Decarbonising the Economy, Energy and the Future

MANUEL COLLARES PEREIRA

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MANUEL COLLARES PEREIRA
Full Professor and Research Coordinator, retired
Scientific Advisor to Vanguard Properties
Member of the Academia das Ciências de Lisboa

ABSTRACT

Sustainable development (SD) is of the utmost urgency for a planet with over 8 billion people and problems like greenhouse gases (GHG) emissions, particularly those related to fossil fuel energy consumption and the release of CO_2 into the atmosphere. Growing deforestation is hindering the world's capacity to sequester CO_2, causing negative climate change to accelerate. In response to this danger, scientists set a limit of 1.5ºC as a tolerable rise in temperature until the end of the century. So far, 1.2ºC has already been used.

Essentially, sustainable development is nothing more than the need to manage life on a finite planet that imposes restrictions (resources and nature's limited capacity to (in useful time) resistance to excessive impacts) that we are in danger of exceeding. The accumulation of GHG in the atmosphere implies that SD involves urgent decarbonisation of the economy, achieved primarily by reducing or even ending fossil fuels use.

Here, this issue is approached with a focus on (i) energy, discussed in relation to sufficiency and efficiency, pointing out the need for a transition towards "clean" energy forms that produce much lower GHG emissions, (ii) the adoption of new materials (e.g. wood) and new practices (e.g. in the construction sector) , a change capable of reversing the carbon foot print from positive to negative – CO_2 sequestration (iii) and the circular economy.

Energy transition is presented as much facilitated by the growing electrification of the economy, not only because electricity allows for useful energy to be produced in the most efficient fashion (think electric engines or heat pumps), but also because it can be produced by "clean" energy sources, such as renewable energies, which are now the cheapest way of producing electricity. Using nuclear energy to produce electricity is also discussed, highlighting its very high costs (direct and hidden), inherent unsustainability, difficulty and time involved in nuclear reactor construction and delivery. It is not a solution for the short or even medium term. There is also a strong argument for the fact that it may not even be so viable in the future.

Major technological advances, as well as a wide variety of existing practices and solutions, allow us to predict that the elimination of fossil fuels is within reach. The paradigm shift behind it requires citizens stop being part of the problem and start being part of the solution. The well-known cost of energy transition, with all its new practices and solutions, should be seen as an investment with a strong return that leads to better life quality. That said, this requires the civil and political will to face powerful lobbies and vested interests determined to resist the change.

INTRODUCTORY NOTE

There is no shortage of reports available from the European Union, International Energy Agency (IEA), Intergovernmental Panel on Climate Change (IPCC), and private bodies (e.g., insurance, finance and investment fund sectors, etc.) that explain energy issues. Often, they are associated with climate change and forecast different scenarios regarding urgent and specific energy policies. In Portugal, the most important documents on the subject are the Plano Nacional de Energia e Clima – *National Energy and Climate Plan* (PNEC) and the Roteiro Nacional de Carbono – *National Carbon Roadmap* (RNC).

I have no intention of replacing any of these documents, nor repeating their content. My aim is a different one: to offer the perspective of a physicist who has dedicated his academic and professional life to these issues, contextualising the problem and presenting the main constraints, whilst attempting to avoid a more ideological stance.

We often allow ideology to become embroiled in these issues, due to years of energy-related behaviour that is no longer possible (change is always difficult and nobody wants to change!). We have also become accustomed to hearing propaganda regarding a variety of solutions that are often unrealistic. However, when dealing with any energy policy requiring definition and implementation, a policy conditioning our behaviour regarding energy supply and demand, the line between scientific reality and ideology may seem more tenuous... That said, I will attempt not to cross it, although I often say that we should follow this path and not the other... based on a knowledge and analysis of the facts.

I aim to be concise, as much of the discussion (e.g., climate change) has been exhausted and can be considered as known. I want to help people understand that the technology we currently have is enough to solve the problem (cognisant that it is constantly evolving and providing new opportunities and solutions). That said, I also want to explain that every one of us is at the end of that energy consumption line. As such, we must help by accepting the need to change for energy transition to occur, modifying our own behaviour and the social and cultural norms essential to a timely solution! The change, the energy transition, is now presented to citizens as a moral obligation [52].

Sustainability is crucially dependent on recognising the boundaries on what one wants and is able do. Unfortunately, most people do not share this perception. There are limits to nature's capacity to absorb (in a timely manner!) the impact we have on it. Today's culture tends to believe precisely the opposite, which hinders development processes that understand constraints are necessary to be sustainable within the physical conditions on which they depend.

One of the major problems regarding the climate crisis is the fact we are not dealing with a single, global and catastrophic event. If this were the case, it would likely trigger a consensual, continuous response. This issue is happening in an almost invisible, incremental way, albeit with momentary consequences that are both visible and powerful, but separated in time and space… It is almost as if nothing is happening… And without drama, there is no response… and there is no intuitive perception of how urgent a change in culture and attitudes is needed.

Such a situation requires quality information and its internalisation, a slow and difficult cultural process, especially in less literate societies. Scientists can and should produce this information, as well as help others understand it. Everyone needs to realise the truth and the consequences!

Finally, Portugal will be the focus of the analysis; a concrete example where change can happen and is already underway.

1.

THE DIFFERENT THREADS

On a planet that is home to eight billion inhabitants, with growing consumption of finite resources and nature struggling to deal with the fallout of human actions, sustainable development is essential.

One key area is the emmision of greenhouse gases (GHG), particularly those associated with energy (fossil fuel consumption), which results in increased CO_2 in the atmosphere and deforestation, which affects the gases' sequestration. The ensuing climate change is accelerating and urgently needs to be controlled. Of the 1.5°C increase in average temperature that scientists had established as tolerable until the end of the century, we have already used 1.2°C. A few tenths more and we will have reached the point of no return with devastating consequences that will take hundreds, if not thousands of years to rectify. Such a catastrophe will affect everyone's life on this planet, including that of our own direct descendants.

The solution involves decarbonising the economy by reducing and then ending **[1]** the use of fossil fuels.[1]

This scenario requires an energy transition that involves energy sources that do not cause GHG emissions. CO_2 emissions are caused by burning fossil fuels, which account for around 80% of total GHG emissions (see Annex 1 for definitions and more detail).

The major problem is that, over the last century, we have created an almost total dependence on fossil fuels, a form of (chemical) energy that is extraordinarily convenient, concentrated (high density) and stable at room temperature. It is also easily transported and transformed into electricity, mechanical energy for transport, heating and cooling for industry and buildings, for example.

In technical terms, we talk about primary energy, which is now being removed from the scene, from statistics and from the discourse surrounding energy itself. The issue of energy statistics is important, because without being understood in these terms, the solution seems much more difficult and complicated than it is.

What we want is final energy, that which is available before the final transformation into useful energy. In other words, the energy in the network that feeds the socket to which the lamp is plugged into before it is turned on.

The concept of primary energy allows us to understand that the coal burnt in the thermal power station produces electricity, which is then transported to the socket that powers the lamp. This process involves many losses (one unit of electrical energy requires ~3 units of thermal energy – a loss factor of 3 – since the efficiency of the coal-fired power station is

1 — To reach a carbon neutrality, acceptable fossil fuel use (for all purposes, including the chemical industry) should be between 1/6 and 1/7 of current levels, (consumption/emissions = absorption/sequestration) [IPCC].

between 30% and 40%) increased by further losses (between 8% and 12% more in line losses) until it reaches the point of consumption.[2]

When it comes to oil, we must also consider the energy needed for its extraction, refining and transport to the supply point.

When we talk about a renewable source capable of producing electricity directly, the concept of primary energy is no longer relevant. Even line losses may not have to be considered when electricity is produced in a decentralised way, such as on the roofs of our houses.

When electricity produced using fossil fuels is replaced by electricity that is not, the impact this has in reducing primary energy is important, as is the final stage of conversion into useful energy. This can be seen in transport or in thermal transformation processes.

For example, the fuel in the tank of our car (final energy) has a conversion into movement, efficiency rate (useful energy) of only about 20%. If the same vehicle is powered by an electric motor, it obtains the same unit of movement with 95% efficiency. If the electric energy in question is not fossil fuel in origin, the resulting reduction of primary energy is considerable (a factor of over 5). Even if the electricity is obtained from fossil sources, compared to the direct use of fuel, the outcome is still favourable (1 to 3 instead of 1 to 5).

When these aspects are considered, we realise that by removing primary fossil energy from the energy statistics panorama, we will move forward, no longer having to use the usual terms (primary energy). This means not having to listen to the discourse of slow and lengthy transitions, like those regarding coal to oil and from oil to gas, something often heard when discussing the transition to renewables, for example.

The important conclusion is that the discourse of the future will have to be made in terms of final energy.

2 — For natural gas thermal power stations, efficiency is closer to 50%, thus offering a loss factor of only 2.

2.

HOW TO DECARBONISE

We will continue to analyse the energy issue, searching for alternatives without losing sight of the key aim, which is decarbonising the economy.

Rapidly reducing fossil fuel consumption will require widespread consideration of alternative energies (2.1). However, it will lead to other game-changing possibilities, primarily the issues of materials and their use (2.2) and the discussion regarding recycling and the circular economy (2.3), not forgetting cultural norms (2.4), particularly consumer behaviour.

Energy is involved in all, but the perspectives are different, which is why we will deal with them separately.

A more complete analysis would involve energy issues and the environmental impacts associated with other aspects, such as food production (agriculture and livestock). These areas have progressed a great deal in recent years, far beyond the changes in habits and procedures that are already happening and are likely to have major consequences in the medium and/or long term. Just one of the remarkable developments of late is the production of meat (and other foods) using stem cells **[2]**.[3]

2.1. ENERGY

2.1.1. ENERGY SUFFICIENCY AND EFFICIENCY

Before focussing on alternatives (energy supply), we must introduce the concepts of energy sufficiency and efficiency, which are key and an integral part of energy demand. This includes avoiding consumption (energy sufficiency) and ensuring minimum use of energy to achieve a given objective (service), which we call energy efficiency.

The issue of demand management is key, as it can help reduce fossil fuel consumption and includes the consumer, whose attitude (individually or collectively) is the cause of the problem we need to solve.

Examples of energy sufficiency are many and varied: from construction techniques that favour thermal insulation, double glazing (even triple or quadruple!), the right orientation of buildings, so as to take advantage of natural ventilation, solar gains, etc., to city planning, which minimises travel, reducing individual transport in favour of public transport. There are many ways to avoid consuming energy without sacrificing our quality of life.

Energy concerns are increasingly important in the building sector,

3 — We Tasted the World's First Cultivated Steak, No Cows Required, TIME, Aryn Baker/Rehovot Israel, November 2022 including demanding energy certification (in Portugal: Direção Geral de Geologia e Energia – Directorate General for Geology and Energy – DGEG and the ADENE – Agência Nacional de Energia – National Energy Agency and the ELPRE programme). Such developments will affect behaviour, comfort and even cost, affecting the profitability of investments in the near future!

Every day, energy efficiency is making strides via energy-saving equipment and increasingly efficient processes (e.g., industry).

European and Portuguese legislation in this sector is increasingly tighter, aiming to encourage reductions in consumption of 32.5% by 2030. This can only be seen as an effective way of helping us change our energy consumption. After all, there is a lot we can and should do: such as improving the thermal performance of our houses, thinking about being energy producers with photovoltaic or solar panels on our roofs, replacing gas cookers and/or boilers with electric ones (see 2.4, below), etc. Sooner or later, if we are pushed by legislation, we will have no alternative.

Also, if we manage to control the desire to consume (consumer goods), something that underpins the society in which we live, we will also achieve something quite important.

2.1.2.
ALTERNATIVES TO FOSSIL FUEL ENERGY

After learning and implementing such demand side management, we must then focus on choosing alternatives to fossil fuel energy. The options are renewable energies and/or nuclear energy.

The first possibility includes solar, hydroelectric, wind, bioenergy, wave and tidal and geothermal. This last one is not strictly renewable, but it is practical to consider it as such. The second possibility includes nuclear fission and fusion.

Renewables, especially solar energy, can be used to produce electricity, as well as for the direct production of fuels, biofuels and so-called synthetic fuels (such as H2 and others), as well as heating and cooling. As for nuclear energy, apart from special applications (primarily military), it is limited to producing electricity.

The major technological developments of recent years have been in renewable energies, particularly wind and solar, which are now the cheapest forms of producing electrical energy on the market. Not only are they more economical, but they are also versatile, quicker to implement and they make use of abundant resources found throughout the world.

Meanwhile, nuclear energy has become increasingly more expensive, primarily because of safety issues (after major incidents at Chernobyl and

Fukushima, as well as many smaller episodes that have happened and continue to happen) and growing awareness of so-called hidden costs.

The difference is huge. Nowadays, the cost per Watt peak for a large photovoltaic solar plant can be between €0.3 and €0.4/Wp, while a new nuclear plant offered potential buyers prices between €3 and €4/Wp.[4] In practice, it ends up costing much more (€8.5/Wp (Oilikuoto-3 plant in Finland and >€17/Wp at Flamanville, France, etc. [4][5]). A factor of 10 difference initially, which can then reach values over 50! (see Annex 2).

We will revisit this issue when we analyse nuclear energy further. For now, we will continue to focus on the importance of energy production, electricity generated by alternative sources.

