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Goals to meet the 2100 Global Warming Target after COP26: A Green Revolution

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Abstract

Fossil fuels are the main contributor to global warming and add about 9.3GtC (34.2GtCO_2) to the atmosphere each year. Deforestation adds an additional 1.4GtC (5.1GtCO_2).

Population increase is a principal driver of deforestation. Tempering population increase is therefore essential for meeting the global warming target of the Paris Agreement by 2100. With more effective family planning programs, 167 million ha of forests, containing 17GtC, valued at an estimated $42.5 billion could be saved from conversion to subsistence agriculture. Improving agricultural productivity, especially in the subsistence sector, would avoid additional significant forest loss.

Fossil fuel consumption can at the same time be reduced in part through efficiency measures, and especially by greatly expanding the use of renewable energy. While renewable energy from water, wind and solar have a major role to play, biomass is currently the most important renewable fuel. Expanding its use requires improvements in intermediate and end-use efficiency. Increased use of biomass energy from sustainably managed sources could facilitate more investment in forests and increase the capture of carbon. A program to plant trees on 0.9 billion ha of land could capture more than 205GtC in wood and soils.

These measures would greatly assist in keeping the global temperature increase to 1.5^{0}C above the pre-industrial level, ensuring that the world remains habitable and environmentally sustainable.

Keywords. Deforestation, reforestation, renewable energy expansion, Paris Agreement, tempering population increase; improving agricultural productivity.

1. Introduction

The latest Climate Action Tracker (CAT November 2021) lists only one country – The Gambia - to be on target to limit global temperature increase to 1.5^{0}C from the pre-industrial level by 2100, with another 7 countries out of a total of 167 almost there ((CAT Nov. 2921). With current policies, the world as a whole is proceeding towards an increase of 2.9^{0}C, nearly twice the internationally agreed target figure. With Nationally Determined Contributions (NDCs), pledges and targets, presented at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties 26 (COP26), held in Glasgow, UK in early November 2021 reduced this figure to 2.4^{0}C. But even this lower number is likely to have a dramatic effect on the environment, especially for *Homo sapiens*. Whether countries and world bodies can agree to and achieve the 1.5^{0}C target seems doubtful. Pressure is to be put on all the 197 countries who signed the Paris Agreement (COP21) in December 2015 to come up with more realistic figures by COP27, to be held in Egypt in November 2022. It will be the young and future generations who will suffer the consequences of slow actions taken by the present (senior) generations, who amble towards 'doomsday'. **What is needed is a green revolution.**

Most of the 'energy' goals to achieve only a 1.5^{0}C target increase are well known, namely reducing fossil fuel consumption, reversing deforestation, increasing agriculture and silviculture productivity, improving energy efficiency at all levels, promoting carbon capture and storage (CCS) and dramatically expanding the use of renewable energy namely wind, water (hydro and wave), solar and biomass power.

What was and was not agree at COP26?

The following is a summary by *The US Council on Foreign Relations: COP26. Nov. 15 2021.*

1. Phase down (not eliminate) unabated coal power by 2030 for developed countries and 2040 (or 2050) for other countries.
2. New rules for trading carbon credits.
3. Call for nations to return to COP27 in 2022 (and not COP31 in 2026) with more ambitious and realistic targets to curb Greenhouse Gas (GHG) emissions.[1]
4. Request for yearly NDC reports of nations annual commitments to reduce GHG emissions.

In addition:

a. The USA and China agreed to work together to reduce global warming increase.
b. Over 100 nations pledge to cut 30% of methane (CH_3) emissions by 2030.
c. More than 130 nations, together possessing 90% of the world's forests agree to half and then reverse (commercial) deforestation by 2030.
d. Over 450 financial institutions overseeing \$130 trillion (10^{12}) assets promise to align their portfolios with the goals of achieving Net Zero Emissions (NZE) by 2050.
e. Many nations pledge to increase tree planting.

There were notable failures.

1 The COP26 President Alok Sharma urged negotiators to consign coal to history by 2030. This did not happen.

2 Failure to make significant progress on climate finance. The UN Environmental Program (UNEP), estimate that developing countries need US\$70 billion (10^9) per year for adaption and this could double by 2030. But present pledges are below this figure.

[1] Independent global emissions measurements indicate considerable underestimates of GHG emissions. They come from the Global Carbon Project, Minx *et al* and the U.N.'s Food and Agricultural Organization. Combined estimates were given in The Washington Post on Tuesday 9 Nov. 2021. These measurements indicate that countries have underestimated emissions of GHG's in 1919, ranging from 8.5 to 13.3 billion tonnes (t) CO_2equivalent (e). The reported figure for all countries was 44.2 billion tCO_2e The Washington Post 9 Nov. 2021.

3 Poorer nations renewed their call for financial help to adapt to the effects of climate change and establish a loss and damage fund. But COP26 did not resolve the funding challenge.

If governments are serious about the Paris agreement's temperature limits and their own net-zero goals, they need to translate those long-term goals into net-zero aligned ambitious 2030 targets and implement the necessary policies today. Developed countries will also significantly increase the climate finance available to support the transition. Until this happens, there is no cause for celebration. (Climate Action Tracker November 2021: Glasgow Creditability Gap).

However, an underlying cause for the present hiatus in committing to the 2100 target is little mentioned, either by countries or world bodies, and that is **population increase.** By 2100, the estimated population of the world will be 10.875 billion (of which 99% will be in Less Developed Countries - LDCs) as compared to the 2020 estimate of 7.795 billion (85% in LDC) – an increase of 3.080 billion (Population Pyramid 2021). 3,044 million of this increase will be in developing countries. (Table 1). If China is omitted from the LDC total, then the estimated LDC increase from 2020 to 2100 would be 3,413 million!

