Energy Demand from our Society, CO_2 Emission and Climate Change: The Big Challenges we need to win

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Abstract

World population is expected to grow from actual 7 Billion people to close to 10 Billion people by 2030. The growth of population coupled to the wished increase of the standard of life, that calls for an growth of the energy consumption per person, in a Business as Usual-BaU trend will cause the increase of the emission of CO_2 from actual 32 Gt/y to over 45 Gt/y, with an increase of the accumulation of Greenhouse Gases-GHG in the atmosphere and consequent major impact on climate. CO_2 is considered the protagonist of such climate change-CC, but indeed the most abundant Greenhouse Gas-GHG is water vapor. This paper analyzes the future energy trend and changes necessary for reducing the impact on climate, for avoiding that non-return points are reached. Recycling of carbon is expected to play a key role, implementing the concept of Circular Economy.

1. Introduction

The over 7 billion-people living on Earth, emit *ca.* 7 Mt_{CO2}/day or 2.55 Gt_{CO2}/y just for theirvery basic life operation: respiration. To such amount, CO_2 produced through the combustion of fuels in a variety of activities, including cooking, is added, summing up to over 32 Gt/y (1 Gt=1 Billion ton). Since over 30 years, a continued growth of energy consumption has been observed all over the world, reaching 13 978 Mt_{oe} (Mt_{oe}= million-ton-oil-equivalent, i.e. expressing all the energy used as if oil was burned) in 2018. [1] The average increase is 63% (2018 with respect to 1990) with highest growth in Middle East (260%), Asia (177 %) and Africa (123 %), areas that are still much below the average standard. The lowest growth has been observed in Europe (3.5 %) followed by North America (21 %, including Mexico). Such areas,together with Japan and South Korea, are the most economically developed and those where the technological level is most advanced. The high technological level makes that the specific emission (per each kWh used) is lower.

A key fact is that today most of the used energy (80+%) comes from fossil-C (coal, lignite, oil, gas), which are converted into other forms of energy such as electrical, thermal (heating), mechanical (transportation), *etc*. through processes characterized by a quite low efficiency, laying in the range 27-50% with an average of *ca.* 30-33%. Noteworthy, lower technologies are present in less advanced areas that result to be those where the specific impact (pro capita) is higher. Major users of fossil-C are: the production of electric energy, industries, and transportation (on road, avio and maritime). As a consequence of the low efficiency, an average 67-70 % of the original chemical energy of fossil-C is released as heat, often at high temperature, that causes the direct heating of the atmosphere and our planet, rising serious worries.

2. Fire, biomass, fossil-C and industrial development

Humans depend on carbon-based materials as energy source since the first man-controlled fire (Fig. 1) was lighted, *ca*. 1.5 My ago. [2] For millennia, the combustion of wood has represented the only source of energy, that has allowed the development of a number of life necessary practices (heating, cooking), productive activities (metal forging and the first industries), and transportation means (trains and boats, powered with wood).

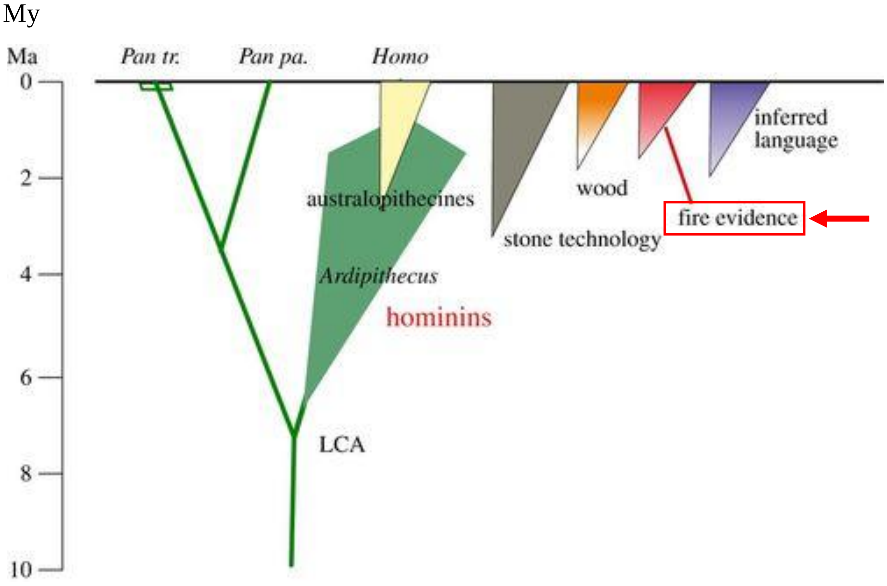

Figure 1: The appearance of Hominins and Homo and the first anthropogenic-fire.

Pan Tr.=Pan Troglodytes; Pan pa. = Pan Paniscus; LCA= Last Common Ancestors of Hominins and Pan.Reproduced from Ref [2] (CC BY 4.0).

Around 3490 bC, man discovered coal and started to make use of it. Coal was followed by gas, discovered around 1000 bC, and oil that appeared on the scene some600 years bC: all such carbon-based fuels were discovered in China. A curiosity is that the first non-energy use of coal was in jewellery (necklaces and cufflinks, made by the Aztecs).

The push to the extensive mining and using of coal came from Romans in Britain, where they found abundant mines, and started to develop extensive forging of metals, not so possible with burning wood that reaches lower temperatures than coal.

Coal permitted the industrial development at the end of 1700 beginning of 1800, when countries today known as UK and USA were the largest producers and marketers of coal with 260 and 350 Mt/year, respectively. Coal has been extracted since then all over the planet where it is fairly distributed: Australia, North America, Asia, Europe, Africa are rich of coal that for decades has been a great source of jobs and the main source of energy. Today the major producer of coal is China (3770 Mt/y), followed by India (982), USA (624), Russia (234), Germany (217), Japan (189), S Korea (150), Poland (129), Turkey (125), Australia (113), Indonesia (109) and other minors for a total of over 7700 Mt/y. The drawback with the use of coal is that it is rich of sulphur and nitrogen compounds. Upon combustion, they emit SOx and NOy, causing serious environmental problems linked to the formation of acid rains, aggressive on vegetation that is burned, humans, animals and even stone buildings. During the golden-age of coal (1800s-1900s) and until 1960s, coal was extensively used even for civil heating, producing *smog* in larger cities that still today is causing serious respiratory affections and even cancer. Emitted nanoparticles of unburned materials when inhaled can travel down the respiratory apparatus and reach lungs: 2.5 and 5 nm particles, known as 2.5PM and 5PM, are the most dangerous. Cleaning coal (desulphurization) prior combustion and abatement of post-combustion particulate is a practice that was implemented in the 1970s and is reducing the environmental impact, allowing coal to be used at higher and higher rate. Today, mining coal is a practice not too appealing to workers as it is very hard, dangerous and unsafe, despite all preventions implemented. It is less and less popular in some areas (France, Belgium, Germany, UK in Europe) and innovative technologies have been attempted for avoiding that men have to go down in mines. The *in-situ* gasification would be greatly beneficial as a gas would be extracted, but is not so easy to implement. Technology innovation is playing a great role for reducing the impact on the environment. The direct burning of coal is avoided and instead it is converted into other forms of cleaner fuels, such as Syngas - a mixture of CO and H_2 –through the high temperature (800-1 000 °C), strongly endothermic "*reforming process*" shown in equation 1. Syngas can be directly burned or be converted through the catalytic Fisher-Tropsch (FT) process into gaseous, liquid and solid products (equation 2).

$\mathbf{C + H_2O} \rightarrow CO + H_2$ (Syngas) 1

$nCO + mH_2 \rightarrow\rightarrow\rightarrow C_nH_{2n+2}$ (Gaseous, liquidandsolidhydrocarbons) 2

Countries such as South Africa and Malaysia today make most of their gasoline through FT-processes, as Germany already did during the Second World War for making liquid fuels for their cars, trucks, tanks and aircrafts.

Reaction 1 makes hydrogen-H_2, an energy vector well known to common people. The production of H_2 can be increased by pushing further reaction 1 with the so-called Water Gas Shift (WGS) reaction (equation 3).

$CO + H_2 + \mathbf{H_2O} \rightarrow CO_2 + 2H_2$ (WGS) 3

$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$ 4

H_2 and CO_2 are separated and H_2can then be used in a clean combustion with oxygen affording water as combustion product (equation4).Ifsuchreactiontakesplace in a cell (*FuelCell*), electricityisproduced.

The search for cleanerenergysourceshasbroughttothe use ofoilthat, evenifknownsincesome 650 yearsbC, onlyafterthediscoveryofPennsylvania-USA wells in 1859 started to enter the consumer market and after the discovery of the Texas-USA wells in 1901, entered the large-scale commercialization. Oil has greatly benefited of technology innovation that allows extraction at a deepness (6000-7000 m) not imagined 40 years ago: it is drilled on Earth surface, in seas and oceans. Oil is the main source of fuels and chemicals today and is a key feedstock for the largest chemical industrial sector: petrochemistry. Leader in the production of oil is the Middle East (1496 Mt extracted in 2018) followed by USA-Canada-Mexico (935), CIS (691), Latin America (432), Africa (398), Asia (349), Europe (168).

The peculiarity of oil is that long chain liquid hydrocarbons (gasoline and diesel) distilled from it are by far the most efficient energy carriers and the most concentrated form of solar energy, better than coal, NG, methanol and much better than H_2 and batteries. (Table 1) This property, together with the fact that: it is easy to ship everywhere, can be easily stored in tanks without problems. If carefully handled and used, oil does not create any problem to the environment

Table 1: Energy density of various carbon-based vectors

Vector	*Diesel*	Gasoline	Carbon-coke	Brown coal	Methanol	Bio-oil (algae)	H_2 (liq)	CH_4 (g)c	H_2(g) 20MPa
Density GJ/m^3	*36*	34	30	18	17	13	9	8	2

And health, and finds ubiquitous use. It is difficult to substitute in transportation and several other applications. Nevertheless, its transportation by sea may cause huge environmental problems in case of accident, as we are well aware.