2.1.3. ELECTRIFICATION OF THE ECONOMY

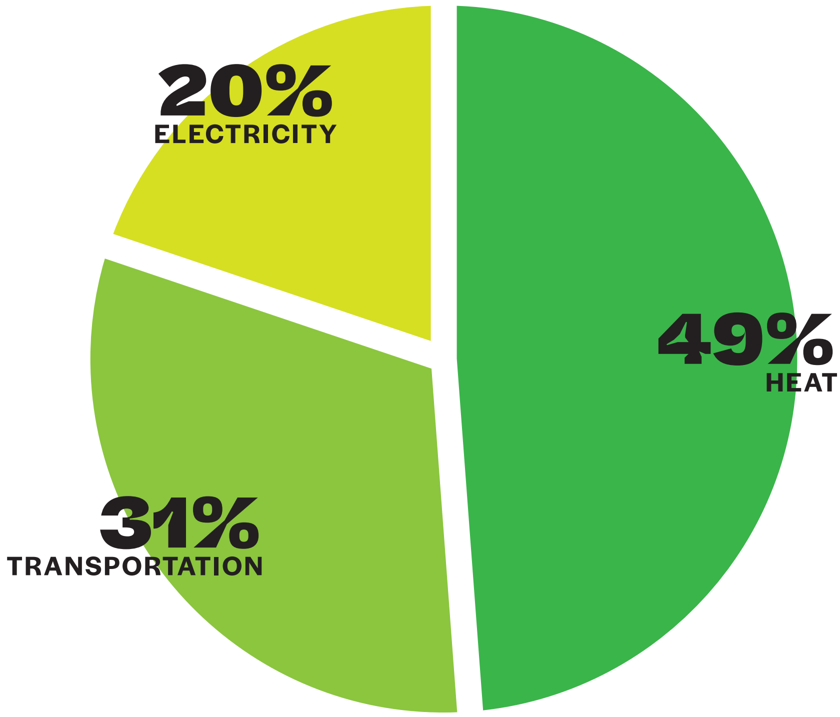


FIG. 1
FINAL ENERGY IN THE EUROPEAN UNION

4 — Production potential – rating of a given technology; in the case of photovoltaic panels, it corresponds to the production possible when transforming 1000W/m2-solar radiation at solar noon, on a clear day.
5 — In 2022, nuclear power's future looks grimmer than ever, Renew Economy, Jim Green, 11 January, 2022

Figure 1 illustrates the distribution of final energy, final use electricity, heating (including heating and cooling in the building sector, but also heating processes in industry) and transport in the European Union.

We have seen the great impact that electrification can have on primary energy (e.g., vehicles). Other examples we could mention include substituting gas cookers for electric ones (with energy savings easily reaching a factor of 2), or substituting house heating systems with heat pumps, which can turn one unit of electricity into 4 or 5 units of heating (or cooling), which contrasts with gas boiler efficiency in the production of thermal energy, which is less than 1. The use of electricity is also growing in industry, not to mention the possibility of decentralised self-production (e.g., photovoltaic).

These examples are a strong incentive to electrify all economic activity, provided that we can produce electricity that is not fossil-based. Also, when we want to use renewable energy, the cheapest, most immediate, direct and impactful way of doing so, involves producing electricity.

The yellow slice of the final energy pie is expected to increase from 20% to at least 40% in the next 20 years, with major impact on primary fossil energy, increasing its importance in transport (collective and individual) and the heating sector.

That said, renewables may make a greater contribution, both for thermal purposes (biomass/waste, solar) and the production of alternative fuels (synthetic fuels, including green H2 and biofuels, to a lesser extent, as will be seen).

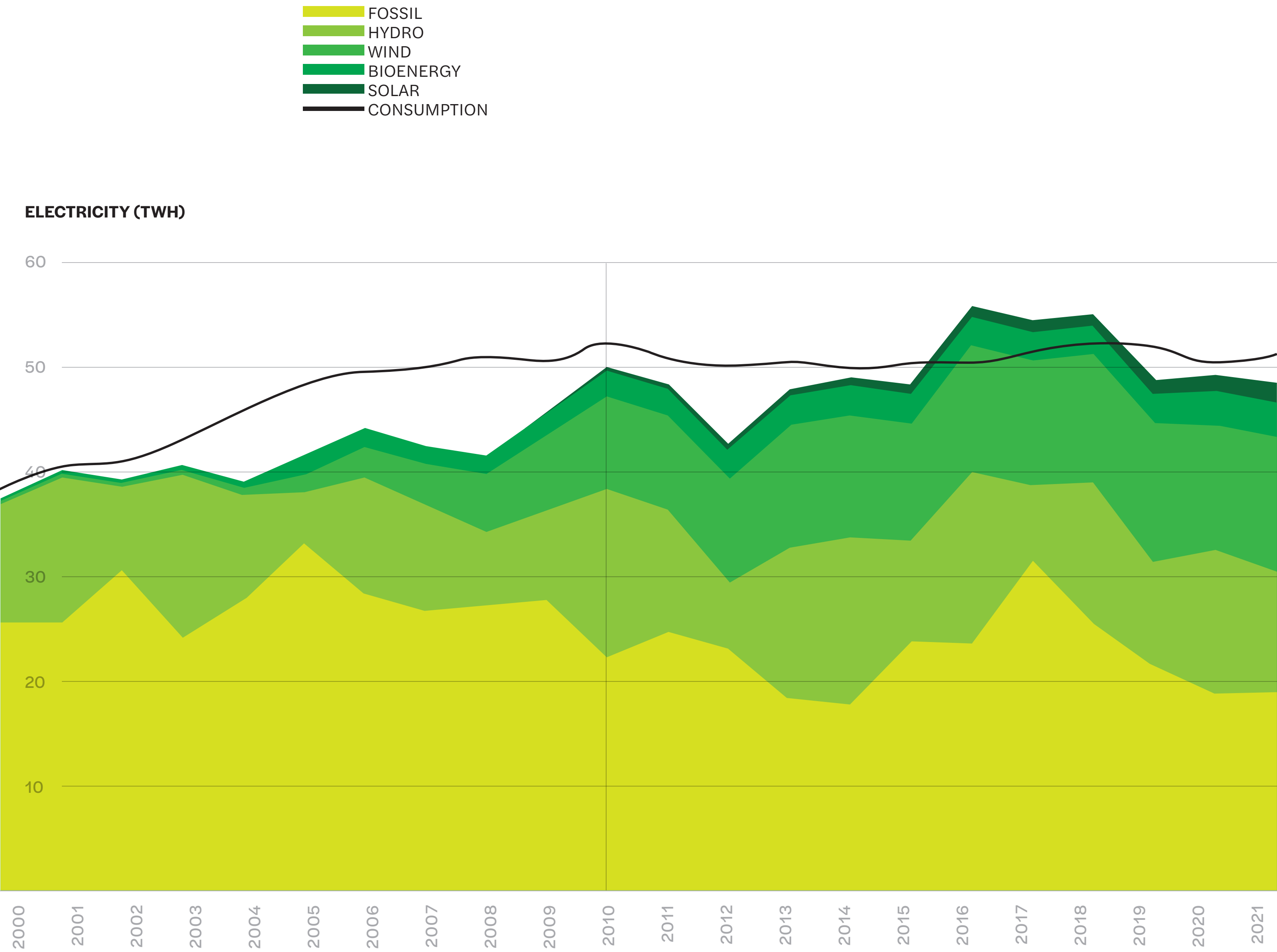
2.1.4. ELECTRIC ENERGY IN PORTUGAL

Before offering further thoughts on the future and role of alternatives, it is worth looking at the current situation regarding the electricity generation sector in Portugal (see Fig. 2).

There is around 20GW of installed capacity (see Fig. 3), of which 7.1GW is in hydroelectric power stations, 5.6GW in wind power, 4.5GW in natural gas power stations, 1.8GW photovoltaic and 0.7GW in biomass power stations. Peak consumption is slightly above 10GW in winter, so installed capacity is considerable.

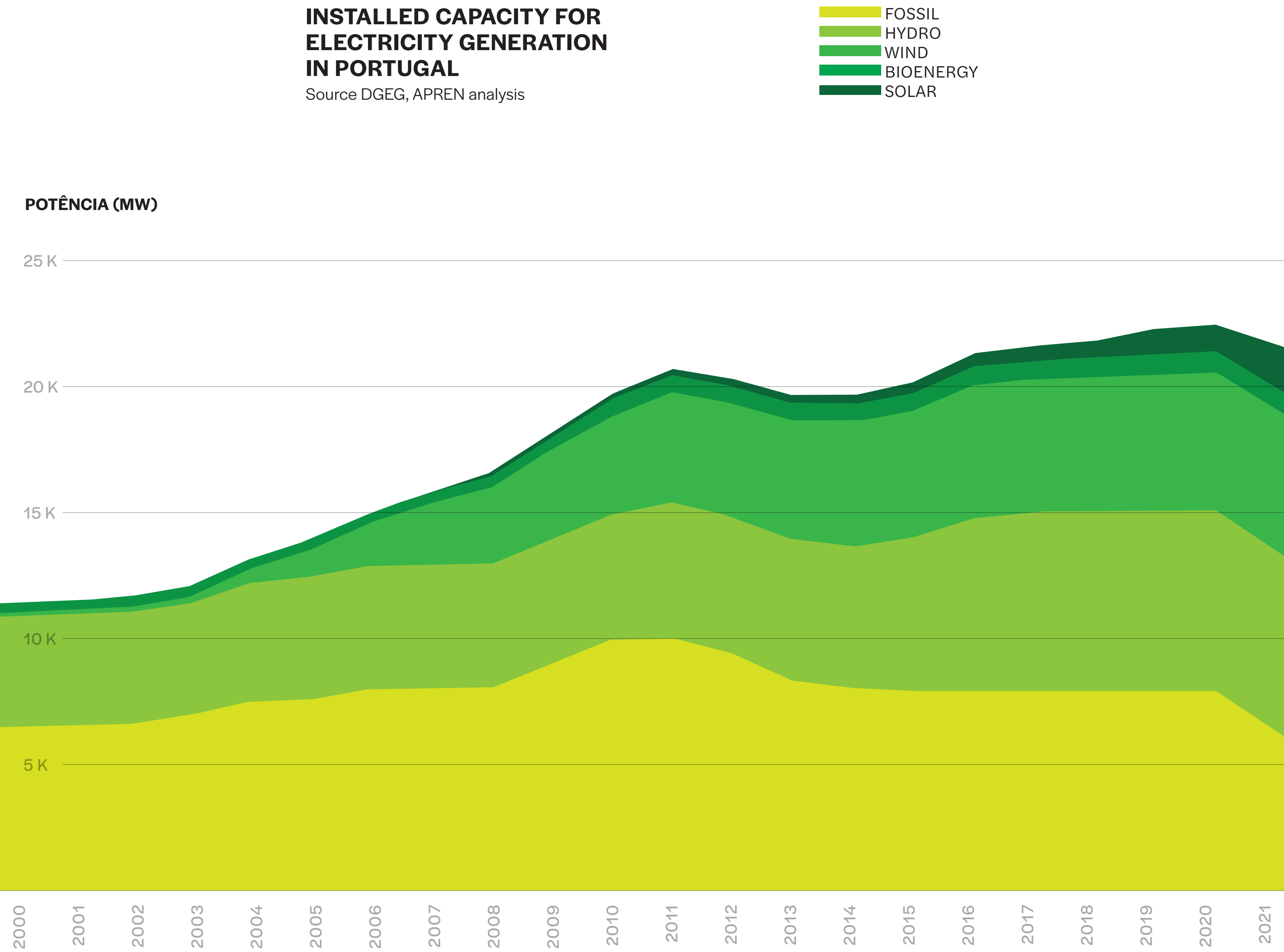
The production attributed to renewables is approximately 60% (the value calculated in 2023 - APREN - was 70.7%) and dependency on fossil fuels, which is now exclusively natural gas, has been decreasing. In some years, and on many days, consumption may be exceeded by production (equivalent to electric energy exports), however, the opposite is also true with electric energy being imported.

FIG. 2
ELECTRICITY PRODUCTION IN PORTUGAL
REN – Rede Eléctrica Nacional – Source, Analysis,
APREN – Associação Portuguesa de Energias Renováveis



The contribution of solar energy (photovoltaic) is still limited compared to hydro and wind energy. In recent years, with lower rainfall (drought) and less wind power available, this has had important consequences, reducing its contribution to levels that would have been much higher with greater solar installed capacity. This situation seems to be about to change with solar being forecast to become increasingly significant (see below).

FIG. 3
INSTALLED CAPACITY FOR ELECTRICITY GENERATION IN PORTUGAL
Source DGEG, APREN analysis



According to the PNEC – Plano Nacional de Energia e Clima 2030 (National Energy and Climate Plan), it is estimated that the national electricity generating system will reach installed capacity of around 30 GW, with renewables representing around 80% of the total (24 GW)[6]. Of these, 9 GW will be hydroelectric energy, between 8 and 9.2 GW wind energy and between 8.1 GW and 9.9 GW solar energy.

This is in line with the need for a growing electrification of the economy, as explained above. Note the surge in solar energy underway!

6 — Recently (December 2022) the Secretary of State for Energy announced that this goal might be brought forward to 2026!

2.1.5. RENEWABLE ENERGIES

2.1.5.1. CHARACTERISTICS AND LIMITATIONS

This is not the place for a technical explanation of these various forms of energy and the equipment used to transform and employ them.[7] That said, it is worth highlighting some of the more salient aspects that help us understand the type of role they will play in our future.