Table 1. Estimated word population by region from 2020 to 2100. Units Million

Year	**2020**	**2030**	**2050**	**2100**	**2100-2020**
World	7,795	8,548	9,735	10,875	3,080
Africa	1,341	1,688	2,489	4,280	2,939
SSA[1]	1,094	1,400	2,118	3,775	2,681
Asia	4,641	4,974	5,290	4,720	79
China	1,439	1,464	1,402	1,065	-369
Indian Sub-c[2]	1,817	1,072	2,228	2,041	224
Asia -China	3,207	3,510	3,888	3,655	448
LA &C[3]	654	706	762	680	26
LDCs[4]	6,636	7,368	8,541	9,680	3,044
LDCs-China	5,202	5,984	7.139	8.615	3,413
Dev. C[5]	1,159	1,180	1,194	1.195	36

Note. 1, SSA =Sub-Saharan Africa. 2. Indian Sub-c. = India, Pakistan, Bangladesh. Sir Lanka, Nepal and Bhutan. 3.LA&C = Latin America and the Caribbean 4. LDCs = Less developed countries. 5. Dev. C = Developed Countries.
Source. Population Pyramid 2021.

At the very minimum, the additional population will require food, much of which will be provided by the subsistence sector from the clearing of forests and woodland for arable and pastoral agriculture. At the same time, a general increase in wealth will promote the expanded use of fossil fuels. Not only will the increased population and rising average wealth cause further clearance of forests, woodlands and grasslands, but it will also bring about significant social challenges such as mass unemployment and the movement of people to cities[2] and to developed countries. How are these problems to be tackled?

2. Tempering Population Increase

Because of the Coronavirus pandemic, especially the delta and now the omicron variants, the health systems of many if not all countries are being put under additional strain and attention is being diverted from the equally serious effects of global warming. However, measures could be put in place to temper global population increase. Restrictions on family planning services must be lifted so that all women (and men) have access to birth control measures, including abortions. The US government banned organizations such as Planned Parenthood referring women for abortions under the 'Title X' rule[3]. This has led to Planned Parenthood, withdrawing from this program, affecting women both in the USA and worldwide (Population Connection Vol 51, 4 Dec. 2019). On 28th January 2021, the new Biden-Harris administration passed a presidential memorandum seeking to review this Title X rule. It is hoped that much will be overturned. This same issue points to the fact that education, especially for girls, is one of the best ways to temper population increase. Indeed, in some countries, the UN World Food Program offers cooking oil to families that send their girls to school, as I have personally witnessed in Pakistan.

The greatest population increase will be in Sub-Saharan Africa (SSA), where a rise from 1.1 billion to 2.7 billion is expected between 2020 and 2100 (Table 1). Few countries in SSA, except perhaps Botswana, have adequate family planning measures to temper this population increase. Indeed, the late President of Tanzania urged women to have more children! (Reuters 2019). Yet Africa, especially SSA, is the continent at greatest risk from the effects of global warming. Efforts must be redoubled to increase (women's) education and to make family planning provision freely available in all countries, especially to the poor.

If the population peak could be limited to 9 billion by 2100 and thereafter start to fall, this would benefit the environment considerably. If it is assumed that the universal per capita daily food requirement is 2,000kcal (8.4MJ) - equivalent to 0.54kg of grain - (U.K. National Health Service 2020) and that the average per-hectare (ha) yield for (subsistence) agriculture is 2,000 kg/year[4], then a family of five would require about 1 ha to meet their basic food requirements. If the 2100 peak population was limited to 9 billion rather than the currently projected 10.875 billion, there would be 1.875 billion fewer people by that date, of which an estimated 1.695 billion would be from LDCs. This would save an estimated 167 million ha of forests being cleared for subsistence agriculture, equivalent to approximately 17 billion tonnes (t) of carbon[5] (62GtCO_2) stored in the wood and the soils. **This is why it is critical to tackle**

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[2] By 2100, it is estimated that 38 of the world's 100 most populous cities will be in SSA and more than 1 billion people will live in those cities. (Hoornweg D & Pope K Sept. 2016).

[3] The Gag rule under the US government's Title X program jeopardizes healthcare access for millions of Americans and worldwide.

[4] The average yield of grain crops equivalent to 2,000 kcal/day per person at 14% moisture content is 0.54kg, giving an annual per-capita total of 197kg. 2,000kcal/per person per day is the assumed universal energy requirement.

[5] It is assumed that tropical forests have a store of 100t/ha of carbon in the wood and soils.

population increase. If it is 'business as usual', from 2020 to 2100, the world's population will increase by over 3 billion, nearly all in LDCs, (Table 1) and this could lead to a reduction of 270 million ha of forests, resulting in 27.5GtC of carbon (101GtCO_2) being vented to the atmosphere[6,7]. This does not take into account forests being cleared in the cash economy for agriculture. Replacing this through tree planting would cost an estimated 105 billion US dollars ($) in planting and maintenance costs over 35 years or $3 billion per year. (Openshaw 2015). Such funds could be invested in family planning and infrastructure development, to the benefit of future generations and the environment.[8]

3. Economic Development

Developed countries have jointly guaranteed $trillions ($10^{12}$) to assist their economies and populations to counter the effects of the coronavirus pandemic. Such sums of money could more than solve the global warming crisis. However, as stated above, the nations who attended COP26 have not agreed to sufficiently increase their Nationally Determined Contributions (NDCs) under the Paris Agreement (UNFCCC 2016) to reach the '1.5^{0}C' target by 2100. To approach the sums needed to meet the target figure to reduce greenhouse gas (GHG) emissions, will need an international perspective, rather than a national one. This is why people, especially the young, need to act now to change governments' minds.