Spontaneous emissions of Natural Gas (NG), known since 1000 bCas "*eternal fires*", found early use as flames in front of or inside temples by antic Greeks. In 1800, NG was used for lightening houses and streets (UK, since 1785, and USA were pioneer in such area) and for domestic uses (cooking, heating), without any large industrial application, being oil more convenient to use.The use of methane in reforming (equation 5) has opened the way to the

$CH_4 + H_2O \rightarrow CO + 3H_2 \rightarrow\rightarrow\rightarrow \text{Chemicals}$ 5

large-scale use of methane because it emits less CO_2(0.5 kg) than oil (0.75) and coal(*ca.* 1 kg) for the same amount of energy generated (1kWh). North America is the largest producer of LNG (976 billion cubic meters), followed by Asia (787), CIS (671), Middle East (539), Europe (538), Latin America (243), Africa (151) and Pacific area (51). Methane reforming has brought methane in the chemical industry: methane as feedstock is quite useful for the production of a variety of chemicals, such as: methanol (CH_3OH), hydrocarbons, formaldehyde (CH_2O), ethene ($CH_2{=}CH_2$), propene ($CH_3CH{=}CH_2$), chemicals that have markets of tens of Mt/y.

The recent economic implementation of "*shale fracking*" (hydraulic fracturing of shale clay rocks that contain gas formed upon decomposition of organic materials) has open a new market that is already exploited at an interesting level in USA.

3. The need to move away from Fossil-C

What said above indicates the dependence on fossil-C developed by humans in the last 200 y.

A dependence that does not imply only the energy sector, but even the chemical industry, the transportation sector (automotive, heavy tracks, aviation, rail, maritime), the production of materials and goods, and so on: in all aspects of our life we use carbon, in many different forms.

Now, there are two serious issues that force to find alternatives to fossil-C, namely: (i) natural reserves of fossil-C are not infinite, and (ii) any time we use C-based products or goods CO_2 will be formed and emitted into the atmosphere. The emission can be immediate (combustion of fuels) or take months (several daily used products release CO_2 when they decompose) or decades (polymeric materials). In this way, humans emit 32 Billion tons (Gt) of CO_2 every year. This is only less than 5% of the total amount of CO_2 cycled in natural processes (*ca.* 800 Gt_{CO2}) that make a myriad of products from CO_2 and water under solar irradiation, nevertheless it cannot be buffered by the natural C-cycle that was developed in million years until an equilibrium was reached so that emitted and transformed CO_2 did equal, keeping constant its atmospheric concentration. Nature cannot repair our mistakes or misuses.

Going back to the natural reserves, the estimate is that our planet stores 607 $Gt_{oe}$of coal, and 167 of either oil or gas that will be enough to cover our needs for a few decades. This is dramatic. The general wish is that new extended fields of gas and oil are discovered.

The other point is that the continuous emission of CO_2 and other GHGs is impacting our planet climate and causing a change that bears heavy and sudden events difficult to manage and to face in addition to major changes relevant to the polar temperatures and ice coverage, and seas levels. CO_2 has been indicated as the responsible of such climate change. Is this the case? Is CO_2 the key-actor of such dramatic play?What lessons can we learn from past?

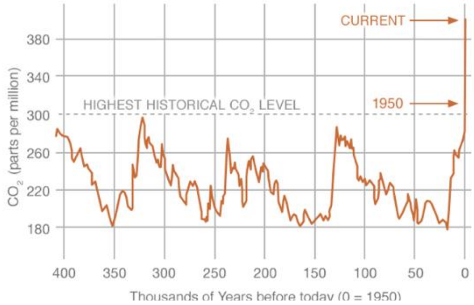

Figure 2: Trend of atmospheric CO_2 concentration. [3]

Figure 2 shows the cyclic CO_2 atmospheric level trend over the past millennia, with excursions as high as 120 ppm, neves stepping above 300 ppm. Interestingly, the lows of CO_2did correspond to periods of glaciation. This has suggested a possible univocal correlation between the atmospheric CO_2 level and the average planet temperature, that is a topic still under discussion. It is obvious that the cyclic trend illustrated in Fig. 2 was not caused by anthropic activities, but were just naturalcycles, most likely originated by the Earth movements. What we are living these days is a continuous rise of the CO_2 concentration since 1700s, that has reached the 410 ppm unprecedented level. This is a fact.In my, and others opinion (*vide infra*), CO_2 is not the protagonist of climate change but one of the actors, with a key role played by water vapor that is a stronger GHG than CO_2 and is much more abundant in the atmosphere by two orders of magnitude with respect to CO_2. The real key responsible of the climate change is the inefficiency of use of fossil-C that causes the emission of heat to the atmosphere with direct heating that rises the atmospheric amount of water vapor, [3] causing heavy rains and extreme events. CO_2 contributes to increasing the natural Ghreenhouse Effect, but is not the major direct cause of Climate Change, that is more due to water vapor. [4] In conclusion, is the inefficient use of fossil-C under accuse, such inefficiency is our mistake. The fact that the growth of CO_2 atmospheric concentration and rise of temperature are parallel, does not mean that CO_2 is the responsible of it, but derives from the direct relation existing between CO_2 emission and burned fossil-C.

4. Reduction of anthropogenic GHGs

Why CO_2 is accumulating in the atmosphere? Why it is not buffered by the natural C-cycle? Which is the impact of anthropic activities on the natural equilibrium? The major mismatch is the difference between the rate of combustion of C-based fuels(the combustion of several kinds of wood produces 6-15 g_{CO2} m^{-2} s^{-1})[5]) and that of biomass generation(fastest growing organisms are microalgae [6], more efficient than land plants, and they fix CO_2 at a rate of 0.1-1.7 g_{CO2} $L^{-1}day^{-1}$ or 0.00057-0.0098 g_{CO2} $m^{-2}s^{-1}$): combustion is, thus, some 1 000-10 000 times faster than photosynthetic fixation. Looking at the future, one can infer that the situation can only get worse. In fact, the increasing population, the ethic question of assuring a decent quality of life to 1.1 Bpeople (UNICEF 2017) which leave in poverty (with 750 Mpeople living in extreme poverty), and the general wish of improving the worldwide average standard of life, demand more energy. If such excess energy will be derived from fossil-C, the impact on climate will be aggravated and the emission of CO_2 will grow to over 50 Gt/y by 2040. The effort is to keep the increase of the average temperature of our planet below 2 °C with respect to 1990 (we are already *ca.* 1.5 °C above the reference). How can we reach such target?

The CO_2 balance of a process/product/service is called *Carbon Footprint-CF,* and this should be kept as low as possible in any case. Three intervention lines can be foreseen:

- Implementation of efficiency strategies in the production and use of energy.
- Substitution of fossil-C with alternative sources that emit less CO_2(biomass).
- Substitution of fossil-C with alternative sources that do not emit CO_2 (perennial energy sources such as: solar, wind, hydro, geothermal-SWHG).

The key point is the specification of how much CO_2 should be avoided for staying away from extreme events. Once the target is set, it will be possible to design routes to reach it. Noteworthy, already in 1992 a great concern about the impact on climate of anthropic activities was expressed at the level of United Nations Organizations, where the *equity principle* and *differential responsibilities* were established with the resolution that sounds:

Protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. (UNFCCC, 1992: Art 3)

Developed Countries should, thus, make a wise use of resources, avoiding misuses and assisting less advanced societies in their development, whatever is the case: a practice not always implemented. As a matter of fact, while the UN resolution on reduction and banning of CFCs was implemented worldwide, with the CO_2-reduction resolution several Countries have adopted an ambiguous attitude. For example, the 2015 COP 21 Paris Climate Conference has produced resolutions which go in the direction of a reduced use of fossil-C and of sustain to innovation for not trespassing the limit of 2° increase of the planet average temperature. [7] As we know, major players such as USA who were among the signatories of the document, have later withdrawn from its implementation due to the change in political and economic views. Other international agreements have been signed which target the CO_2 emission reduction. For example, the European Union (EU) have agreed the so called "202020" that states a reduction of the emission of CO_2 by 20% within 2020 with respect to the 1990 emission (not fully reached at the pan-EU level)and the "502050" that fixes a reduction of 50% by 2050. The CO_2-emission global budget for limiting global warming to 2°C was quantified in 2013 by the Intergovernmental Panel on Climate Change-IPCC. According to various scenarios, in order to reach the target it would be necessary to stabilize the CO_2 atmospheric level at 450 ppm with a 50% likelihood of success. [7b] Today, the atmospheric concentration of CO_2 has already reached 410 ppm and continues to growth!

The challenge facing the world will likely require a level of global cooperation far beyond any other previous common engagement (see the mentioned case of chlorofluorocarbons-CFCs ban and substitution, or the banning of phosgene or chloroorganics). But the urgency of the problem is perceived in a different way by each country and measures to implement the CO_2 reduction are adopted with more or less firm belief. Fossil-C touches all levels or our life, everywhere. Reducing the use of fossil-C without finding the best substitutes means stop the economy. Moreover, coal, oil, diesel, gasoline, methane can be easily transported everywhere and stored, that is not the same with other forms of energy and makes more difficult the substitution. Some Countries have large reserves of fossil-C and can live for decades without any threat of energy scarcity, showing the tendency to stay on the border of the problem. Nevertheless, they will not be saved in case of extreme events that are global. However, the atmospheric stabilization goal having been agreed at 450 ppm, the budget of total GHGs emissions for the *entire world* can be calculated, setting obligations for national, state and regional authorities to adopt measures and policies directed to the energy-industry-transport-standard of life sectors for the implementation of equity principles and responsible care:if some Countries do not implement the correct policies, others should implement stricter measures to stay within the budget. Nations should not ignore their ethical duties to the rest of the world and should adopt energy policies for the observance of rules. This is not always the case, as among Countries still todays exist a variety of different behaviors. [8]

But let us enter into the real meaning of the "*2°C maximum rise of temperature of our planet*".