All of them are solar in origin, more or less directly from the sun. As the sun rises and sets every day on the planet where we live, it makes them renewable and limitless in terms of timescale.

In terms of abundance, the power that reaches us from the sun (~1000W/m2 on a plane perpendicular to the Earth-Sun direction, at sea level) is ~10000 times greater than our immediate needs. In terms of availability, we must consider specific issues: these include day alternating with night, the different seasons, as well as rainfall and wind, variations that form part of the general equation for using solar, hydro, wind, etc.

However, this variable availability means that the various forms of energy can "replace" others. For example, the absence of sunshine at night can be compensated by the presence of wind, or increased rainfall, which in turn affects the availability of hydro energy. The other important characteristic is availability in terms of space.

In the north of Portugal (and Europe) it rains more or there is more wind than in the south. With solar energy it is the opposite, especially if we think in terms of Europe.[8] This variation is associated with an important opportunity when considering electricity production and a common European energy market: electricity can be produced in one place

7 — As already mentioned, there have been important advances in science and technology in recent years that have made solar panels (photovoltaic) and thermal collectors available, with or without solar radiation concentration, as well as wind generators and other equipment that provide the cheapest way of producing electricity, for example. Other technologies are evolving rapidly, such as wave and tidal power, which will increase the availability of renewable energy in the future, contributing further security of supply.

8 — Contrary to popular belief, the difference in solar energy availability between the south (Faro, for example) and the north of Portugal (Porto, for example) is less than 20%.

(country) and transported to be consumed in another. European legislation facilitates/improves/increases interconnections between countries to exploit this fact. The management of simultaneities! The Iberian electricity market and the frequent exchanges between Portugal and Spain are clear examples of this.

In the meantime, technology has brought us another mechanism to mitigate the problem, which is energy storage.

2.1.5.2. ENERGY STORAGE

A first form of storage is the symbiosis between hydro and other sources, such as wind or solar.

The hydro power associated with reservoirs allows energy to be stored via reversible processes, which consists of pumping water that has already passed through the turbines and produced electrical energy back into the reservoir. When there is an excess of wind energy, for example, if there is no consumption at the time, it can be stored instead of being lost. The number of hydroelectric power station with dams and reversible processes is now significant in Portugal, boasting reversible production capacity close to 3.5GW (DGEG, EDP) in 2022. The efficiency associated with this process, including both directions, is between 75% and 80% (it can achieve 90% in each direction). Such results make the losses of this strategy acceptable, proving potentially higher than that for electricity stored in batteries (charge-discharge cycles have global efficiencies of between 60% and 70% [80% in each direction]).

N.B.: in a country that is heading towards a drier climate, hydropower should not be viewed as something separate from the issue of water. This is not the place to discuss this issue, however, the increase in hydropower capacity foreseen until 2030 (about 1GW more) is good news for both energy and water.

The reservoirs allow storage for a matter of days, although, in theory, production management can be done on a seasonal scale. This has yet to be put into practice because of the complication associated with water management.

A second way of dealing with storage issues involves battery technology, which offers a wide selection of battery types and rapidly evolving technology. In addition to known lithium reserves, such advances in extraction and battery configuration (density, kWh/m3 or kWh/kg) will allow growing demand to be met for many years to come (2035-2040). This is important because electric vehicle batteries are heavily reliant on the use of lithium [4].[9]

Meanwhile, there will be other technologies for this and other important applications based on other materials, such as sodium, sulphur, aluminium [5], which are abundant and, given the scale of use, will relieve the pressure on scarcity.[10] For vehicle batteries, reuse technologies will be adopted (second life) in less demanding stationary applications, for example.

Alongside this, there are technologies geared towards stationary applications, for large storage capacity batteries, network nodes, major users, etc., which are also associated with other materials. One example is flow batteries, which use vanadium (vanadium redox [6]).[11]

An alternative technology being developed stores energy in the form of heating, only producing electricity when demand is met. This is achieved through concentrated solar thermoelectric power plants (CSP) that mimic conventional thermal power stations, with solar energy stored during the day in the form of heating (molten salts, at 560ºC), producing energy at night or during the following days. This technology is being developed in Portugal, in collaboration with other European Union countries (mainly in the Renewable Energies Chair, University of Évora [7]).[12]

Energy storage can be dealt with in other ways. For example, at a certain time of day, a photovoltaic system for residential purposes may have "excess" energy that can be channelled towards the air conditioning or heating system, thus treating the house as an energy storage unit for the purposes of personal comfort and home maintenance (e.g., humidity control).

9 — Metals & Mining Practice Lithium mining: How new production technologies could fuel the global EV revolution April 2022 © Xeni4ka/Getty Images Lithium is the driving force behind electric vehicles, but will supply keep pace with demand? New technologies and sources of supply can fill the gap. by Marcelo Azevedo, Magdalena Baczyńska, Ken Hoffman, and Aleksandra Krauze (McKinsey & Company)

10 — See, for example, "Aluminium, sulphur and salt batteries. Cheaper than lithium-ion, for homes and EV charging stations" September 7, 2022 by David Chandler

11 — Project PVCROPS – Building Integrated PV, funded by the European Union with the participation of the University of Évora, Installation and testing of a vanadium redox flow battery
Adélio Mendes, FEUP, LEFABE and the development of vanadium redox flow batteries

12 — M. Collares-Pereira, D. Canavarro, L.L. Guerreiro, Linear Fresnel reflector (LFR) plants using superheated steam, molten salts, and other heat transfer fluids, Advances in Concentrating Solar Thermal Research and Technology, ISBN: 978-0-08-100516-3, Pages 339–352, 2017, https://doi.org/10.1016/B978-0-08-100516-3.00015-0

Producing a fuel like H2 by renewable means can be viewed as a way of storing energy. Green H2 and other synthetic fuels (see below) are energy carriers, storing energy between production and consumption (typically staggered in time).

2.1.5.3. PRODUCING ENERGY IN THE FUTURE

2.1.5.3.1. ELECTRICITY

As previously explained, production of renewable electricity in Portugal is dominated by hydro and wind power. Solar energy will increase its share significantly and Portugal will soon be approaching a distribution close to 30% for each energy form.

Other renewables may become part of the mix. One possibility is wave energy, although the technology is not as mature. That said, we are not dependent on this happening for renewables to be a dominant presence.

In the case of wind power, which has been operating in Portugal for some years (wind turbines began being installed more than 20 years ago), there is an interesting development: (i) previous generation equipment will be replaced by today's larger generators (>3MW), which take advantage of existing infrastructures and allow greater production capacity in each location (repower) and (ii) the possibility of extending production "off-shore", exploring the Portuguese coast with better wind availability averages.

Some data on global wind energy (Wind Energy IEA, September 2022 **[8]**): ~830 GWp installed until 2021 for the production of 1,870TWh and growth of up to 3,200 GWp for a production of 8,000TWh in the 2030 Net Zero Scenario)

In the case of photovoltaic solar energy (PV), solar panel production is mainly dominated by Chinese companies, which manufacture in quantities and at prices almost impossible elsewhere in the world.

China (IEA Solar PV, 2021 **[9]**) was responsible for the 38% increase in PV production capacity in the world, followed by the USA (17%) and the EU (10%). The world's installed PV capacity is close to 1,000GWp (production of 1,000TWh) and is expected to reach 5,000GWp (for an output of 7,400TWh) in 2030 (IEA-Net Zero Scenario **[10]**). The conversion efficiency announced on the market for the most common technology – crystalline silicon – now exceeds 20%, i.e., > 200Wp/m2.

The Chinese commercial hegemony is now being challenged by other countries (e.g., USA and EU) mainly for themselves. There are also various developments for niche markets, such as semi-transparent active glass, active tiles, etc.

That said, most development will come in the form of supply. In addition to centralised production in power stations that emulate conventional centralised production, renewables in general, but solar photovoltaic in particular, facilitate decentralised production.

This sector will grow considerably, with Portugal already boasting an important slice of the abovementioned 9.9GW for photovoltaic. This activity involves the installation of solar panels in our homes and buildings in general, as well as in industry, transforming classic consumers into energy producers (consumers). When superfluous to own consumption, the energy produced can be transferred to and absorbed by the grid for consumption by other consumers. Another idea gaining major traction is that rather than simply injecting the excess energy into the network, it can be managed from a renewable energy community (REC) perspective. This is joint management of what other prosumers produce, greatly enhancing the value of the energy produced, instead of selling to energy companies at a knockdown price.

Portuguese legislation in this matter has been particularly positive and forward thinking **[11]**.[13]

There are several operators doing business in this new REC market.[14] The companies creating RECs often tell the members that they do not need to invest in the photovoltaic system that will occupy each of their roofs. Rather, they can just sign an energy acquisition contract with the REC, at a much lower tariff than the conventional one (up to 40% cheaper), which is fixed for a period of 15 years, with several possible options for the following 15 years.

2.1.5.3.2. HEATING

Some references to solar thermal have already been made, for example, those regarding the production of electricity. Bioenergy will be considered in a later chapter. We have yet to mention the important role solar energy plays in the production of heat (and cold), primarily, for solar gains in buildings (passive solar) but also for applications like domestic hot water, heating and cooling (absorption technology), as well as today's technological advances in process heat for industry (e.g. steam production between 180°C and

13 — For exemple, Decree Law 15/2022
14 — Greenvolt/Energias Unidas, Cooperativa Coopernico, etc.

250ºC). Over the years there has been considerable research in Portugal in this area [12] and even the manufacturing of solar concentrators and other collectors.[15] Once again, the main R&D centre in Portugal is found in the Renewable Energies Chair, University of Évora.

Solar energy will allow a part of fossil fuel consumption, especially natural gas, to be replaced via electrical and thermal direct means in industrial and domestic applications.

2.1.5.4. RESOURCES AVAILABLE FOR RENEWABLE TECHNOLOGIES PRODUCTION

2.1.5.4.1. ENERGY RETURN ON ENERGY INVESTMENT

It is still often said that a lot of energy (of fossil origin?!) is needed to manufacture photovoltaic panels and therefore would not be an appropriate response to future energy issues. In 2004, by order of the DoE – Department of Energy (USA), the NREL – National Renewable Energies Laboratory (USA) published a PV FAQS [13] analysis including this issue.[16] This concluded that, with the technology of that time, the various technologies (from crystalline silicon to amorphous silicon and other thin-films) recovered the energy invested in their manufacture within a period of between 4 years (c-Si) and 1 year (thin-films) with their energy production. Calculations were then made for 12% conversion efficiency. Today, in the case of Si-c (crystalline silicon), the conversion efficiency levels are well above 20%, which means that these calculations would give (ignoring manufacturing technology itself, different panel thickness, etc.) a result of between 0.5 and 2 years. For a technology that has been reliable for at least 30 years, this is a non-problem.

Similar calculations, with similar results have been done for wind turbines (1 year of production to recover energy used in manufacture:1 year: Erick Lantz, NREL [14])

However, this type of concern becomes less importance as the electrical energy used in manufacturing is increasingly of renewable origin.

15 — For example, D. Canavarro, J. Chaves, M. Collares-Pereira *Improved design for linear Fresnel reflector systems*, Advances in Concentrating Solar Thermal Research and Technology, ISBN: 978-0-08-100516-3, Pages 45–55, 2017, https://doi.org/10.1016/B978-0-08-100516-3.00003-4
16 — NREL (2004) PV FAQS

2.1.5.4.2. MATERIALS: RESOURCES, RARE-EARTH AND OTHER ELEMENTS

Regarding the materials used to produce photovoltaic panels, we are talking mostly about silicon, one of the most abundant elements on Earth. That said, photovoltaic panels and wind turbines do use small quantities of less abundant elements, including materials from the generic category of rare-earth elements (REE).[17] For example, in the case of wind generators, neodymium is used for the magnets. This is also the case for countless number of other objects/systems that we use in our everyday life, such as electronics in vehicles of all kinds, computer hard discs, batteries, fibre optics, mobile phones, etc.

Some other important aspects are worth noting. These elements are called "rare", however, this term is deceptive: they are not so rare but they often exist in concentrations that make them unviable to mine (something that is also relative, and sometimes changes over time). Total world reserves of REE are over 120 million tons **[15]**. By 2030, it is estimated that 280,000 tons/year will be extracted. At this rate, these resources will last hundreds of years. N.B.: some elements are more abundant than others and this estimate considers them all, as a whole.

China is the world's largest producer of REE, with between a third and a quarter of the world's reserves. Much of its market dominance is directly related to very low production costs, which comes with a huge disregard for the environment. However, this production could be undertaken under other terms, which would be more balanced but also more expensive. In other words, permanently cost cutting involves a red line of sustainability. This means paying more to reduce environmental impacts, although not much more, as the quantities involved are small, product by product.

This idea can and should apply to photovoltaics, as photovoltaic panels are often cheaper than they could/should be. They could continue to be by far the cheapest way of producing electricity, while absorbing slightly higher costs to reflect a cleaner production of these materials. The same could be said for all components in the electronics industry.

It is worth mentioning that photovoltaics is not critically dependent

17 — The 17 REE are: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), scandium (Sc), and yttrium (Y). **[15]**

on REE, like wind turbines (or electric vehicles) are. Silicon is the overwhelmingly dominant material in current global solar cell production, while silver is the predominant metal for metal contacts. That said, there are alternatives to silver that will probably prevail, irrespective of possible scarcity. It is also true that some solar cell technologies employ a range of minor metals, including indium, gallium, selenium, cadmium, tellurium, which are generally by-products of base metal refining (e.g., copper, nickel, zinc) that cause no major concern in this context nowadays.