Turning to economic development, there has to be a redistribution of wealth, both within and between countries, to help solve the problem of global warming. Many poor countries do not have the infrastructure or the means to greatly increase the wealth of their poorest (rural) communities. Without such an increase, however, these communities will languish in subsistence agriculture and be unable to afford electricity and other means of improving their wellbeing.

Clearly, the developing world will need to expand its (useful) energy consumption, particularly renewable energy, if it is to escape from poverty and under-development. Just as important, the developed world must reduce its energy inputs from fossil fuels through a combination of measures including improved energy efficiency in conversion, intermediate and end-use, energy conservation, greater use of public transport and less urban sprawl, and by massively switching to renewable or other forms of "low polluting" energy. It is ill-advised - both environmentally and economically - for LDCs to follow the past energy strategies of the 'West'.

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[6] In Africa, the annual yield of grain crops in 2000 was 1.059t/ha (Openshaw in Pak Sum Low, 2005), With productivity increases this could rise to 1.65t/ha by 2100. Grain productivity in Asia and Latin America is greater than in Africa, and other plant and animal proteins are consumed, hence the choice of an average equivalent yield of 2.0t/ha across these three continents. Thus, each person will require the equivalent of 0.0985 ha of grain crops to achieve an energy intake of 2,000kcal/day.

[7] This is rather simplistic as the rural population will start to decline in many countries about 2050. However, it is assumed that farmers will supply food to the expanding urban population, but imported food may/will be required.

[8] Over 80 years the average population increase would be 1.0136% per year, whereas it would be reduced to 1.0023% per year to achieve a reduction of 1.205 billion to 9 billion by 2100. Spending $ 105 billion over eighty years on family planning and infrastructure development could meet this target reduction. Thailand is an example of what can be achieved. (Openshaw 2019).

The wealthier a population becomes, the fewer babies' women have.[9] This is true especially for the poor in developing countries, especially in China and to a lesser extent in India and other parts of S. and S.E. Asia. Natural resources are limited; supplying the necessary resources to 10.9 billion people by 2100 is likely to exceed the world's sustainability capacity and damage the environment beyond repair for human habitation. It is up to the 'rich nations and the wealthy in LDC to recognize this. Much as a pandemic affects us all, the clearing of tropical forests in Africa, Asia and South America for short-term financial gain affects all living things, especially *Homo sapiens*. The long-term economic costs, including environmental costs, of these actions must be taken into account. Payment to countries with large areas of tropical forests under threat, say through the 'green carbon fund' may not only be necessary but will be essential in order to meet the goals of the Paris Agreement.

The traded price of carbon per tCO_{2e} (equivalent) can vary significantly. An FAO paper # 177 (FAO 2016) gives a range from $1 to $130 per tCO_{2e}, with about 85% priced at less than $10 tCO_{2e}, ($37tC). The paper further states that the global mitigation potential for afforestation etc. can be achieved at less than $20 per tCO_{2e} ($73tC). According to the Carbon Emission Futures (2020), the March 2020 carbon credit price is between $16 and $17 per tCO_{2e} ($59 to $62tC), but this covers a range of carbon pricing.

In 2018, the estimated loss of forest in Brazil, DR Congo and Indonesia for commercial exploitation was 1,349,000ha, 481,000ha and 340,000ha, respectively, for a total of 2,170,000ha, (Quartz Africa, 2020). If it is assumed that, on average, the forest stores 100 tC[10] per ha in the trees and soil, then at a price of $59 tC, the loss is worth about $12.8 billion. For all tropical forests that were cleared in 2018, the value of the cleared areas could be worth $15 to $20 billion in carbon credits alone! This indicates not only their economic value, but also the environmental importance of preserving tropical forests worldwide and managing them properly, by paying government and especially forest dwellers to preserve them. REDD+ (Reducing Emissions from Deforestation and Forest Degradation) allows for payment of a carbon credit through the Clean Development Mechanism (CDM). The price per t of carbon has ranged from $27 to $69 (Schneck *et al* 2011). A price of $147/tC is deemed necessary for the CDM to be successful (Carr and Hestor 2018).

4. Improving Agricultural Productivity

Nitrogen, phosphorus and potassium (NPK) are essential minerals for plant growth. These are normally supplied to commercial agriculture from mining operations or from industrial production using fossil fuels.[11] Because of cost and distribution difficulties, many subsistence farmers cannot obtain these inputs or obtain them in adequate quantities. There are alternative solutions to obtain sufficient quantities of NPK. Traditionally spreading farm-yard manure was

[9] This is demonstrated in a comparison between Tanzania and Thailand between 1970 and 2018. (Openshaw 2019). In Tanzania, between these two periods, the population growth rate declined from 3.1% to 2.9%, whereas in Thailand, with a vigorous population program, the population plummeted from 3.0% to 0.3%. The per-capita GDP increase nearly 7 time in Tanzania, but mushroomed 37 times in Thailand.

[10] This is a conservative estimate. Pristine tropical forests may have up to 500tC/ha. However, open woodlands have as little as 30tC/ha.