To have an approximately 66% chance ([7a]) of staying within this limit, our global society should avoid that global GHGs emissions [carbon dioxide-CO_2 (1), methane-CH_4 (25), dinitrogen oxide-N_2O (298), hydro fluorocarbons-HFC (124-14 800), perfluorocarbons-PFC (7 390-14 800), sulphur hexafluoride-SF_6 (22 800), nitrogen trifluoride-NF_3 (17 200]exceed *ca.* 270 Gt_{CO2eq}. Water vapor is not mentioned here because it is out of human control being caused by evaporation of natural waters, in turn determined by the average temperature. In the list above, besides the name of each GHG, in parentheses is given the relative GHG power of each species with respect to CO_2 taken as reference, as listed at theKyoto 2007 IPCC Meeting. 25 for methane means that 1 kg of CH_4 is 25 times more powerful or lasts 25 times more than 1 kg of CO_2. However, all GHGs must be taken under strict control not only CO_2.When the limit of 270 Gt_{CO2eq} has been reached, the entire world's GHGs emissions should fall to zero or the warming to the 2°C will be trespassed.

However, since the world is now emitting carbon dioxide equivalent emissions at the approximate rate of 30 Gt/y, the world will run out of emissions under the global budget in approximately 10 years. Immediate action is requested, if the impact of GHGs on climate change is in reality what is believed.

In the mean while we are experiencing some extreme events that are hurting our society: heavy sudden rains, flooding, melting of once perennial ice on mountains and at the poles. A major impact on ecosystems is represented by the actual rising of the average temperature of oceans and of their level, the latter caused by flowing of once iced internal waters to the sea, that will cover cost line areas, with serious impact on populations and local economies.

i. The reduction of GHGs can be achieved by empowering a variety of technologies, such as:
ii. Efficiency technologies in the production and use of electric energy, and use of fuels.
iii. Use of low-carbon energy sources or C-free primary sources
iv. Carbon capture and disposal-CCS or Carbon capture and utilization-CCU

Each couple of options will be shortly discussed to give an idea of what is going on in the technology innovation world.

5. Efficiency technologies in the production and use of electric energy, and use of fuels.

Electricity can be produced from various primary sources and with different efficiency. The most performing technology is the conversion of hydropower (running water or tides, that reaches 90-95%). Power stations fired with coal or methane have a standard efficiency ranging around 28-33 %, recently (from 1985 on) improved to *ca.* 50 % with recycling heat and rising the temperature and pressure of steam that actions the turbine. The persisting drawback of such technology is that cleaning of flue gases is necessary in order to cut SOx or NOy, that reduces the neat available electric energy from best 50% to 32-35 %.Most innovative integrated gasification combined cycle or IGCC (only a few plants worldwide), reaches efficiency above 60% and separates CO_2 in pre-combustion (with energy penalty). Such improvement has a great value as *doubling the efficiency would mean halving the CO_2 emission! However, either pre- or post-combustion decarbonization is an energy penalty.* But this is not the only cause of loss. The distribution of electric energy causes a further decrease and so makes the conversion from high voltage used in distribution to the voltage (usually 125 or 220 volt) used by consumers. The old lamps based on tungsten wires incandescence caused loss in the form of heat at the consumer site; the substitution with modern cool lamps is reducing (by 5-10 times) such negative effect [9]. At the end of the story, only *ca.* 5-10 % of the original chemical energy of fossil fuels is really used. Low efficiency is encountered even in industrial processes. And the rest of energy where goes? Most of it (*ca.* 50-70%) is released to the atmosphere as high temperature heat (from 200 to over 800 °C) at the industrial site, that ends with a direct heating of the atmosphere.

The situation is not betterin the transport sector where fuels (diesel, gasoline, methane) are directly burned: in an average car the efficiency is limited to 20-22%, the rest is lost in the engine itself (61-63%), standing idle (16-17%), drive train (5-7%) and various other parts (1-2%). Diesel cars are more performant than gasoline fueled cars because the former use the direct injection. But such difference is going to disappear in coming years due to adoption of turbo-injection and other technological innovations with 18% reduced fuel consumption. [10]

Most advanced truck engines can reach an efficiency of 45% today. Major improvements are obtained under the push of legislation in EU and USA and other countries. The EU legislation has put strict limitations to emissions in terms of NOx and CO_2 per km with the various Euro 4, 5, 6 standards. The latter tends to limit the CO_2 emission to less than 100 g/km. Today in many cities the Euro4 cars are not admitted. The introduction of “hybrid cars” is further reducing the emission for the use of electric motor instead of combustion engine during stops, braking, idling, start,etc.“Full electric cars” are a different case, as they do not directly use C-based fuels.

Further improvements in the transportation sector comes from: the use of lighter materials for building cars, buses and trucks, that will reduce the consumption of fuels; implementing the use of shared cars; reducing the speed; and other good-practices.

Industries consume roughly one third of the total energy (21% the heavy industries) with some 50% lost as waste heat that is now under serious scrutiny for recovery and reuse depending on the temperature [below 200 °C (*ca.* 35% of the total, at the EU level) typical of light industries such as food processing; in the range 200–500 °C (*ca.* 25% of the total) typical of pulp and paper or chemical and petrochemical industries; and above 500 °C (*ca.* 40%, mostly in the range 500–1000 °C) typical of iron-steel and cement industries].[11] High temperature heat (>200 °C) can be used for producing high temperature-high pressure steam for driving turbines and producing electric energy, or for pre-heating fluids used in industrial processes; low temperature heat (150-200 °C) can be used for heating greenhouses (for growing vegetables and flowers) or even civil and industrial buildings.

A significant contribution to the reduction of the emission may come from adopting the due measures in the use of electric energy. This is a responsibility that touches the public, industrial, collective and individual behaviour. Public authorities all around the world have set a limit to the indoor temperature during summer (air conditioning) and winter (heating), for reducing the emission of CO_2.At the collective and individual level, misuse of energy should be avoided. Switching-offlights in empty rooms, avoiding superheating and supercooling of private buildings or seasonal heating(cooling) of interiors keeping open windows or doors, using domestic washing machines with full load, avoiding use of electricity any time is possible are good practices that should be fully implemented by individuals for a more efficient use of natural resources.

6. Use of low-carbon energy sources or carbon-free primary sources

In the last years, so called "*zero CO_2-emission*" fuels derived from biomass (biofuels) have been claimed as the way to the reduction of CO_2 emission. The general view is that the CO_2 formed in the combustion will be fixed back in the newly formed biomass, closing at zero the cycle. Such *biofuels* can substitute: solid fuels (wood instead of coal), liquid fuels (ethanol and long chain hydrocarbons instead of gasoline and long chain fatty esters instead of diesel), and gaseous-fuels (bio-methane made from anaerobic fermentation of waste organics replacing natural gas). As a matter of fact, several issues prevent biofuels to give a real large contribution to CO_2 reduction. First, as solid fuel wood has a quite lower energy density (roughly one third) with respect to coal, and emits several noxious N-based compounds and particulate, rising old problems of atmospheric pollution. Liquid bio-fuels and bio-methane match quite well the analogous fossil fuels. But bioethanol and biodiesel (fatty acid esters) conflict with use of biomass (cereals and oils) as food or feed, a conflict now solved with the use of second and third generation biomasses. Another point of argument is the use of arable land for growing biomass for energy instead for food/feed. Marginal lands (polluted soils or low carbon/nitrogen soils not suited for growing eatable biomass) are today evaluated for growing non-food biomass together with the use of non-drinkable water.[12] Biofuels are defined "*zero-emission*" fuels, a belief partly supported by Life Cycle Assessment-LCA studies that often suffer the definition of system boundaries and quality and completeness of used data. All bio-fuels *are "not* really *zero-emission*" because biofuels do not offset their combustion CO_2-emissions and, in their assessment, carbon taken from soil for growing is not considered as the change of soil from its baseline is not taken into due consideration. The Annual Basis Carbon-ABC [13] and the water footprint of biomass, should be integrated with LCA, for a more correct assessment of the potential of biofuels in mitigating CO_2 emissions. The claimed "*zero emission*" is a wish, not a reality, at least for now. Still a lot of work has to be done for making biofuels environmentally and economically convenient with respect to fossil fuels. Which biomass will expand more will depend on a number of factors and there is not a unified view, as for today. Most likely, bioethanol will remain the major player among biofuels, considered that it can be produced from practically any cellulosic biomass (grown and residual).The expanded use of waste/residual biomass will greatly improve the emission mitigation power of biofuels. In fact, such biomass fraction ends on as CO_2 upon burning or decomposition in soil. The IEA organization has published a "*technology roadmap*" on transport biofuels [14] according to which second generation biofuels will rise their share after 2020 and play a key role towards 2050 reaching (an optimistic) 27% of the total fuels used in transport. [15]

In conclusion, even if all measures are implemented to their best, biomass, among all possible alternative energy sources, will be that that less will contribute to energy portfolio by 2050. The estimate is that of the foreseen 15 000 Mtoe that will be consumed by 2050, only 250 will be represented by biofuels, compared to 1600 Mtoe contributed by hydro, 1145 by wind and 1440 by solar, 290 by geothermal, 1100 by nuclear, and 2433 by fossil-C.