Another important issue is the fact that, at the end of their lives, electronic products still tend not to be recycled, as the amount of worn and broken appliances we own attests. From a circular economy perspective, it is obvious that these items should be treated differently. Recycling will have to become common practice. Will it be more expensive? From a global perspective, not necessarily. If the environmental impact of such resources is reduced, those resources last longer. All these aspects have their own value.

In addition, strong technological development will create ways (besides recycling) of combating a possible shortage of REE in a few decades, both for photovoltaic cells and batteries, for example.

2.1.5.4.3. LAND AVAILABILITY FOR EQUIPMENT INSTALLATION

Confronted with their presence on high ground, many citizens were against the installation of wind turbines. Nowadays, this is less of an issue, as we get used to seeing them on the landscape. As for offshore solutions, it is a non-issue.

Nowadays, most objections are levelled against photovoltaic power stations, mainly because of the supposed competition for land that could be used for farming. This will also become less of an issue because there is a lot of available land with little or no agricultural use, not to mention increasing so-called agrovoltaic applications, a symbiosis of technologies and objectives that will calm the waters. Of course, in the meantime, there may be abuses, especially regarding auctions for the allocation of photovoltaic power on land with direct access to the electricity grid. These are not technical issues, but political ones.

Two other situations are worth highlighting:

– Floating solar or floating photovoltaics (FPV), usually located on dam reservoirs or lakes, which is a very logical use of available areas, as well as grid connections.

FIG. 3
FLOATING PHOTOVOLTAICS, ALQUEVA

– Rooftop PV systems

To maximise annual production, the ideal place for stationary solar panels is that of a slope at the latitude of the place minus 5º, and with a south azimuth. Virtually no roof meets these exact specifications, so it is common to see structures sloping and misaligned with roof gables, unnecessarily.

Not having ideal conditions for tilt and azimuth makes little difference, making the decentralisation of production via photovoltaic relatively easy, with no need for special structures placed on roofs to create the ideal tilt or orientation. Figure 4 shows the penalisation of various inclinations and azimuths.

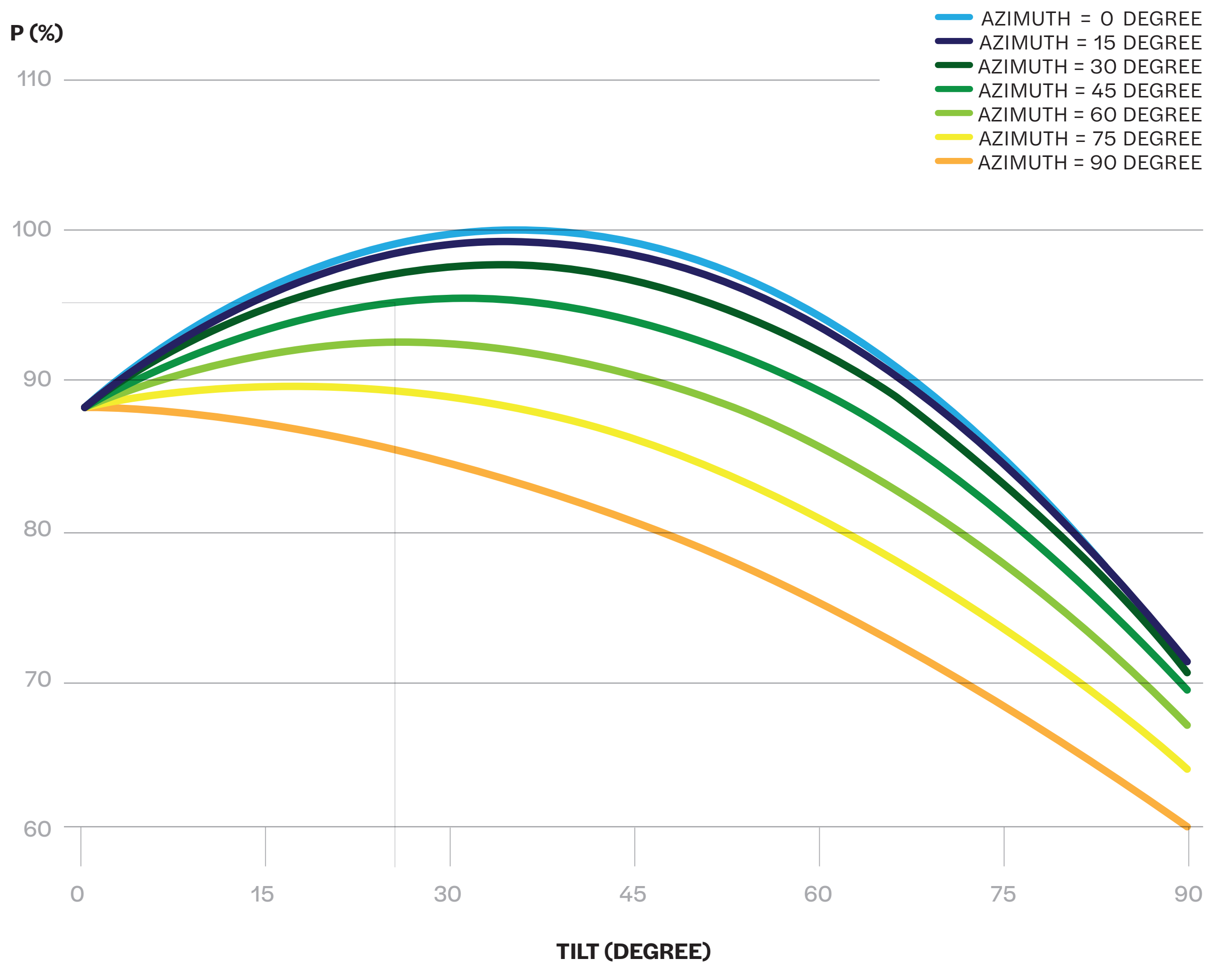


FIG. 4
ANNUAL PENALISATION OF AVAILABLE ENERGY ON A PLANE SURFACE, DUE TO AZIMUTH AND TILT [16]
(Manuel Collares Pereira “Energias Renováveis: a opção inadiável” (1998)) The graph was made for latitude 38, 75º (Lisbon) and for the maximum value (inclination at latitude minus 5º and azimuth 0º). X-axis: tilt (degree) inset: Azimuth

As demonstrated in Figure 4, horizontal placement (on terraces) results in a penalisation of only 12%![18]

Photovoltaic panels weigh around 12kG/m2, so they can be placed directly on most roofs, including factory roofs. Flat terraces can also be used directly for this purpose and other areas, such as car parks, can have roofs with photovoltaic panels.

18 — Horizontal installation is not recommended. Some inclination is necessary for reason related to cleaning and rain.

2.1.5.5. BIOENERGY

This vast subject includes solid biomass (e.g., firewood), biofuels (bioethanol, biodiesel), bio methane, for applications ranging from heat production to the production of electricity in thermal power stations and transport. Consulting EU texts on this subject (the Energy site and **[17]** Renewable Energy Directive 2108/2001), we realise its complexity and links to other policies **[18]** such as agriculture and sustainability itself.[19] It is worth mentioning that to be allowed biofuel power stations must demonstrate direct greenhouse gas emissions that are 65% below the relevant fossil fuel alternative. If it is solid biomass, this requirement rises to 70% (80% in 2026).

Biofuels are expected (2050) to make a significant contribution (up to 14% for transport, for example). Currently, liquid biofuels account for approximately 5%, blended with petrol (ethanol, up to 10%) and bio diesel (up to 5%).

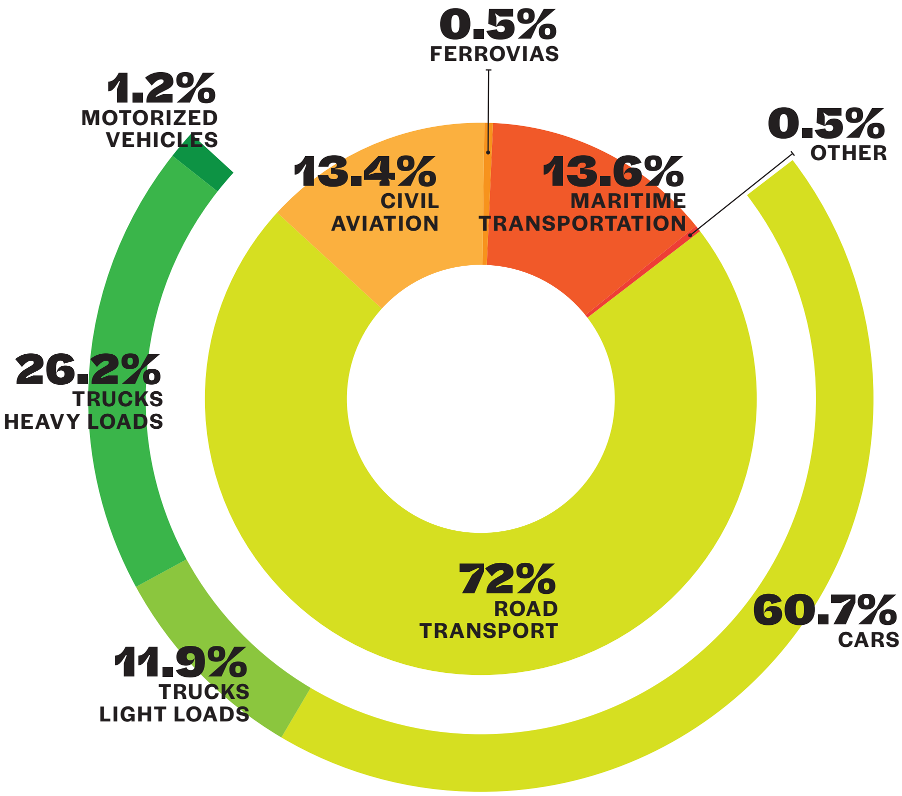


FIG. 5
CO2 EMISSIONS IN EU, TRANSPORT
Emissions breakdown by transport mode 2016

19 — Report, The use of woody biomass for energy production in the EU, May 2020

When it comes to burning liquid fuels, an important issue is related to air and maritime transport, which consume about 20% of total fuels, but with disproportionate emissions. This is especially true of maritime transport with a strong dependence on heavy fuel oils. [19]

Blending biofuels with fossil fuels is one way of mitigating the impact of emissions.

These two sectors (maritime and air transport) will need to develop considerably, with more biofuels but also with new fuels (synthetic, H_2). This will be examined in the next chapter.

Still on the subject of solid biomass (plant matter burnt or used for producing electricity, such as wood, wood waste, energy plantations, agricultural, industrial and domestic waste), it is worth noting that the IEA (Net Zero scenario by 2050) [10]) states that the traditional use of biomass should be reduced from 2030. Here, traditional biomass means firewood, charcoal, agricultural waste, dried animal excrement for cooking and heating in the residential sector. These processes boast very low efficiency (lower than 20%) and depend on irregular supplies/deforestation of biomass. At the same time, it considers that the "modern" bioenergy share (about 6.6% of the world's total energy mix) should reach 13.1% in 2030 and 18.75% in 2050.

Concluding this chapter, it is worth noting that many sustainability and environmental experts [51] are very sceptical regarding the real impact of the development of biofuels, especially when a full carbon balance is calculated between the soil's capacity to fix it and resulting GHG emissions due to intensive cultivation of new species.[20] The balance can often be negative. As such, the targets and methods used require much tighter control regarding deforestation, competition between fuel crops and food crops, uncontrolled use of fertilisers, abandoning of traditional fallow and/or intercropping techniques, etc.

2.1.5.6. RENEWABLE ENERGIES AND THE FUTURE IN THE REST OF THE WORLD

There is a major imbalance between rich and poor countries. Roughly speaking, four fifths of humanity consume one third of the world's energy. The euphemism "developing countries" reflects the need for a significant increase in energy consumption per capita. In fact, one of the necessary

20 — Peter Fairley, The biofuel course correction, The circular economy, Scientific American, January 2023

conditions for eradicating poverty is the increase of per capita energy consumption.

For the one billion-plus people living below the poverty line, this means having at least enough energy to cook, a few litres of drinking water and some capacity to have light and power for a radio, a TV, etc. With these conditions guaranteed, these citizens' health improves, they begin to access culture (have light to study...) and undertake some productive activity of their own, which generates income...

Obviously, it is unsustainable to change this situation with a supply of fossil fuels, which, on the contrary, need to be reduced and even eliminated. It is imperative to bring the need for the decarbonisation of the economy to the economies of the developing countries, essentially, to their new development economies!

Everything that has been said about energy sufficiency and energy efficiency is equally valid here. However, renewable energies are unavoidable and unique, due to several essential characteristics:

– they are distributed naturally and even more abundant in the "Sun Belt", between tropics, where most people live.

– energy production alongside consumption, so there won't be the same pressure found in the past in the economies of developed countries to develop infrastructure (energy, transport and distribution)

What happens to energy may mirror what happened and is happening with the wireless reality of telecommunications. They became quickly viable and accessible, whereas 20 or 30 years ago there was the seemingly insoluble problem of the cost of extending a network with cables. And today there are mobile phones all over Africa. Renewables could become like the mobile phones of energy...

Clearly nuclear power will not be the massive alternative for the developing world, due to its very high cost, associated technological demands, dependence on nuclear fuel supply and the fact that centralised production requires an appropriate electricity transmission and distribution network.