[11] In my youth, apart from composting and adding (horse) manure to the soil, the use of dried blood for N, potash (wood ash) for K, bone meal for P, soot for C and lime for Calcium (Ca) was common.

a common practice as well as crop rotations with clover etc. – nitrogen fixing species. Many leguminous plants fix nitrogen through a symbiotic relationship with bacteria that live in their root nodules. Some farmers intercrop with these legumes such as a maize and beans or plant a cover crop of clover. No-till farming also retains some nutrients from the previous years' crops. There are several nitrogen-fixing tree species which can further improve yields. Planting rows of these trees in fields or pastures can not only supply nitrogen, but at the same time generates stick wood for energy and other purposes. These systems have been termed agro-forestry and their promotion is led by the World Agroforestry Centre (ICRAF), part of the Consultative Group for International Agricultural Research (CGIAR). There are many agro-forestry programs. I was program director for a 5-year USAID-funded Farm Tree Planting Project in Rwanda in the 1970s. Tree planting was revived after the genocide and Rwanda has an overall 2 million ha tree planting program, including farm trees (Nash 2020) and may now meet its UNFCCC NDC target. In addition, Rwanda is extracting methane from Lake Kivu for power generation and for direct use by consumers (Zarembka 2019).

The US National Academy of Science published a book entitled Tropical Legumes: Resources for the Future (NAS 1979). This should be part of the libraries in all tropical agricultural departments and research centres; extension workers should read and use it. There are many existing nitrogen fixing trees (e.g., *Acacia sp*.) on such lands and increasing their presence must be encouraged. Trees are a nutrient pump, transferring minerals from lower soil horizons to the surface via leaves. Trees also attract beneficial birds etc. which keep down harmful insects. Nitrogen-fixing tree species can be used to intercrop in place of shifting cultivation and to eliminate the invasive grass species *Imperata cylindrica*, (ICRAF 1999). Brassicas (cabbage etc.) and beans planted side by side can deter the black bean aphid (*Aphis fabae*) from attacking the cabbage. Another intervention was applied to maize in East Africa. Scientists from Rothamstead agricultural research facility (U.K.) found that planting napier grass (*Pennisetum purpureum*) round the edges of maize fields and intercropping the maize with molasses grass (*Melinis minutiflora*), deters stem borer moths (*Busseola fusca* and *Cholo partellus*). These grasses also attract parasitic wasps that prey on the stem borer moths. Not only do yields of maize (and sorghum) increase, but the two grasses are also edible fodder for cattle, which meant that farmers can increase their animal stock and provide more milk and dung to fertilize the fields (The Guardian Weekly 2003). The grasses also increase the amount of carbon stored in their roots and the soil. Again, one of the curses of farmers on poor land in Africa (and elsewhere) is witchweed (*Striga asiatica*) (CABI 2011), which parasitizes the roots of cereal crops and kills them. The striga seeds can lay dormant for many years and are difficult to control. The same scientists found that a tree legume (*Desmodium uncinatum* or silverleaf), if intercropped with maize, resulted in no striga invasion, while adjacent maize fields without silverleaf were nearly devastated by it. This more than doubled the yield of maize and the silverleaf provides cattle fodder and stick wood, (The Guardian Weekly 2003). These are but some examples of the beneficial symbiotic relationship between plants that can be adapted by farmers, especially in the subsistence sector, to increase plant and animal yields. Another useful

(C4) tropical plant is vetiver grass[12] (*Chrysopogon zizaniodes*). This is a bunch grass which is used against soil and wind erosion, is an excellent animal feed and stores carbon in its roots and stems.

Nitrogen-fixing tree species such as *Prosopis spp.,* including mesquite, can be used to reclaim dry areas, but the total carbon accumulation may only be in the range of 3 to 5 tC/ha/yr. Mesquite is sometimes regarded as a weed species because animals, especially ruminants, eat the leaves and the seed pods. However, they cannot digest the seed, which is passed out with the dung. This generally regenerates and spreads. But, if the seed pods are collected and milled, thus destroying the seed, the resulting product can be sold as an excellent animal feed. All legumes, especially tropical tree legumes, have a critical role to play in land reclamation and improving agricultural productivity.

Phosphorus (P) is an essential element for plant growth, but on acid soils, P (plus N & K) may be unavailable because it is locked up. Applying lime (calcium hydroxide – $Ca[OH]_2$), to the soil to increase the soils alkalinity (pH>6) could release P (N & K) to the plants. There is an urgent need for soil testing to be provided to all farmers, especially subsistence farmers, and advice given as to the amount of lime, if any, to be applied to the fields. This should be part of governments' agricultural extension services. If necessary, (subsidized) lime could be provided to farmers. Local lime producers could benefit from such an initiative, as would the farmer and the environment. Pasture land could be planted with nitrogen-fixing tree species covering about 10% of the area to provide improved fodder and shelter for animals. P is present in urine and dung so pastures could benefit from increased animal numbers. The slurry from biogas digester provides a superior natural fertilizer for farmers etc. This will be discussed later.

Potassium (K) is the third essential element for plant growth. As mentioned above, increasing the hydrogen ion concentration (pH) of the soil would make more K available to the plants. Another ready source of K is wood ash (potash). Wood ash is relatively rich in K, in the form of K_2O (1% to 10%), as well as in lime. Many subsistence families still cook on wood-fired stoves and so the potash could be collected and applied to the fields or at least the 'home garden'. There is also an opportunity for wood-fired power systems (or power and heat systems) to sell the wood ash as a fertilizer. Mulching of plant residues and applying the mulch to the land will also improve soil fertility.