Such general trend, considering all alternative energy sources, will impact positively the emission of CO_2 that will be reduced by over 10 Gt/y with respect to today. [16]

7. Carbon capture and disposal-CCS or Carbon capture and utilization-CCU

A technology proposed for reducing the atmospheric carbon load is the pre- or post-combustion capture of CO_2 with the intent of avoiding that it can enter the atmosphere. CO_2 can be captured from point sources such as power plants or industrial sites or even from the atmosphere (Direct Atmosphere Capture-DAC), with a quite variable and significant expenditure of energy 2-15 GJ/t_{CO2}. As a term of reference, 1 GJ is the energy consumed by an average home in 10 days. Captured CO_2 can either be disposed in natural fields (spent gas wells, coal beads, aquifers, deep waters-oceans) or even used as a technical fluid or else converted through chemical processes into chemicals, materials or fuels. The first option is called CarbonCapture and Storage-CCS and has pros and cons. The attractive positive aspect is that natural fields are estimated to be able to store the CO_2 formed in the combustion of all C-based materials existing on Earth. This belief has pushed to large investments during last twenty years in a technology that so far was able to dispose *ca*. 5Mt/y of CO_2, most of it for Enhanced Oil Recovery-EOR that stores into rocks part of the injected CO_2used for oil deeper extraction. However, CCS has not yet demonstrated its real potential because the permanence of the injected CO_2(real capacity of sites to store for long time)has not been demonstrated: as a matter of fact, disposal sites need to be investigated with much care for their safety, in order to avoid that leakages may disseminate CO_2 outside or explosive emissions may cause serious damages. It is worth to recall that in 1986 the sudden emission of hundred(s) thousands ton of limnicCO_2in Lake Nyos (Cameroon-Africa) caused the death of over 1700 people and some 3500 livestock. This makes the disposal of large volumes of CO_2 quite risky if the site is not safe. Long term storage of CO_2 is even possible through its fixation into inorganic carbonates (rocks) by reacting it with basic natural minerals (mineral carbonation) that contain excess of Ca- or Mg-oxide (CaO or MgO), or better with basic industrial slug. CCS is energy demanding, and this is an issue in an energy frame based on fossil-C: any use of energy causes the release of CO_2. Real-life says that storing CO_2 at a distance of *max*30 km from the production site (power station) causes a loss of energy of 25 % of the produced electric energy.

This is an optimistic case, because not in all cases is possible to find a disposal site so close to the source. Longer is the distance higher is the energy penalty that can reach 60% and more in the worst of cases: this is not acceptable. Therefore, CCS is very site specific, non-ubiquitous, energy-intensive: it is banned in several countries.

The technological use of CO_2(as gas, liquid or solid) covers, besides EOR, several fields such as: metal cleaning during soldering and cutting, cleaning of electronic devices, cooling agent, air conditioning, washing agent, water treatment, bactericide in cereals storage and shipping, food storage and packaging, water treatment, water-wells sanitization, surface cleaning, fire extinguisher and other minor applications. After use, in general CO_2 is vented to the atmosphere or even recovered. Even if vented, the benefit is that other chemicals with much higher Climate Change Power-CCP (chloro- and fluoro-carbons, for example) willnot beproduced and used, with a significant reduction of the environmental burden.

Finally, captured CO_2 can be converted into chemicals, materials and fuels, mimicking Nature.

Industrial utilization of CO_2 is practiced since over 150 years and has reached today a level of *ca.* 220 Mt/y.Most of it (over 135 Mt) is used in the synthesis of urea (H_2NCONH_2), a fertilizer that releases CO_2 upon use. A significant part (50-60 Mt) is used in the synthesis of inorganic carbonates ($NaHCO_3$, Na_2CO_3, $PbCO_3$ and others used in the production of glass and in other industrial applications at a level of a few hundred Mt/y). Another product derived from CO_2 is salicylic acid (25 kt/y), basis of Aspirine. Even methanol (CH_3OH, 85 Mt/y) uses CO_2 (*ca.* 10 Mt/y) as C-source besides CO, for a better use of H_2. An aspect that must be emphasized is that CO_2 with water is at the bottom of an energy well (both are products of combustion of C-based materials)and with exception of a few reactions (synthesis of inorganic carbonates and some organic carbonates and urethanes) requires energy for conversion into other compounds. Moreover, several products (fuels) in addition to energy require hydrogen that today has a fossil origin. Therefore, developing a CO_2-chemistry in an energy frame based on fossil-C, has little sense: in fact, the use of energy will cause CO_2 emission. The risk is, then, that more CO_2 is emitted than converted. The development of C-free primary energy sources (SWHG) changes the paradigm [17] and the conversion of CO_2 linked to the H_2 production can be carried out using such C-free energy sources. A barrier to the full exploitation of such options is the cost of alternative energy. Making H_2 by water electrolysis using PV electricity has a cost that today is 2-3 times higher than making hydrogen by methane reforming. Looking at the future, one can foresee that installed PV will grow from actual 350 GW to some 4500 GW in 2040, while the efficiency of solar light conversion may grow from 20% to 40% and the cost of materials will decrease and their life will extend: all such events will make the cost of PV electricity to decrease, and so will be for hydrogen. As the result, one can foresee an expanded conversion of CO_2 for making fuels, that have a much larger (15 times) market than chemicals.