Naturally, of all the fossil fuels available, natural gas will play a dominant role in energy transition (throughout the world, in fact). This is because it is more abundant than oil, more evenly distributed (more sources, more disperse, reducing hegemony of certain countries and large energy companies) and cleaner burning (from an environmental point of view).

There is a huge reliance on firewood (solid biomass and other waste) in developing countries, particularly in rural and suburban areas. Burning wood, which has very low efficiency, has two harmful effects: upon the environment through associated deforestation, and upon health (respiratory diseases, eye diseases, etc.), which urgently need to change. Above all, this effort will occur using new burning equipment technologies, low consumption solar electricity equipment for basic needs and equipment for cooking food. The latter has been the subject of research [20] and industrial development in Portugal. [21] [22]

2.1.6.
NUCLEAR ENERGY

Nuclear energy has been mentioned throughout the text, mostly in contrast with alternative renewable energies. However, certain aspects need to be highlighted, especially regarding nuclear fission energy.

Nuclear energy's contribution to the world's current electricity production is around 10% (IAEA – International Atomic Energy Agency, PRIS 2019) [21], from a total of 443 reactors. Many reactors are reaching end of life and being shut down, with some countries, such as Japan and especially Germany, deciding to abandon nuclear energy. In 2019, there was a decrease in total installed capacity. That said, several reactors have been under construction (54 in 2019). The IEA–International Energy Agency's forecasts expect ~10% for nuclear energy's contribution by 2050, which indicates some increase in installed capacity (IEA World Energy Outlook, 2022) [22]. In the authors opinion, this forecast has much to do with the Agency's own relationship with nuclear energy.

There are a variety of obstacles to achieving such results. It is worth highlighting the following:

– the enormous cost of nuclear, even if we ignore the hidden costs, compared with alternatives ("too expensive to matter"?!)
– the unresolved issue of waste storage
– the prohibitive cost of decommissioning reactors that have reached the end of their lives (most existing reactors).
– technological dependence and associated dependence on the supply of raw materials (enriched uranium). [23]
– increasingly negative public opinion regarding nuclear energy.

21 — M. Collares Pereira, J.P. Almeida, J. Correia de Oliveira " Description and testing of a novel solar box type cooker incorporating CPC type optics" ISES Solar World Congress, Gothenburg, June 2003
22 — SUN CO; SUN OK
23 — Uranium U235 exists in nature with levels below 1% (today, on average, 0.5%); currently, the most common fission technologies require a U235 level (enriched uranium) of around 3.5%. Processing requires a particular technological competence practised in only a few countries, which supply it to the others.

– a very long gap between the decision and the reactor becoming operational (>10 years currently, >15 years in several recent cases).
– the fact that it seems much less indispensable than recently thought, when compared to renewable energies, which are clean, much cheaper and found everywhere in today's inhabited world. A huge difference!

A more detailed discussion of this issue can be found in Annex 3 (adapted from the book "Jeremias e o Desenvolvimento Sustentável", Manuel Collares Pereira, ISBN 978 972 241978 9, Livros Horizonte, which is part of the National Reading Plan **[23]**). It includes an approach to new technologies proposed for small modular reactors (SMRs) as an alternative or to solve the problems of larger reactors.

Annex 3 also addresses the subject of nuclear fusion, a technology that still needs decades of development before being market ready.

2.1.7. SYNTHETIC FUELS, H2

Another huge topic in its relative infancy, this summary of technologies and future paths, two important routes are highlighted:
– synthetic fuels, with thermal solar energy input (under development)
– H2, via the electrolysis or thermolysis of water

One path for synthetic fuels is biomass pyrolysis, with a heat input involving burning biomass, but mostly concentrated solar thermal power, capable of producing the necessary temperatures (hundreds of degrees Celsius) in the (total or partial) absence of oxygen.

One result is synthesis gas ($CO+H_2$), which can be used directly or transformed into conventional liquid fuels, liquid hydrocarbons (Fisher-Tropsch process).

For the second, green H_2 **[24]** the route involves electrolysis, using non-fossil electricity, especially solar electricity.[24] This focus on renewables is justified by cheaper electricity production.

The efficiency and cost of electrolysers are key factors in the H_2 economy of the future **[25]**.[25]

At today's prices (costs of electrolyser, energy, water, etc.), green H_2 is between €3 and €4/kg **[26]**.[26] It is estimated to cost €1.5/kg in 2030, due to

24 — Green Hydrogen, a guide to policy making (IRENA-2020)
25 — Green Hydrogen: reducing the cost needs scaling up of electrolyser plants
March 15, 2021(IRENA report) by Herib Blanco and Emanuele Taibi
26 — Harry Morgan, Why market dynamics will reduce the average price of green hydrogen to $1.50/kg by 2030, Energy Transition, September 2022

technology advances, the cost of electrolysers and reduction in energy prices (from €3 to €2/kWh with PV).

At these prices, green H_2 becomes competitive with fossil based H_2 and conventional fuels for many applications in industry and transport. While applications are being developed, precursors of future use on a much larger scale, the technology will continue to advance, also encompassing other essential aspects for the green H_2 economy: how it is transported and stored.

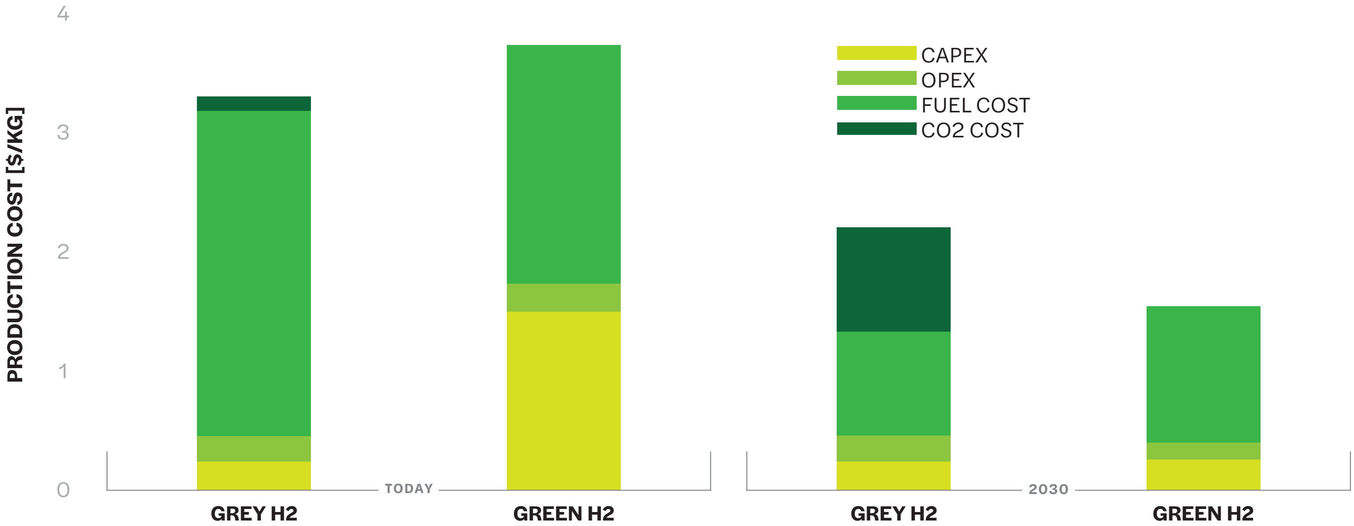


FIG. 6
H2 PRODUCTION COSTS (HARRY MORGAN, [26]

One important aspect is that seawater (or brackish water) is not yet used for the abovementioned electrolysis. Using it requires prior desalination, which makes the H_2 more expensive to produce. However, there is already substantial research into the direct use of seawater **[27]**.[27]

Green H_2 is usually stored in pressurised tanks (hundreds of bars). That said, there are several other storage options **[28]**.[28] This includes liquification, being mixed with other gases, in solids (e.g. metal hydrides) and chemical combination with other elements (e.g. nitrogen, N) in the form

27 — The Open Fuel Cells Journal, 2010, 3, 1-7 1 1875-9327/10 2010 Bentham Open Access Hydrogen Production Using Sea Water Electrolysis H.K. Abdel-Aal*, K.M. Zohdy and M. Abdel Kareem Higher Technological Institute, Tenth of Ramadan City, Egypt; other recent references, February 2023, The Chemical Engineer, University of Adelaide, Australia, University of Shengen, China, etc.
28 — Hydrogen and Fuel Cell Technologies Office (DoE): Hydrogen Storage

of compounds, such as ammonia (NH_3). This last example is particularly interesting, due to the many possible applications **[29]**.[29]

Another note on green H_2 production: the water thermolysis route (direct lighting), using catalysts, can be undertaken at around 800°C, which is perfectly achievable with solar concentrators. Efficiencies > 5% (solar energy for H_2) have already been achieved and will soon be around 20% **[30]**.[30]

Green H_2 is predicted to play a key role in economies of the future, replacing fossil fuels via decarbonisation.

Final note: being truly green is 100% dependant on the electricity used not being fossil based, i.e., renewable! If the electrolysis is done through a dedicated photovoltaic or wind system, then there is no doubt! However, if the energy comes from the main grid, while renewable penetration is not particularly high, the H_2 /emissions balance is very different. This issue is much discussed in the EU, with H_2 proponents claiming that intolerance of non-renewable power supply for electrolysis (and when a renewable energy supply is unavailable) will hamper H_2 technology development **[31]**.[31]

2.2. MATERIALS AND DECARBONISATION OF THE ECONOMY

Technological developments allow us to approach the decarbonisation of the economy differently. This is associated with new practices and procedures, involving the use of new materials, which have a completely different relationship with energy and environmental issues. A good example of this is the use of wood in the building industry.

29 — Potential Roles of Ammonia in a Hydrogen Economy A Study of Issues Related to the Use Ammonia for On-Board Vehicular Hydrogen Storage U.S. Department of Energy
30 — Drop-in Fuels from Sunlight and Air - Remo Schäppi, David Rutz, Fabian Dähler, Alexander Muroyama, Philipp Haueter, Johan Lilliestam, Anthony Patt, Philipp Furler and Aldo Steinfeld
Nature, vol. 601: no. 7891, pp. 63-68, London: Nature, 2021.
31 — Marta Lovisolo Keith Whiriskey, "Cannibalising the Energiewende? 27 Shades of Green Hydrogen;" Bellona Europa 2022 https://network.bellona.org/content/uploads/sites/3/2021/06/Impact-Assessment-of-REDII-Delegated-Act-on-Electrolytic-Hydrogen-CO2-Intensity.pdf

2.2.1. WOOD AND SUSTAINABILITY

Currently, building is based on materials like cement, in the form of reinforced concrete (combining steel and cement), and brickwork, or concrete blocks. These materials have a major greenhouse gas footprint when produced and thus are highly unsustainable.

There are two components in the emissions associated with the buildings sector **[32]** that make up ~40% of the total emissions (~28% operation/function and 11% for construction.)

Cement production alone accounts for between 8% and 9% of total CO2 emissions worldwide **[34]**. There are two reasons: an energy-intensive manufacturing process that is still dependent on fossil fuels, and a chemical cement manufacturing process, which is itself a CO2 emitter/releaser.

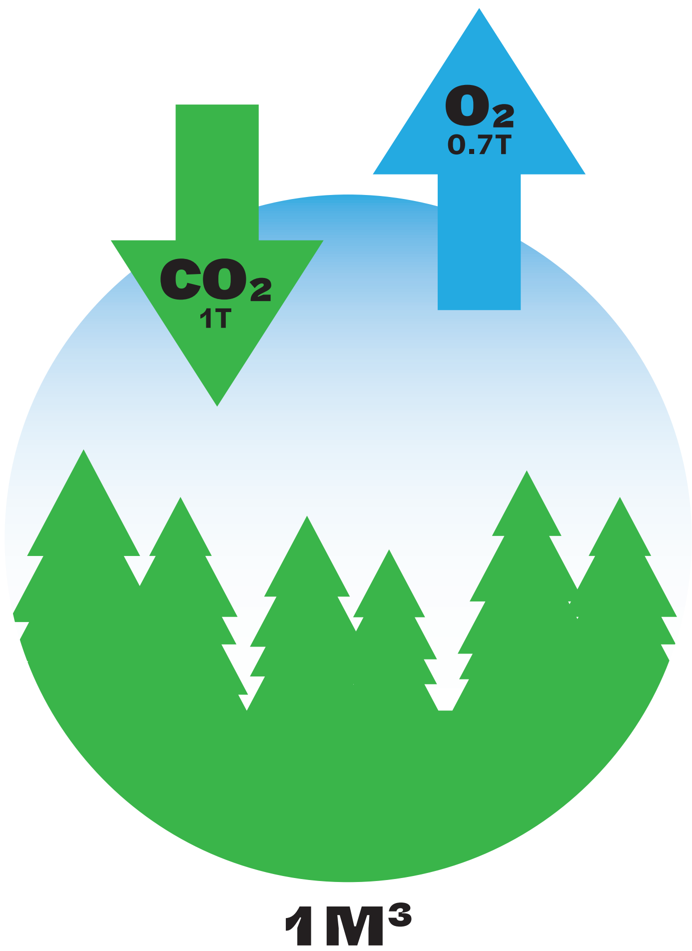


FIG. 7
REFERENCE [2] – INCORPORATION (SEQUESTRATION) OF CO2 IN 1 M3 OF WOOD

These figures demonstrate the importance of reducing emissions and the cement industry is currently making a serious effort to reduce its footprint.

However, there is a powerful alternative, which involves building mostly with wood and other natural materials (e.g., cork, bamboo, waste, fibres, etc.). The reason is that the carbon content of wood is a direct product of CO_2 having been sequestrated from the atmosphere by the trees that produce it via photosynthesis.

On average (see Fig. 7), every time a ton of wood is used in construction rather than non-natural materials, CO_2 emissions are reduced by ~2 tons [33].

As such, wood's effect on the atmosphere contrasts with that of conventional materials. We talk about a negative carbon footprint. This is the great advantage of using these natural materials, which combat climate change directly [2].

In terms of environmental plusses, wood offers excellent thermal performance, both in terms of cooling and heating needs. It is a natural insulator and can easily be combined with others, such as cellulose fibre, cork, etc., which can boost thermal characteristics. This will fit snugly with bio-climatic architecture, energy sufficiency and efficiency, and joint use of photovoltaic and thermal solar collectors to produce NZEB – Net Zero Energy Buildings, facilitating energy transition and sustainable development: all this while maintaining or improving comfort levels.

Large-scale use of wood for construction will clearly involve good forest management, replacing each tree cut down with one or more others. This management can even increase the capacity for CO_2 sequestration associated with forests in comparison with those that are simply left alone. Such attention given forests will be key to reducing the fires that have become more frequent (due to climate change).

2.2.2. A NEW WOOD TECHNOLOGY

Over the next few years, a revolution will occur. Wood and other organic materials will become increasingly common in the construction sector, not only as something used for conventional buildings or the small, prefabricated houses currently available, but a true alternative to traditional construction, even in multi-storey buildings [35].

Here, when we talk about wood for construction, we are not necessarily thinking of the traditional forms familiar to us (e.g., one-piece beams). Instead, we are thinking about specially designed components that are the result of recent technological developments, with names like CLT, Wood Frame, Glulam (generally designated by mass timber).

FIG. 8
18-STOREY BUILDING IN NORWAY, MADE ENTIRELY FROM WOOD

What are they?

– Cross Laminated Timber (CLT) consists of layered lumber boards stacked crosswise at 90-degree angles and glued. Depending on its thickness, the whole will have a certain resistance, equal to a classic slab of reinforced concrete but between one quarter to one fifth of its weight.

FIG. 9
CLT SLAB BEING LAID

– A Wood Frame component consists of a wooden frame containing thermal insulation (cork, cellulose fibres, etc.) with spaces for plumbing and electric cables.

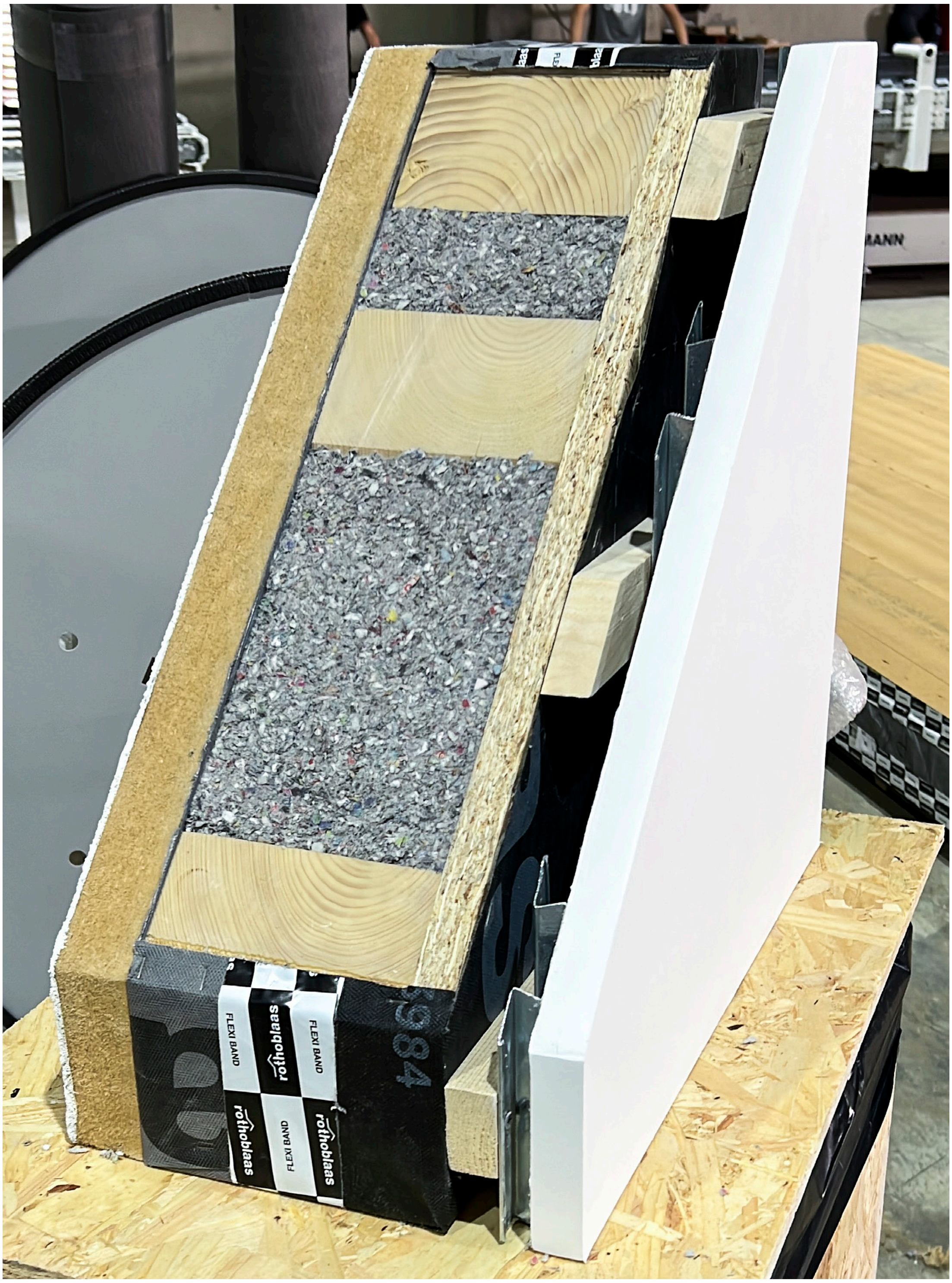


FIG. 10
IMAGE OF A WOOD FRAME SYSTEM

– Glulam (glued laminated timber) consists of wood laminations glued to one another. These are used as beams and pillars in porticoed systems (e.g., roof of the Altice Arena in Parque das Nações, Lisbon), spans, etc.

FIG. 11.
IMAGE OF GLULAM (GLUED LAMINATED TIMBER)

The wood used is normally found throughout Europe (e.g., fir, pine, eucalyptus, among others). These woods boast growth rates better adapted to forest management for this purpose.

These components are produced in factories and allow prefabrication, which significantly reduces the environmental impacts associated with conventional construction, as well as construction times and better control of construction quality.

In Portugal there are already several initiatives along these lines[32].

The so-called mass timber components can be made using renewable energies: after the trunks are processed into boards, they can be dried using thermal energy, which can be produced by burning the associated raw material waste. For all other fabrication stages, electrical energy is used, which may be photovoltaic installed on the roof of the factory.

32 — In Portugal, important initiatives are taking place to this end. Among others, the major property developer, #Vanguard Properties, is investing in this sector, having decided to focus future construction on wooden buildings, integrating the whole chain, from forestry, to component production and prefabrication (#Kozowood Industries, SA, Esposende). This development will be based on locally grown woods, namely pine from the continent and cryptomeria japonica from the Azores Islands

Legislation in the EU and other countries is already facilitating the transition to wood in the building sector. For example, in France, new buildings must now incorporate at least up to 50% wood (Guide RE2020 – 49% emissions reduction from the building sector up to 2030) **[53]**.

2.3. RECYCLING AND THE CIRCULAR ECONOMY

(Adapted from the book "Jeremias e o Desenvolvimento Sustentável", Manuel Collares Pereira, Livros Horizonte, 2020)

Recycling is a key concept in sustainable development, with steps having been taken everywhere in this area, such as separation of waste. Generally, it means significant energy savings on transforming original raw materials (e.g., bauxite ore in the case of aluminium production) into the final product we use. Instead of starting the process with the original raw material, we can recycle and save a lot of energy. Just a few examples: 40-60% recycling paper to make paper, 25% if it is cardboard, 10%-15% in the case of glass, 70% in the case of iron and steel, and 94% for beer and coke cans.

Any energy saving means fewer fossil fuels being burned, hence less C2, less greenhouse effect, less climate change. This is the kind of reasoning behind the circular economy, not only because of energy and its impact upon climate, but for a multitude of other reasons. Many resources are finite, and it makes sense to use them more slowly, while attenuating the issue of waste accumulation! However, the term circular is not precise. It is not possible to go all the way around and arrive at the same starting point. Physics teaches us that there are always losses in the process. It is called irreversibility, and it is the second law of thermodynamics... Ultimately, we will never have a circle (returning to the same point). It is more like a spiral. Perhaps this exactitude would render the concept less intuitive and more complicated. Hence the adoption of the circular image.

A more complete approach to the circular economy **[51]** means focussing on the three Rs: reduce, reuse, recycle, in that order.[33] Here, the primary aim is to reduce consumption, not using if possible. Then comes the concept of not "throwing things away", not discarding what can still be used, and, finally, recycling. A complex example is plastics, which have an enormous impact on the environment, food chain, etc. Although they can be produced via bio rather than fossil sources with some degradability, their predictable and harmful accumulation is of such an extent that the three Rs are key to the approach that must be followed. Another very important example is that of electronic components, which stem from the profusion of

33 — The circular economy, Scientific American, January 2023 devices around us. Their multiple impacts range from the extraction of metals needed to make them to public health, especially in countries where recycling in done under abusive labour conditions, involving basic, manual processes.

There are other resources that should also be conserved and recycled when possible. For example, fresh water. Due to climate, it is scarce in many places... in others, although currently plentiful, climate change will soon have a negative effect. We need to adapt, saving and reusing as much as possible. Examples are water management in agriculture or reduction in domestic consumption. Homes can reuse water: bathwater can be reused to flush a toilet, the concept of grey water…That said, water is not a key issue of this text.

In short: recycling is important but not a silver bullet. There must be a strong antidote to the unbridled, single-use consumerism we are used to, finding new ways of behaving, and reducing consumption.

We should think [36] of moving towards a type of development that will eventually lead to a reversal of the current trend.[34] We should indeed try to "de-globalise" the economy in material terms, living more from what is around us, reducing and even eliminating waste, leaving globalisation for other things, such as knowledge, culture, the virtual transmission of information and communications...

2.4. IN THE MEANTIME: CHANGING BEHAVIOURS, THE WAY FORWARD

All energy used has consumers at the end of the line, which means they are part of the problem. They can and should be part of the solution today, not waiting for technological advances and new energy policies mentioned to solve the problem.

Below is a list of immediately achievable actions, most of which require little investment, just simple changes in attitude and harmful habits.

Cheap opportunities:

1) Stop cooking with a gas cooker. It costs the same (or even less) to cook with an electric induction plate.
2) Replace your old gas water heater with an electric water cylinder, or heat pump.
3) Replace old appliances with new ones (at least class A).
4) Use double glazing (windows and doors).

34 — Manuel Collares Pereira "Energia e Ambiente num Mundo com muita Gente" – Chapter of publication "Despertar para a Ciência, Novos Ciclos de Conferências", Gulbenkian Foundation, GRADIVA, Lisbon, December 2007.

5) Insulate your loft/roof.
6) If you have central heating (air conditioning), set the thermostat to one or two degrees Celsius lower (or higher, if cooling is the problem), you won't notice much difference. Also, avoid heating the whole house, only the rooms you are using.
7) Light your house with more efficient bulbs. Don't leave everything switched on in unoccupied rooms or when you are not at home.
8) Use public transport as much as possible and walk or cycle.
9) Reduce use of your petrol or diesel-powered vehicle to the strictly necessary; drive more slowly and avoid sudden starts. Don't leave the engine running when you are not moving. All these are excellent ways of saving fuel and money.
10) Holidaying abroad? Why not travel within your own country and visit its different attractions?
11) Avoid sea cruises on floating cities, which are an energy and environmental disaster.
12) Don't consume for consumption's sake, e.g., make your wardrobe last longer by not buying new clothes and/or wear second-hand clothes in good condition.
13) Eat food produced closer to home (meat and fish, for example) and seasonal fruit and vegetables, instead of other foods from the other side of the world... with unnecessary greenhouse gas emissions.
14) Try to reduce all waste (e.g., separate waste, save water).

Opportunities requiring greater investment/effort:
15) Replace your gas boiler with a heat pump, which provides heating in winter, cooling in summer, and sanitary host water, thus offering cheaper energy and greater comfort.
16) Invest in producing your own electricity – self-consumption – with photovoltaic solar panels. Use energy communities, production cooperatives and self-consumption. Also use solar thermal collectors to produce domestic hot water. In both cases, the payback time is a few years and the solar panels/ collectors last over 20 years.
17) Make the transition to electric vehicles as soon as possible. In Portugal, 60% of electricity is already from renewable sources (and the Government's plan is to reach 80% by 2026).
18) If you are thinking of building a new house or renovating your home, think about passive solar solutions. These are associated with good orientation, natural ventilation, solar gains (useful in winter, to be avoided in summer).
19) When choosing materials, buy ones with a longer life cycle. For example, think, of a wooden house, instead of resorting to

conventional construction!

