Negative Emissions and the Circular Economy

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Abstract

There is no doubt about the need to stay under 1.5C global warming target in relation to pre-industrial times. To achieve that, lowering emissions down to zero is not enough. Historic GHG emissions have to be removed from the atmosphere, this process is called negative emissions. Once the GHGs have been captured they have to be stored, which can be done in the form of reforestation, sequestration or the production of biochar, synfuels and other products. In addition there are processes to neutralise GHGs using photocatalytic reactors while generating electricity. There needs to be a policy framework that incentivises negative emissions processes. Previous generations have borrowed the cost of mitigating CO2 emissions and now society has to pay for this, like paying off something bought on credit with an interest free period. The circular economy's aim is to have zero waste. Negative emissions are in part of closing the loop of emissions captured by using CO2 as a resource or sequestering and is therefore to be an integral part of the circular economy.

Keywords : