons, for the world as a whole and for OECD[2] and non-OECD countries. It is striking to see that developing countries catch up with developed countries around 2005 and by 2030 emit 2.5 times more CO_2 to the atmosphere than the latter.

In 1990, petroleum was the main producer of CO_2 emissions (42%), followed by coal (39%) and natural gas (19%). In 2030, according to the forecast, coal is first (44%), with petroleum second (35%) and then natural gas (21%). The spectacular increase of emissions linked to coal (and to a lesser degree to natural gas) is basically due to the increase in electrical power generation.

Playing with Fire

According to the study by Svensen and his team, the volcanic eruptions in the Eocene may have released about 6 gigatons[3] to the atmosphere during a period of time ranging between 35 and 350 years. This amount is similar to what has been released since 1990 as a direct consequence of human action.

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[2] The Organisation for Economic Cooperation and Development (OECD) is made up of 30 countries, mostly developed countries; its aim is to stimulate economic progress and world trade.

[3] A gigaton or Gt is a billion tons, see Chap. 2.

The reasoning is straightforward. If the volcanoes of the Eocene brought about the destabilization of carbohydrates, can't this happen again today?

Not immediately. The oceans are not yet warm enough for this to happen. However, even if we were able to stop CO_2 emissions dead in their tracks right now, the planet would keep on heating up for centuries. The current CO_2 levels (380 parts per million, ppm) are already above any maximum level in the past interglacial periods and their effect can be likened to a time bomb that will set off a retarded explosion. The oceans have already started to warm up, and if this goes on long enough, in a few decades or one or two centuries we will be going through the Gaia methane hydrates experiment revisited. The bomb has been activated, and a species wiser than us would be doing everything possible to defuse it before is goes off.

Nuclear Ecologists

In his work *The Revenge of Gaia* Lovelock does complain, but he does not leave it at that. He suggests urgent measures to stop CO_2 emissions before climate change turns irreversible. And he, the father of modern ecologism, makes a case, above all, for nuclear energy.

I am a Green and I entreat my friends in the movement to drop their wrong-headed objection to nuclear energy.

Lovelock is not the only ecologist to hold this view. Patrick Moore, one of the founders of Greenpeace and president of the NGO in Canada for years—though he would later leave this organization to found another group, called Greenspirit—shares his opinion. Even more noteworthy, the association Environmentalists for Nuclear Energy,[4] headed by engineer Bruno Comby, is a do-or-die advocate for the apparently blasphemous idea that nuclear energy is necessary for a better world. In the ranks of scientists, the supporters of nuclear energy are in the majority.

In contrast, organizations like Greenpeace are staunch opposers of everything atomic and have recently launched a harsh anti nuclear campaign in Spain, which is riddled with news that are unsourced, exaggerated or just plain false.

Who is right? In order to reach an unbiased opinion, you need some detailed knowledge of this fascinating subject. I challenge the reader to answer the following questions—without resorting to Google—and only then to check the footnotes.

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[4] Which has inspired the title and the cover of this book, see http://www.ecolo.org/.

1. What releases more radioactivity into the atmosphere, a nuclear power station or a fuel or coal-fired power plant?[5]
2. What entails a greater risk, living next to a nuclear power station or smoking a cigarette?[6]
3. Isn't it true that the consumption of coal is going down across the world?[7]
4. Isn't saving enough to deal with the problem?[8]
5. Do nuclear power stations release CO_2?[9]
6. How much uranium do you need to generate as much energy as a ton of coal?[10]
7. How many wind turbines do you need to replace a nuclear power station?[11]
8. What happens during times of peak electricity demand if the wind doesn't blow?[12]
9. How do the building costs of photovoltaic solar parks compare with building a nuclear power station?[13]
10. A nuclear power station generates highly radioactive waste. What is the amount, in volume, of the waste produced by a typical 4 people family in Europe during all of their lives?[14]
11. How deep must they be buried so they don't have any harmful effects?[15]
12. Isn't it true that radioactive waste remains active for millions of years?[16]
13. Isn't it true that there is little uranium left?[17]

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[5] A fuel or coal-fired power plant Chap. 9.

[6] Smoking *just one cigarette* entails the same risk as living next to a nuclear plant for two years Chap. 10.

[7] Quite on the contrary, it is growing dramatically Chap. 4.

[8] Not at all. Coal consumption and CO_2 emissions are especially high in developing countries, such as China and India, whose per capita consumption is much lower than ours, offset by a population of almost 3 billion people Chaps. 4 and 7.

[9] Direct emissions are zero. "Indirect emissions", related to their construction or to uranium mining, are lower than for photovoltaic or thermo solar plants, and in any case ridiculously small Chap. 11.

[10] Ten grams, in bulk equivalent to a pinhead Chaps. 9 and 11.

[11] Around two thousand latest generation models. If you place them 500 m apart, as needed to be efficient, the row of wind turbines would stretch from Barcelona to Geneva crossing all of France Chap. 12.

[12] You have to resort to hydropower or to "reserve" gas plants. Electrical energy can't be stored.

[13] As of today, a photovoltaic park is 10–20 times more expensive, per kWh, than a nuclear plant Chap. 12.

[14] A golf ball Chap. 9.

[15] A few meters depth is enough Chap. 9.

[16] A small percentage of the substances that accumulated in spent fuel have long half-lives. However, after a few thousand years, the activity of the waste is lower than natural uranium radioactivity in a coalmine. Besides, the waste with longer half-lives can be recycled and burnt with fast neutrons reactors Chap. 9.

[17] It depends on what you consider little. There's enough for about seven million years if we use it lavishly Chap. 11.

14. What's the need for nuclear energy? We can get all we need from renewable sources.[18]

If you have come close to the correct answers, you are either extraordinarily smart, or you belong to a minority of people who have a reasonable understanding of the pros and cons of nuclear energy. These questions, and many more, will be dealt with in what follows.

In brief: today, few people doubt that the most important concern of our times is how to avoid a global catastrophe due to climate change. However, serious as it is, the threat is not immediate enough for people, policy makers and those who still call themselves ecologists to be seriously alarmed. There's the paradox that we are still worried about the likely radioactivity of nuclear waste ten thousand years from now while we should be much more concerned about the explosion of methane hydrates in a century. In our days, being an environmentalist can't be synonymous with repeating the worn slogans over and over again and sticking to fanatic dogmas. All that glitters is not green.

How to Read this Book

This book is about energy, so it is worthwhile to start by reviewing the meaning of this term, which we all understand but few of us are able to define precisely, and by explaining the units used to measure it (Chap. 2). Five chapters devoted to understanding our society from the point of view of energy follow. We are absolutely dependent on fossil fuels (Chap. 3), and there is no way to understand the dilemma we are in unless we have a grasp of the history and the current situation regarding coal (Chap. 4), oil (Chap. 5) and natural gas (Chap. 6), all of which, but especially coal and gas, are used to generate the vital fluid that runs through the veins of our times: electricity (Chap. 7).

The second part deals with nuclear energy, one of the few alternatives left to us to avoid the disaster predicted both by Lovelock and the IPCC. Its history, one of the most enthralling of the 20th century, is told in Chap. 8. I also talk about nuclear reactors, explaining how they work and the reasons why they are safe (Chap. 9). I take a look at how the fear of radioactivity, accidents and terrorist attacks are justified (Chap. 10). And of course I address the touchy topic of waste. Finally, I shed some light on matters such as the abundance of uranium or the cost of nuclear energy (Chap. 11).

One of the points that is often made is that nuclear energy is unnecessary because we have renewables. This hypothesis is examined in Chap. 12. The last chapter glimpses into the future, wondering if there is a way to solve this mess we have been creating for a century.

[18] That's wishful thinking. The solar dream is still impossible, for reasons both physical—variability of sunshine—and technological and economical.

The future. Our grandchildren, or perhaps our grandchildren's grandchildren, will not resign to keeping chained to Gaia. Children grow up and leave home, and so will ours, one hundred or one thousand years from now, heading first to Mars and then who knows where. They will be few at first and a great crowd as time goes by. To travel, to know, to discover, it's in our nature. When they leave, they will do so in spaceships that have nothing in common with those imagined by the science fiction authors of my teenage years, except for one small detail: they will be powered by the atom.

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