20) (…)

In short: these are just some of the important steps that citizens can take to combat climate change. They are not associated with less comfort or severe limitations to quality of life. On the contrary: they signal more comfort and less expense. And having a clear conscience for doing the right thing!

This new attitude will also signal to those young people suffering from “climate anxiety” that a fairer, more inclusive, more sustainable and much better world is still possible.

2.5. IN CONCLUSION

The energy policy documents mentioned plot various routes to achieve carbon neutrality objectives by 2050, while limiting the global temperature rise to 1.5°C by the end of the century.

This text was written to demonstrate that we already have the technology to achieve such objectives. And that there is much more technological development to improve and facilitate the ability to respond.

So, is the problem solved? Will we achieve 1.5°C?

It would be possible, but it is not happening in the right way. The energy transition needed to save humanity as we know it is clearly pressing **[52].**[35] However, it all depends on citizens, consumers, their culture and their behaviour, specifically regarding politics and the politicians they elect.

Portugal is on the right path, as the PNEC and RNCA show.

There are still many obstacles, such as contradictory legislation (try putting a photovoltaic panel on a building with a tiled roof! If it has any historical character, it is even harder, even if you can’t see the roof from anywhere?!) There are incomprehensible decisions and hesitations. Lisbon welcomes floating ecological disasters that are giant cruise ships, while there seems to be little or no control over what goes on…

On top of this, both in Portugal and abroad, there is little real capacity to combat vested interests, be it those behind fossil fuels and other energies, be it those representing the savage capitalism of an unfettered consumer

35 — Desenvolvimento Sustentável, Verdade e Consequências, Manuel Collares Pereira, coordinator and presenter, Prefacio de Viriato Soromenho Marques, authors: Alfredo M. Pereira, Cristina Conceição, Elsa Lamy, Fernando Capela e Silva, João Manuel Bernardo, José M. Belbute, José Manuel Martins, Manuel Collares Pereira, Manuel Vilhena, Margarida Simões, Maria Ilheú, Maria Raquel Lucas, Mariana Valente, Miguel Rocha de Sousa, Publisher DOCUMENTA 2022, ISBN 978-989-8833-86-0 society. These bodies are doing their best to slow down the transition and even deny it is necessary.

When will we be able to view the trillion-dollar costs of energy transition not as costs (propaganda!), but as investments, with guaranteed return? Such investments are pillars of a new economy, capable of spawning many new agents that will have interesting consequences on the energy sector's capacity for democratisation.

And when will we realise that the path to energy transition offers remarkable consequences on the collective quality of life? It means better air to breathe and more comfort. The traditional approach, in contrast, either does not provide this, or it does but only to the few of those who have the means to pay.

Although the abovementioned documents contain the best choices and intentions of ongoing environmental and energy policy, what they do not mention are uncontrollable events with unforeseeable consequences. One such example is Russia's invasion of Ukraine, which has had a major effect on the economy but also, and directly, on energy and environmental issues. Even the best laid plans do not stand a chance! Europe's dependence on Russian gas, oil and enriched uranium (a fact that often goes unnoticed) has led to a less firm and more hesitant reaction from the European Union, with the only positive consequence so far being the EU's decision to speed up the transition to renewable energies. Other less palatable consequences include the resurrection of nuclear power (Germany?), and an increase of coal use (Poland), which only aggravate the current situation.

Portugal's energy policy has been effective in controlling electricity production costs and other costs. Renewables account for approximately 60% of electricity and the country has little or no dependence on Russian gas and oil (Eurostat).

However, it is still very difficult to combat the existing greenwashing and vested interests, which are backed by major finance. It requires a lot of courage and political nerve, which has been seriously lacking.

The United Nations and its Secretary-General, António Guterres, make the right and proper speech every day. They propose global measures that would be very effective if they were implemented. For example, ending enormous direct and indirect subsidies that favour fossil fuels and putting an end to oil and gas prospecting, considering that current oil reserves and oil already produced are sufficient to satisfy our needs for more years than we would wish. Such action would go a long way to achieving such goals.

Although some climate protestors may not fully understand the implications and the consequences of what they demand, Greta Thunberg and the young people who emulate her are right about what they want. They want a future world, where everyone can live a better life, which will never be achieved with "business as usual". The future world will be theirs!

3.

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ANNEX

1

GREENHOUSE GASES

There has been a significant increase in the three main greenhouse gases (GHG) of anthropogenic emission (CO_2, CH_4 and N_2O) compared to pre-industrial levels (18th century) – 46%, 254% and 21% respectively – Filipe Duarte Santos "O Sector dos Transportes na Descarbonização da Economia de Portugal" Opinion Article, November 2019 **[37]**.

Citing the abovementioned text **[37]**, the main human activities contributing to GHG accumulation in the atmosphere are energy, transport, agriculture, industrial processes and waste. Figure 1 shows the relative share **[19]** of sources emitting greenhouse gases (European Environmental Agency 2017).

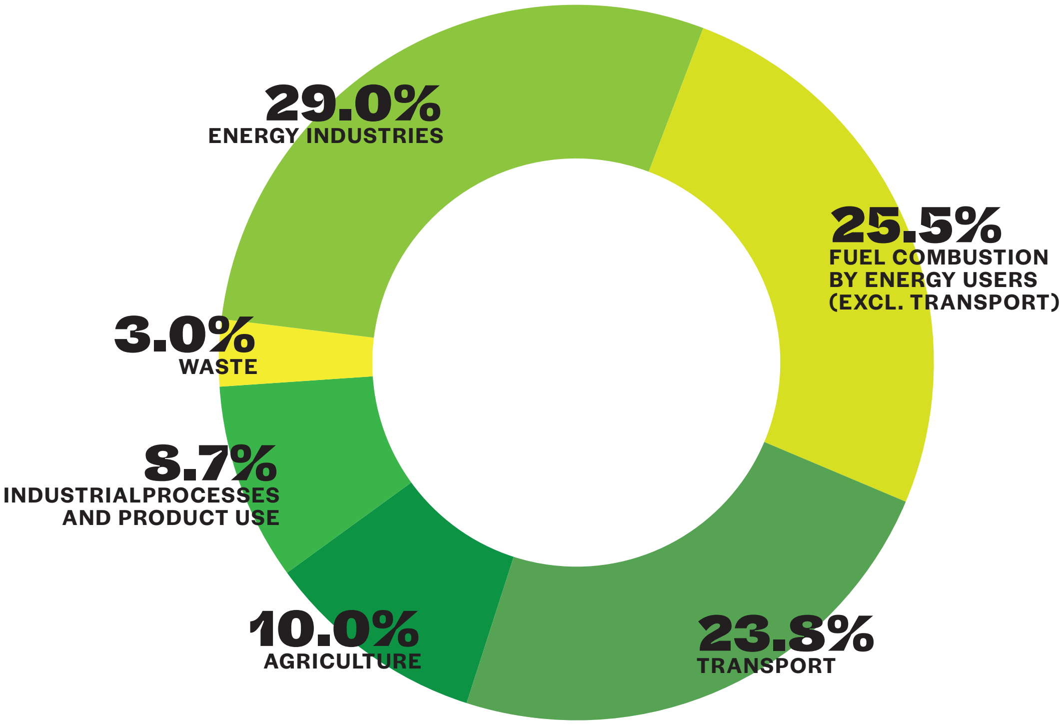

FIG. 1
SHARE OF EU GREENHOUSE GAS EMISSIONS (GHG) BY SOURCE

Energy industries: Emissions from fuel combustion and to a certain extent fugitive emissions from energy industries, for example in public electricity, heat production and petroleum refining.
Fuel combustion by users (excl. transport): Emissions from fuel combustion by manufacturing industries and construction and small scale fuel combustion, for example, space heating and hot water production for households, commercial buildings, agriculture and forestry.
Transport: Emissions from fuel combustion of domestic and international aviation, road transport, railways and domestic navigation.
Agriculture: This includes among others emissions from livestock – enteric fermentation – greenhouse gases that are produced when animals digest their food, emissions from manure management and emissions from agricultural soils.
Industrial processes: Emissions occurring from chemical reactions during the production of e.g.: cement, glass etc.
Waste: Emissions from landfills, wastewater treatment and composting among others.
Data including international aviation, excluding indirect CO2 emissions and land use, land use charge and forestry.
Source: European Environment Agency

In Portugal, the transport sector contributed 24.3% of the total 78 million tons of CO_2 equivalent (CO_2e) in 2017, according to data from Portal do Estado do Ambiente (REA), which translates the amount of CO_2 that would produce the same effect as the GHG mix that exists. It defines what is called GWP-Global Warming Potential (an index of radiative "forcing"). Taking CO_2 as a reference (1 unit of GWP), the GWP of methane (CH_4) is 25 and that of nitrous oxide (N_2O) is 298.

In physical terms, the presence of CO_2 in the atmosphere is measured in ppm (parts per million) and is currently 415ppm. CH_4 is measured in ppb (parts per billion), scoring around 1,800ppb in 2017. N_2O is measured in ppb and registered around 270ppb in 2017.

In 2017, total emissions in the EU were approximately 4,000Mton of CO_2e, of which ~3,250Mton CO_2e were CO_2, ~400 Mton CO_2e were CH_4 and ~200 MtonCO_2e were N_2O.

ANNEX
2

COMPARING THE COST OF PRODUCING ELECTRICITY USING NUCLEAR AND RENEWABLE SOURCES, PARTICULARLY PHOTOVOLTAIC

New photovoltaic power stations have already been auctioned in Portugal, with winning bids offering below €1.4/kWh (€14/MWh). This cheap price probably reflects not only the very low cost of PV power, but also issues like the value of an access point to the network.

That said, in many other places in the world, we can safely say we are looking at prices of between €20 and €30 euros/MWh for PV, establishing a fixed power production cost for at least for 25 years **[38]**.[36]

Regarding the investment cost itself and centralised production, it can be as low as between €0.3 and €0.4 M/MWp in large power stations.

Currently, decentralised production costs are between €0.7 and €1.0 /Wp in mid-sized systems and perhaps another 20% to 30% in small systems (individual installation in the domestic sector).

These figures are currently the lowest for new investments in comparison with those of any other form of energy.

In contrast, the figures for nuclear energy's costs place it at the highest level of all. It has never been cheap ("too cheap to meter", as they used to say in the 1960s) and was only developed with the aid of major subsidies, as is normal for an emerging technology (e.g. USA and France). However, this idea is partly responsible for the myth that nuclear energy is cheap.

The nuclear industry indicates the investment for a new EPR-type plant as between €3 and €4M/MWp (even so, 10 times more than photovoltaic); however, in practice, the final costs of reactors under construction are much higher: between 5 and 6 times higher, i.e. over €120 to €150 M/MWp (or more than 50 times those of photovoltaic) (see Annex 3).

The table below offers a summary of the figures.

36 — Woodhouse, Michael. Brittany Smith, Ashwin Ramdas, and Robert Margolis. 2019. Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: 1H 2018 Benchmark and Cost Reduction Roadmap. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/72134.pdf.

	INITIAL OUTLAY (INVESTMENT) (MEURO/MW)	ACTUAL COST (INVESTMENT) (MEURO/MW)	TIME BETWEEN DECISION AND ENERGY AVAILABLE (YEARS)	COST PRODUCING ENERGY EURO/MWH
Nuclear				
Hinkley Point (UK)	2.3	> 13	10-15	127
Flammanville (FR)	2.0	> 18	10-15	-----
Vogtle (US)				-----
PV				
Centralised	0.3-0.4	0.3-0.4	1-2	14-30
Decentralised	0.7-1.0	0.7-1.0	<1	

TABLE 1
COMPARATIVE TABLE OF INVESTMENT COSTS (NUCLEAR AND PHOTOVOLTAIC): REACTORS UNDER CONSTRUCTION

This is the case for the EPRs at Flamanville (France) and Hinkley Point (UK). The figures for the reactors at Vogtle (USA) are also high (Jim Green, In 2022, nuclear power's future looks grimmer than ever, Renew Economy Jan. 2022, 77) **[3]** ; Wikipedia Hinkley Point; Wikipedia .Flamanville (FR) **[39]**

These figures do not include, do not reflect, a series of other costs. These include decommissioning the plant at the end of its life, storage of all radioactive waste, the entire chain from mining to fuel processing, accident insurance (which only covers a very small part of the consequences of major accidents), etc. Who pays these costs? Undoubtedly consumers, via the electricity tariff or not, by political decision, of course.

The cost of nuclear energy is much, much higher than that of renewable energies, which is why there has been very little recent investment in the sector... and why many countries have decided to abandon it.

As for the energy produced, the contracts come with guaranteed minimum prices for energy sold to the grid (see, for example, the ~€127/MWh required at Hinkley Point, UK). To have a minimum return, this is guaranteed for many years, not counting subsidies and other support.

We could say that nuclear energy is, instead, "too expensive to matter".

ANNEX 3

NUCLEAR ENERGY: AN OUTDATED OPTION?

Here, we address some of the most important aspects of nuclear energy, fission and fusion [49].

3.1. NUCLEAR FISSION

The idea of nuclear energy (nuclear fission) engages our imagination and expectations. However, the more we study the subject, the more we encounter worrying aspects regarding cost, plant safety, nuclear waste management and others, thus dampening enthusiasm...

The principle: a uranium atom (U235), i.e. with a nucleus containing 235 protons and neutrons, absorbs another low energy neutron (known as a slow neutron) after contact, and becomes U236... another uranium isotope. This new isotope is unstable and will split or fission, i.e. split into two other atoms that make up a pair, generically called pair (X, Y), as there may be several possible pairs, and emit more neutrons. If the initial isotope is placed on one set of scales and, on another, the pair (X, Y) that resulted from fission (and other neutrons that are also released), the initial mass of the uranium isotope is found to be greater than the sum of all other masses resulting from fission! The difference of mass between the two sides, tiny as it is, now appears transformed into energy (Einstein's old formula for the transformation of mass into energy).[37] This is the nuclear energy of fission.

The same principle is used to produce electricity in thermoelectric power stations. The associated heat produces steam, which then passes through a turbine that powers a generator.

Certain problems are immediately apparent if not properly controlled, the neutrons produced will find other U235 atoms and produce more fission and more energy and new neutrons. Such a chain reaction could cause a huge explosion. This is how atomic bombs work. Fortunately, there are ways of controlling the process, ensuring we get the energy production we need in the thermoelectric power station. There are several ways of controlling the process.

The technology has developed considerably over the past 70 years. Initially, it was highly subsidised, with the promise that it would be a cheap, infinite energy source ("too cheap to meter"!) that never happened.

Today, we can see that commercial nuclear energy [40] (i.e. based on

37 — E=mc2 (author's note)

the market) is not “infinite” and is based on the uranium isotope (U235).[38] [39] This makes it an unsustainable solution, as it depends on a resource that will last mere decades, and even less if its use is extended, as proposed. We can also see that building a new power station, at today’s prices, is the most expensive way of producing electricity (see Annex 2). Also, there is no commercial solution for disposing of radioactive waste at the end of the power station’s life, nor for their decommissioning, which is estimated to cost as much as building them from scratch.[40]

The reality of this “new” cost is now affecting taxpayers in countries like the UK and Spain. The nuclear industry always claimed that it would have the money to cover such an expense, but it turns out to be untrue and taxpayers will have to cough it up. In other words, nuclear energy has never been intrinsically cheap.[41] Everything produced in power stations operating now was subsidised at the start, as well as at the end of its life, not to mention the danger and cost associated with major accidents....

Major accidents, like those at Fukushima, Three Mile Island, and Chernobyl, imply huge expense. They are not considered part of the normal operating costs, nor are they sufficiently covered by insurance! They are also the grounds for protests against nuclear energy all over the world.

It is legitimate to ask why nuclear power is still considered a real alternative. Reasons often cited are: (i) because huge sums of money have been invested in its development and large interest groups have been created around it, (ii) because these interest groups do not wish to be outdone by cheaper, cleaner and benign alternatives that have appeared in the meantime, (iii) because, most of all, this industry is linked to another, more deadly industry, which is that of nuclear weapons. The governments that manufacture and own them will not give them up easily (an understatement).

Even in Portugal, there are still some who believe such technology is appropriate for the country... based on all of the above, the author believes that, despite the elegance and beauty of nuclear physics, this form of energy

38 — See Manuel Collares Pereira, book chapter “Almaraz e outras coisas más”. Coordination António Eloy ISBN978 989 98835-5-0 Cooperativa Editorial Caldense, December 2017.
39 — U_{235} has an average abundance of around 0.5% relative to the U238 isotope , which is the most abundant.
40 — See figures of the latest AREVA (French) contract for the power station to be built in the UK.
41 — The electricity produced in operational nuclear power stations can be sold cheaply now because they were heavily subsidised when constructed; the subsidy was paid by the taxpayer from another pocket, i.e., the British or French consumer did not suffer this extra cost in their domestic tariffs.

is unviable without major protectionism and/or corruption in the market economies of democratic countries.

Despite what nuclear proponents say, renewable technologies boast much lower costs, zero risk and huge and rapid response (deployment) capacity for the energy transition, seemingly rendering nuclear options obsolete. Also, with renewables, electricity grids of the future will be very different in nature. They will offer great flexibility between different sources and different types of production (small/large scale, centralised/decentralised). In contrast, nuclear energy tends to monopolise, involve great rigidity, centralising, with its large scale and continuous operating conditions. As such, the author predicts that nuclear energy will gradually become a thing of the past (despite the IEA keeping its ~10% share in the future). The same will happen with fossil fuels! As for nuclear power, certain countries (e.g., Germany) already have policies decreeing the end of nuclear power stations, with the last ones to close in 2030.

Meanwhile, the proponents of nuclear power in the EU have used every means at their disposal to ensure that nuclear power is classified as one of the more ecologically sustainable technologies, claiming that it causes less (negligible?!) greenhouse gases.

That said, greenhouse gases are produced in all activities related to nuclear plants, from uranium mining, ore processing, station construction and dismantling to building waste repositories, waste processing and transport, because there is major fuel consumption, which produces CO2 … Despite everything, this is still less than a natural gas plant of the same size.[42]

The real reasons why nuclear power is not ecologically sustainable are: (i) it has a major impact on the environment, from mining to waste storage due to the radioactivity it produces and releases and because this type of waste remains radioactive for thousands of years and, (ii) as already mentioned, reserves of U_{235} uranium are very limited.

It should also be noted that nuclear alternatives to conventional nuclear are being funded and studied.

It is possible to consider alternatives to commercial fission based on U_{235}, via other nuclear fuels (U_{238}, Thorium- Th_{232}), which are quite different from the current commercial technologies (fast breeders).[43] These alternatives, which use much more abundant raw materials, would be potentially more sustainable, as they could be available much longer.

42 — Emissions (CO2) from a natural gas power stations 185 g/kWhe; studies for nuclear (full life cycle) give results between 16 g and 55 g/kWhe (CO2 equivalent) for the United States (Fthenakis-2007)
43 — Breeder reactors.

Other concepts also being explored: smaller modular reactors (SMR), which are presumably more secure (with passive safety), and reactors that can use waste from other reactors, thus “recycling” them and helping solve the waste problem.

SMRs would introduce the concept of prefabrication (a positive aspect), potentially helping to reduce costs through greater quality assurance, as a result of manufacturing in an industrial environment. This could also reduce reactor production times, in contrast to conventional power stations, which take over ten years to build. However, there are still no such reactors being demonstrated, leaving more questions than answers regarding such technology.

The use of new nuclear fuels contains a profound technological change, as fast neutrons (which are much more energetic) must now be used and cannot be moderated simply, nor can energy be extracted directly using water, as is done in conventional reactors. For example, the technology of breeder reactors requires liquid metals (sodium) or molten salts to perform these functions.

As such, the current interest in these solutions is tempered for several reasons: (i) until they become commercial, if they ever do, these new breeder reactors will need 20 or more years development, (ii) we cannot wait so long for a large-scale solution **[42]**[44] and (iii) these solutions are not expected to differ much on cost (on the contrary!) from current commercial fission **[43]**,[45] [46] still making it difficult to compete with the renewable and clean energy discussed[47]. And, in any case, the issue of dismantling and waste storage costs remains for these new solutions!!!! **[44]**[48]. About these ideas, if they ever succeed (and it is a big “if”!), it is a little like solving all individual transport problems by using luxury cars! A solution by the very rich, for the very rich.

44 — No use in the climate crisis, Linda Perez Gunter, Beyond Nuclear International, Nov, 27, 2022.
45 — Small Modular Reactors cost overruns: the same problems haunt new nuclear in Utah, David Schlissel, Nov. 25, 2022 (IEEFA.)
46 — The current conventional reactors are between 900MW and 1600MW and have been increasing in size in the belief that the larger they are, the lower their fixed costs will be. SMRs are proposed below 300 MW and contradict this aspect of costs.
47 — Also, famous investors, like Bill Gates, probably did not expect the cost of renewables would fall so much and so fast when they started investing.
48 — Stanford-led research finds smaller modular reactors will exacerbate challenges of highly radioactive nuclear waste, Stanford News, Mark Shwartz, May 30, 2022.

In conclusion: a few years ago, nuclear fission energy seemed a necessity, something inevitable. Suddenly, it seems its problems have not been resolved satisfactorily, having been overtaken by major developments in renewable energies, which are much better adapted to energy for all, throughout the world.

3.2. NUCLEAR FUSION

This concept is perhaps the most elegant solution in the field of energy. It involves reproducing what happens in the sun, fusing two hydrogen nuclei and obtaining one helium nucleus, with a difference in mass that corresponds to energy, which can be transformed, for example, into electricity. All from the most abundant atom: hydrogen.

There has been research on this concept for decades. Confining the hydrogen nuclei is crucial for their fusion and there have been important developments regarding the two main processes, the mechanical (lasers bombardment, the nuclei fusing) and the magnetic (confinement achieved by powerful magnetic fields).

The recent results obtained at LLNL-Lawrence Livermore National Laboratory (USA) (ignition fusion) **[45]** were reported the world over as something offering unlimited, clean and cheap electricity.[49] Although remarkably interesting in terms of physics, it had no visible impact on the production capacity of so-called clean and cheap energy.

Finally, a fusion process was achieved in which the energy provided by the lasers responsible for confining the plasma of the hydrogen isotope atoms and subject to fusion into helium atoms with energy release, offered a positive balance, i.e., there was more energy from the output than from the input. The figures mentioned involved 2MJ input to 3MJ output, a gain factor of 1.5. Remarkable, yes!

Until now, this ratio has been less than 1. However, this is not the full picture. It omits the energy needed to operate the lasers, which is at least 300MJ. This means that the total balance is still much less than 1 (0.01!!!). And this is for a single instant, without considering continuing energy production. Truth be told, this was not the aim of the experiment (the objectives were focussed on maintaining nuclear weapons) and it was not reported by the scientists at LLNL in exactly those terms.

49 — David Kramer "National Ignition Facility surpasses long-awaited fusion milestone" Physics Today, December 2022

The most developed technology in Europe is the International Thermonuclear Experimental Reactor (ITER), a demonstration reactor of about 500MW (Portugal participates in this research with IPFN-IST), based on magnetic confinement and the concept of a Tokamak-type reactor. A commercial demonstration reactor will not happen before 2050.

ITER intends to demonstrate that confined and confining plasma is self-powered (the objective is to produce continuous commercial electrical energy!) It is designed for a first production of positive energy, with an amplification factor of 10, 50MW input for 500MW output. However, this is the objective. Again, it does not take into account the power required for the auxiliary equipment **[46]**.[50] This means that ITER is still many years from producing significantly more energy than it consumes and is expected to need a total power of at least 300MW to 500MW to produce 500MW when it starts operating in 2035 **[47]**.[51]

In theory, the breakeven point occurs above a factor 3, as producing electricity using thermal means offers low efficiency, typically 0.3 to 0.4 (thermodynamic conversion efficiency). However, this breakeven is insufficient. We need at least a factor of 10 to claim we have clean energy, since the electricity used in the process, if fossil in origin, must be present in very small quantities.

Meanwhile, there have been reports of other approaches regarding the configuration and production of the necessary magnetic fields, using superconductors, which may simplify and reduce costs **[48]**.[52]

Regardless, issues with the process (still on a conceptual level), and the decades needed to produce a commercial product (extraordinarily complex aspects of engineering, see for example **[49]**), the eventual solution of commercial nuclear fusion is postponed well beyond 2060.[53]

The emphasis is on the word “eventual”, as we do not know the costs of doing this. Will they be sufficiently low? Once again, it will probably be a solution by the very rich, for the very rich....

50 — Isabelle Bouboulon <isabelle.bourboulon@gmail.com>
Soleil trompeur, ITER ou le fantasme de l’énergie illimitée
51 — Reporterre, Enquête en 3 volets – Celia Izoard (Reporterre) 18 juin 2021
52 — MIT-News, MIT-designed project achieves major advance toward fusion energy.
New superconducting magnet breaks magnetic field strength records, paving the way for practical, commercial, carbon-free power. David Chandler | MIT News Office, September 2021
53 — https://www.scientificamerican.com/article/fusions-false-dawn/ (2010)

Manuel Collares Pereira

ACADEMIC QUALIFICATIONS

PhD in Physics - University of Chicago
Electrotechnical Engineering - Instituto Superior Técnico (IST), Lisboa

PROFESSIONAL EXPERIENCE (some highlights)

1996-2010 Full Guest Professor at the Physics Department of IST, Technical University of Lisbon
2012 – 2020, President of the Portuguese Institute for Solar Energy (IPES)
2010- 2019: Coordinator Researcher - University of Évora; Chairman of the Renewable Energies Chair; Director of IIFA- Institute for Research and Advanced Education
1998-2011: Founder and CSO - AO SOL Energias Renováveis (manufacturer of thermosolar collectors)
1982 - 2005: Head of Solar Energy Research - National Laboratory for Engineering, Technology and Innovation (LNETI-INETI-LNEG)
Member of the Academy of Sciences of Lisbon (ACL) ; member of the Engineering Academy (Lisbon) and of Mexican Energy Academy (C. de Mexico)
Author of three books on Renewable Energy and on Sustainable Development, 14 patents and of more than 250 scientific papers on Solar Energy and related topics

LANGUAGES

Portuguese: Native
English: Advanced
French: Advanced
Spanish: Advanced
German, Italian: reading knowledge

CONTACTS

E-mail: mcp@vanguardeagle.com
Website: www.vanguardeagle.com

Vanguard Properties

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