There are other elements that can help with plant growth. Carbon is one. Black carbon has been criticized because, if it lands on snow, it absorbs the sun's energy, rather than being reflected back. However, the benefits of adding carbon to the soil far outweigh the costs, especially in the tropics. Carbon added to the soil in the form of soot improves the soil-water quality. It is a valuable fertilizer. It is changed by bacteria into nitrates, in which form it is available as a plant food. (Oakbrook Chimney Services 2018). Copper is a trace element that is deficient in some soils. Soil testing could provide information about this and other trace elements and allow appropriate treatment regimes to be recommended. Trees build up the soil carbon content through surface litter decomposition and the death of roots, rootlets and

[12] A C4 plant fixes atmospheric carbon more efficiently that the 'normal' C3 route.

bacterial activity in the soil. The minimum annual increase per ha in short-rotation tree growth is 0.82tC/yr. (Silver *et al* 2000). The greatest store of organic carbon in soils is in tropical high forests. (Pan *et al* 2013), followed by woodlands then grasslands. Arable agricultural areas have the least store of soil carbon per ha. This carbon store could and should be increased by improved farm management and silvicultural practices etc.

Many watersheds are being converted to agricultural areas or trees are being over-cut. This is subjecting such areas to flash floods, causing mud slides and the destruction of property and agricultural land. It also seasonally diminishes the flow of water, thus affecting the livelihoods of the surrounding population. The REDD+ program could and should be used to save such areas: they should be given priority. In India and Pakistan, groundwater from aquifers is being overused for the production of agricultural crops. This cannot continue and more economical irrigation methods have to be used if the groundwater is to last. Otherwise, food production may have to rely on rainfall, with a fall in yields and the inevitable abandonment of some agricultural land! On a practical note, more water could be stored by households and schools, especially in Africa. When it rains, much of the water is not collected but flows away. In Thailand, for example, rainwater from the roof is collected in ceramic tubs and used for a multitude of purposes. This practice could be copied by households world-wide. I was asked about setting up a market garden and tree nursey in a rural African school, which had to rely on rainwater. I suggested that the rainwater from the school roof could be collected in a simple lined sand-trap and used to water the allotment when required. I also stressed that students should be taught about environmental protection and improved farming methods, such as alternatives to shifting cultivation.

Shifting cultivation is a method whereby farmers can grow crops for two or three years on cleared forest areas, before the crop yields become too low for sustenance. The farmer then moves to a new forest area and repeats the process, allowing the former cleared lands to recover for about 20 years before the cycle is repeated. Due to increased population pressures, however, the recovery cycle in many cases is shortened and the cropping time is curtailed, resulting in lower yields and shorter recovery times. Inter-planting such areas with nitrogen-fixing crops, especially tree species, can stabilize agricultural productivity and provide animal browse and/or mulch to the soil, as well as stick wood, eliminating the need for the farmer to move on. Planting shelterbelts and hedges reduces evapo-transpiration of agricultural crops to increase yields. These are used in several countries from China to Egypt and have world-wide application where seasonal winds are normal. The best practices from countries throughout the world should be publicized and promoted. Also, silvicultural productivity has to be increased.

5. Renewable Energy, especially Biomass Energy

According to the International Energy Agency (IEA 2018), out of total global energy demand of 598.8EJ per annum, biomass and waste accounts for 59.5EJ (10%). Hydro-electricity accounts for 15.2EJ (3%) and other renewables for 12.1EJ (2%), bringing the total for renewables to 86.8EJ (14.5% of total demand). Despite its great significance, biomass - especially woody biomass used by poor people in developing countries - is neglected by energy planners and governments, except as a fuel to transition away from, for it is regarded as polluting and unsustainable as currently used by households in its present forms of fuelwood and charcoal. Out of a mid-2020 estimated global population of 7.8 billion, 6.6 billion are in LDCs, of which at least 4 billion will be using traditional (woody) biomass for cooking (and heating). This figure is likely to increase by 2100 as the population in LDCs may reach nearly 10 billion, unless steps are taken to actively temper population growth (Openshaw 2019).

The World Bank has stressed the importance of assisting the private sector; biomass energy production is principally in the hands of the private informal sector and is a fuel consumed by the poor (and rural industries). Yet very little help is afforded to such people. Development banks could assist through training, market intelligence, encouraging the removal of inappropriate bans and restrictions and improving infrastructure. Above all they should ensure a level playing field regarding fuel subsidies.

At present, most fuelwood is burnt inefficiently on three-stone fires and this generates products of incomplete combustion (PIC), which are deleterious to health and cause premature deaths, especially so if the stove is indoors. Relatively low-cost improved stoves have been promoted for some time. Barnes *et al* (2012) concluded that improved stoves should be based on what the cook wants, rather than maximum efficiency. Critical parts should be manufactured commercially (as in China) and the price should be affordable, with little or no subsidies. If stoves are bought rather than given, they will be used all the time. There are also simple things that can be done such as ensuring adequate ventilation, adding a chimney to the stove, using dry wood, pre-soaking hard foods (e.g., beans) and keep children from the kitchen. If there is a chimney, the soot can be collected periodically and used as a fertilizer. There are more efficient wood-gas stoves on the market, but these cost in the region of $30+ and are beyond the reach of the subsistence farmer and the urban poor. As economic opportunities improve, such stoves may become affordable.

Charcoal is a relatively smokeless fuel with very few PICs, except at the lighting stage, when carbon monoxide is produced. Cooks know this and therefore light their stove outside before it is brought into the kitchen. Charcoal can be bought in small quantities, hence its use in urban areas, especially in LDCs. The charcoal production process is wasteful in the sense that up to 60% of the original energy is lost in the conversion process, but the resulting fuel has twice the energy per unit weight of the parent material, is less polluting and is more convenient to use. This wastefulness is decried by some, but the same argument is hardly ever applied to electrical generation from fossil fuel, when up to 75% of the energy may be lost in production and distribution. Of course, charcoal production can be improved, and producers should receive training in woodland management, charcoal production and in marketing. Charcoal production should be treated as a legitimate activity that is supplying a renewable and convenient energy form, while generating rural employment in production, transport and trading. There are petroleum engineers and electrical engineers, but there are few biomass engineers (charcoal, methanol/ethanol, biodiesel, biogas/producer gas). Yet these are, or could be, important fuels and their status would be enhanced through systematic university or technical training in their production and use.

Regarding improved stoves, in 1979, I compared the traditional metal stove (jiko) used in East Africa with the ceramic bucket stove from Thailand. (Openshaw 1979). It was found that the bucket stove was about twice as efficient as the jiko. When I moved to Kenya, to work on a Beijer Institute (now the Stockholm Environment Institute) fuelwood cycle project, I organized a stove testing competition for KENGO (Kenya Energy and Environment NGO) at the UN New and Renewable Conference in 1981. This aroused much interest and USAID financed an Improved Stove Program (ISP) within the Ministry of Energy. At the same time, I was involved in an Improved Stove working group. Through the Beijer Institute, I arranged a trip to Thailand for the ISP project manager (PM) and a potter from Clayworks Ltd. in Nairobi to examine charcoal stove manufacture. The PM returned full of enthusiasm for the Thai stoves. A private firm (Jerri International) worked with the PM and together they designed a clay-lined stove. This stove was field tested with women's group and modified accordingly. In 1983, I was appointed the regional director of a USAID funded project entitled Energy Initiatives for Africa. Through that project, USAID financed a 'Regional Stove Training Program' with KENGO. This program trained stove makers throughout Eastern and Southern Africa in all aspects of the stove business. The resulting clay-lined jiko was commercially manufactured and became very popular. Through the Stove Training Program, many people throughout Africa received training and improved clay-lined stoves are now manufactured across the continent. While such stoves are commercially manufactured, there is a role for government to ensure quality, run training courses and demonstration and - if required - provide loans. This was a very successful South-South initiative. I was proud of the part I played in introducing more efficient charcoal stoves to Africa.

Biogas from crop and animal waste is important in some counties, such as China and India. It contains about 60% methane and has an energy value of 30.5MJ/kg (22.6MJ/m^3). The slurry provides an excellent fertilizer and importantly it kills most if not all pathogens in the feedstock. One drawback to biogas production is the cost of the digester and appliances, which is $500-600 per unit. The individual farmer also requires the equivalent of four healthy cows. There are cheaper and smaller digesters that cost about $100 and can be used by individuals using household and pig waste and vegetation etc. (IRENA 2017). These have both health and fertilizer benefits: it may pay from an environmental viewpoint to subsidize such units.

There are two main types of bacteria that anaerobically break down plant and animal waste, namely mesophilic (operating at $30^{-}40^{0}$C) and thermophilic (operating at $50^{-}60^{0}$C). The former is used in tropical countries, while the latter can be used in temperate countries if some of the biogas is used to heat the substrate. Sewage plants etc. throughout the world could use thermophilic bacteria to produce biogas as a part substitute for natural gas (methane) from fossil fuels, especially if a carbon tax is placed on such fuels! One important fact is that **coronavirus and similar viruses** are present in animal faeces. Sewage works and factory farms should install appropriate digesters to kill such viruses. The biogas could be a substitute for fossil-fuel methane, especially if a carbon tax is placed on such a fuel and the slurry substituted for artificial fertilizers - a win-win situation.

While household biomass is the dominant energy use, especially in LDCs, it is also used by many people in industrialised countries, especially for domestic heating. From various demand surveys undertaken by the Energy Sector Management Program of the World Bank[13], non-household use accounts for about 10% of biomass energy consumption in LDCs. It is used

[13] I was a staff member of ESMAP from 1988 to 192.

for crop drying and food processing, in the ceramics industries, for brick burning, lime production and in the service sector - restaurants, food shops, school canteens etc.

Biomass is also a feedstock for heat and power production worldwide (0.5% of the total), although electricity generation from water, wind and the sun dominate the renewable energy mix and account for 23% of total electricity production, equivalent to 96 EJ in 2018 (IEA 2018). Electricity production accounts for 16% of energy demand.

Motor ethanol and biodiesel are produced from sugar, maize and plant oils. In the US, all gasoline (petrol) contains 10% ethanol. The US and Brazil are the largest producers of ethanol, whereas such countries as Indonesia and Malaysia lead the production of biodiesel. Production of these fuels is expanding, although in the US maize (corn) production is subsidized. Biodiesel from plants such as *Jatropha curcas* is expanding; this tree can be grown on marginal land, although it needs nitrogen fertilizer to maintain its productivity. Inter-cropping with nitrogen-fixing (tree) species may solve this problem. In 2018, the estimated demand for liquid biofuels was 419PJ or 3.5% of motor fuel demand (IEA 2018).

Hydrogen has been touted as the new and renewable energy of the future. It has 4.3 times the energy value of carbon per unit weight (141.7MJ/kg compared to 32.8MJ/kg for carbon), but its impact in LDCs will be negligible, especially in rural areas. Also, because all fossil fuels came from biomass, biomass can be and is turned into solid, liquid and gaseous fossil fuel substitutes. It may be cheaper and safer to use renewable carbon-based fuels than to rely on hydrogen. Indeed, because hydrogen is difficult to handle, it has been suggested that methanol (CH_3OH) be the ‘carrier’ for hydrogen. Methanol can be produced from the dry distillation of biomass (wood alcohol), therefore, why not use methanol directly rather than as a hydrogen carrier?

The amount of carbon dioxide (CO_2) in the atmosphere today is estimated to be 410 parts per million (ppm) and increasing at over 2% per year. The estimate in pre-industrial times was 280 ppm. One way to reduce CO_2 in the atmosphere is through carbon capture and store (CCS). Capturing CO_2 from power plants and cement factories and sequestering it belowground in leak-proof areas or in oil wells has been proposed (Bryant 2013). The cost of CCS using this method is at least $60/t$CO_2$. (Openshaw 2016). This only captures CO_2 from specific sites, whereas it is universally emitted. A cheaper method with global applicability is CCS in trees and soils. Between 2015 and 2050, about 1,540GJCO_2 (420GtC) will be released to the atmosphere (IPCC AR5 2014), of which an estimated 154GJCO_2 (42GtC) will be from forest clearing for arable and pastoral farming etc. To capture 42GtC in tropical and temperate plantations (or their equivalent) would cost in the region of $121 billion (optimistic) to $188 billion (pessimistic) and require 115 to 172.5 million ha (3.6% of farm and grassland). This works out at a cost of $0.78 to $1.17 per t$CO_2$, excluding the cost of the land (which may add another $3.00 per t$CO_2$ to the cost). This capture is for storage and use. If only storage is considered then on average only 19.32GtC out of 42.00GtC are stored and this increases the cost to between $1.69 and $2.39 per t$CO_2$,[14] excluding land costs, but it is still far cheaper than sequestration from power plants and cement factories etc. below ground etc. What is more,

[14] The shorter the rotation, the less carbon is stored in the wood. Over 35 years, only 11% is stored in the wood on a 7-year rotation, 16% on a 10-year rotation and 76% on a 35-year rotation. (Openshaw 2015 amended version).

when the plantations are mature, there will be an annual sequestration of wood and soil carbon of 15.50tC/ha of which an estimated 10.92tC/ha (1,256 million tC) will be in stem and branch wood, from the proposed 115 million ha (Openshaw 2015, corrected version). This amount of wood could be used for biomass energy and/or other purposes.

Work is now underway to increase the storage of below-ground carbon in agricultural plants. One initiative is by the Salk Institute's Harnessing Plant Initiative (HPI) under the leadership of Joanne Chory. (Salk Institute La Jolla CA, USA 2021). This initiative is an innovative, scalable and bold approach to fight climate change by optimizing a plants natural ability to capture and store carbon and adapt to diverse climate conditions. Chory and the HPI team aim to help plants grow bigger mor robust root systems that absorb large amounts of C by burying in the ground in the form of suberin, a naturally occurring carbon-rich substance. The Salk team will use cutting-edge genetic and genomic techniques to develop the Salk Ideal Plants ™. Joanne Chory www.salk.edu

Another initiative from the non-profit Land Institute in Kansas, USA is to develop a perennial wheatgrass named Kernza®, *Thinopyrum intermedium.* It can be harvested year after year, develops deep roots- up to 5 meters- and extract over 16t of CO_2 from the air (4.4t C) and store it in the roots and soil after 4 years, thus building up soil carbon rather depleting it. Ref. Kernza.org 2021. The same institute states that a form of perennial rice, developed at Yunnan University in China, has been in commercial production since 2018. This is described by Zhang, Yujiao *et al* 2021. Like Kernza, soil carbon is built up rather than lost.

Over the next 78 years many developments will take place to increase the storage of carbon in the soil. This a race that must be won if the world is to feed the increased population in a sustainable way!

Each year, plants fix about 100 billion t of atmospheric carbon through photosynthesis, of which about half – 50GtC - is from land plants (the carbon cycle), (Hall & Rao 1994). Some of this is used for food and biomass energy etc. before it decays and returns to the atmosphere: 50GtC has an energy value of 1,640EJ. Annual use of biomass energy accounts for 60EJ and food production (including animal feed) for 107EJ (Berners-Lee *et al* 2018) and between 15 and 25EJ could be added in trees, grasslands and soils.[15] This represents under 12% of annual land plant production. Much more of the annual carbon sequestration could and must be used, before it returns to the atmosphere.

Wood is the most convenient form of biomass for energy purposes. For the world as a whole, and for LDCs in particular, the annual growth of wood is 3 to 4 times annual demand, (Openshaw 2011). It is not the use of wood that is causing 'deforestation' but the clearing of land for arable and pastoral agriculture (and urbanization) as a result of population increase and the need to generate cash income. There are areas in LDCs where trees are being over-cut and other areas where there is a surplus. Many proposals have been made to reduce

[15] According to the Berners-Lee article, this annual production of food is sufficient to feed the global population even in 2050. However, through waste, transportation losses etc. the subsistence sector, receive little if any of commercial supply. Hence the continued clearing of forests for food.

consumption and increase supply, which I and others have made while working in LDCs for various development agencies.

It is not the 'traditional' collection and use of biomass energy that is unsustainable, rather it is the policies of developed countries and one-sided 'market' solutions that are unsustainable: this is accelerating deforestation and keeping many rural communities in poverty. A level playing field with regard to subsidies for agriculture (and energy) will do more for development than the current trade and aid policies.