8. CO_2 conversion, carbon recycling and the Circular Economy

The utilization of CO_2 for making chemicals, materials and fuels is a key step towards the Cyclic Economy, mimicking Nature.[18] Recycling of goods is an old practice in human economy.Table 2 shows a list of common goods, their world utilization volume, their recycled amount and targets/perspectives of recycling. Carbon based goods are those that have the largest market and the lowest recycling rate, even if Nature uses CO_2 and water for making a myriad of compounds and materials. As mentioned in the Introduction, Nature has developed the processes we observe today in million years, a time non commensurable to human life. For centuries men have lived with the belief that natural resources are infinite: it is not so, as already discussed. Neither biomass nor fossil-C will satisfy the human energy needs for the future. The Linear Economy model will not stand for long time. We need to learn from Nature that does not produce waste, is synergic and systemic, uses cycles for a more efficient use of resources. This is our future.

The Cyclic Economy is our future. Therefore, CCU is the best technology for climate change mitigation. What expectations do we have? CO_2 can be used in future for making chemicals and materials (*ca.* 1 100 Mt/y used), but even fuels (> 5 000-6 000 Mt). The forecast is that by 2040 *ca.* 40% of CO_2 emissions will be cut, [16] and fossil-C will be substituted with solar, wind, hydro, geothermal energy. The role of the conversion of CO_2 is central because if we can make liquid (diesel or gasoline) or gaseous (methane) fuels by cycling carbon, then the existing infrastructures (for example, transportation) will continue to be used, with reduced economic efforts with respect to the use of hydrogen in cars or the extended use of electricity.

In order to reach substantial innovation we need to develop integrated strategies that maximize the efficiency: integration of biotechnologies and chemo-catalysis will represent an innovative solution for large volumes of CO_2 conversion, maximizing C-recycling.

The exploitation of innovative bioelectrochemical systems [19] will produce substantial benefits in terms of CO_2 mitigation and climate change control.

Table 2: World trend of recycling of goods

Good	Amount used	Percentage recycled	Best cases
Freshwater (global: agricultural, industrial and drinking)	3 996 757 700 000 cubic meters/y Per-capita: largest user Turkmenistan 16 281 L/d; lowest: DR Congo 34 L/d. Average use: 70% agriculture, 20% industry, 10% drinking. In industrialized countries the industrial use of water can reach 80% (Belgium)	< 1 A target of 30% worldwide average recycling is set for 2050.	Recycling best cases: Israel 85%; Kuwait 35%; Singapore 30%; Queensland (AUS): >35 %; California (USA): 50% in Orange Country.
Paper	**423 Mt/y (2017)**	***Ca.* 50%** **Recycling paper saves 65% of the energy needed to make new paper and also reduces water pollution by 35% and air pollution by 74%.**	**Recycling one tonne of paper saves up to 31 trees, 4 000 kWh of energy, 1.7 barrels (270 litres) of oil, 10.2 million Btu's of energy, 26 000 litres of water and 3.5 cubic metres of landfill space.**
Iron	1 000 Mt/y	40	Iron is the good recycled since longer time.
Aluminum	***ca.* 94 Mt/y (production 2017)** ***ca.* 81 Mt/y (used 2017)**	**31** **In special cases, Al is made of 75% recycled material.**	**Aluminium is one of the most commonly recycled goods.**
Copper	19.1 Mt/y (2017)	> 45	Copper can be recycled without loss of properties
Plastics	**360 Mt/y**	**9**	**Recycling depends on the composition and structure of the polymeric material.**
Glass	205 Mt/y	33.9 Six tonnes of recycled glass avoid 1 t of CO_2 emission.	The use of recycled glass depends on the properties of the recovered materials. Food class glass can be reused for the same use only if sorted in the proper way.
Fossil-C Produced CO_2.	**13.4 Gt/y (as C)** **32.4 Gt/y**	**0.68**	**Used mainly (90%) in the chemical industry. The rest is used for technological uses, including EOR.**

Transportation will greatly benefit from converting CO_2 info fuels because some sectors (aviation and maritime) cannot make use of electricity or H_2even if they will be produced on a large scale. Then using electricity for making H_2used for converting CO_2 into liquid fuels or methane would solve the problem. Comments can be found opponent such strategy because the chemical conversion of CO_2 with hydrogen causes loss of some 30% of efficiency of H_2 with respect to direct use. Such penalty is balanced by the benefit of less CAPEX and OPEX, and higher safety.

We have to face serious problems and overcome high barriers. The human mind has demonstrated that can do better than Nature: no bird flies higher and faster than airplanes, no animal can compete with tractors and trucks, no fish is faster than racing boats. Maybe one day we shall use a device much better than a tree in converting water and CO_2 into goods. An economy based on CO_2 and Water [19] will then be possible?

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