There has been an upsurge by individuals, NGOs, government and international organizations to increase tree planting as a means to offset global warming. A publication from the Crowther Lab, part of the ETH Zurich University (Bastin *et al* 2019), estimates that 900 million ha of land is potentially available for tree planting. Tree cover on this land could absorb two-thirds of the CO_2 that human activities have emitted since the start of the Industrial Revolution. According to the Climate Action Tracker of the Global Carbon Project, since 1751 the world has emitted over 1.5 trillion t of CO_2 (409+GtC). (Ritchie & Roser 2017). A similar quantity of emissions - 1,540GtCO_2 (420GtC) - is anticipated between 2015 and 2050 (IPCC AR5 2014). This is why it is necessary that tree planting be an essential part of the Global Warming Initiative, coupled with tempering population increase. The cost of capturing 1.5 trillion tCO_2, could be in the region of $1.5 to $2.5 trillion, including carbon capture and storage, but this could be spread over 80 years. Other costs include family planning, rural development, infrastructure development, and payments to preserve tropical forests. This could bring the total cost of achieving the goals of the Paris Agreement to keep temperature increase to 1.5^0C above the pre-industrial level to a ballpark estimate of $2-3 trillion. This is the minimum amount that industrial nations have pledged to fight the coronavirus pandemic. Saving the world from the effects of global warming is a necessary and vital investment to ensure *Homo sapiens'* survival.

The U.K. government still holds the presidency of COP26, until COP27 in Egypt in November 2022. However, the independent Climate Change Committee (CCC) in a report to the government in December 2021, states that while the UK's Nationally Determined Contributions (NDC) already has one of the most ambitious 2030 targets for reducing emissions in the world, it does not yet have all the policies in place to deliver these outcomes. (CCC report Dec. 2021 COP26.Key Outcomes and next steps). The CCC states that the NDC should be legally binding and the strong COP26 team should be maintained and encourage the UK's led to strengthen the NDC's in other countries in order to achieve the goal of limiting the temperature increase to 1.5^0c.

For example, regarding tree planting. The UK proposes to substantially increase the planting of trees to capture more atmospheric carbon and to curtail erosion and decrease flash-flooding etc. At present, about 13% of the land area is in forests and woodlands - 3.19 million ha).[16] It is proposed to double the area under forests by 2050 to achieve the U.K.s net-zero target, but perhaps the UK government should have an aspirational tree planting target of 10 million ha - 40% of the land area, similar to that of Norway! This would cost in the region of

[16] In 2019, the U.K. woodland area was estimated to be 7.88 million acres (3.19 million ha). This excludes trees outside the forest. (U.K. Forestry Commission data 2018).

$25-30 billion, excluding the cost of land. If natural regeneration, planting on all land-use types and management could be spread over say 35 years, it could give a carbon capture and store of 0.74Gt by 2055.[17]

At COP26, the UN's Secretary General Antonio Guterres recognized what he called the *climate action army*. Guterres acknowledged the power of activists to propel governments and companies beyond words and into action. He urged them "Never give up. Never retreat. Keep pushing forward". The 'young' generation can join Greta Thunberg to fight climate change. It is her generation and future generations that will suffer from the present inadequate measures.

6. Conclusions

This paper has stressed the importance of population increase, which is accelerating global warming. Concerted efforts have to be made to temper this increase, otherwise it becomes more difficult to achieve a target temperature increase of 1.5^0C above the pre-industrial level by 2100. The temperature increase has already reached 1^0C (Climate Action Tracker 2020). Solutions have been proposed to temper population increase and to intervene in both biomass supply and demand levels. On the supply side, proposed measures include increasing agricultural (and silvicultural) productivity, increasing tree planting significantly, including carbon capture and storage, adapting methods to improve agricultural output; including agro-forestry and paying people to preserve tropical forest and so on. With help and improved management, it can be used to improve agricultural productivity and stabilise the environment, add to the store of organic carbon and generate additional income. Expanded biomass use could be a key ingredient in the initiatives to alleviate poverty.

Additionally, trees can provide browse and fodder for animals; the manure from these animals can be used directly or indirectly as fertiliser rather than being used as unprocessed fuel (as happens in several countries such as India where wood is scarce[18]). Again, trees etc. can reclaim marginal land and improve the microclimate through shelterbelts and hedges on rainfed and irrigated arable lands and protect watersheds, thus benefiting lowland agriculture and hydro-dams etc. amongst other measures. Perennial grain crops could increase carbon storage in roots and farm soils

On the demand side, this paper has concentrated on biomass energy initiatives, because at present it as treated as a fuel of the past to be substituted by 'clean energy' (solar, water, wind) rather than a 'Cinderella' fuel that has a bright future. Biomass is the most important renewable fuel at present and should be embraced as a legitimate, renewable and versatile carbon-based fuel that is used in unprocessed and processed forms or used as a feedstock for

[17] The carbon sequestration will gradually build up and reach an additional 0.74GtC (2.71GtCO_2) by 2055 if on average 195,000ha are planted each year for 35 years, assuming an annual stem growth rate of between 10 m^3/ha and 15m^3/ha. Thereafter, there will be an annual yield of 30 million m^3 of stem and branch wood. This could be used for wood products including biomass energy. If use in wood products it will increase the carbon store, or provide more renewable energy. The stumps of felled trees will also store organic carbon until they gradually rot, unless harvested say for energy. Thus, the overall store of carbon will increase somewhat. The cost of carbon capture and store (CCS) is an estimated $16 to 25t$CO_2$ far cheaper than CCS from power plants etc.

[18] The methane from manure can be extracted using biogas digesters and used as a fuel. The resulting biogas has about 60% of the energy of natural gas and the resulting slurry is an excellent fertilizer. China has an estimated 25 million digesters and India 4 million.

electrical generation and motive power. After all, all animals, including humans, rely on carbon-based fuel (food)[19] for energy and there is no reason why biomass should not be a significant part of the world's energy mix in the future, together with supply-side initiatives and population-tempering activities to help solve the global warming crisis. They are win-win solutions.

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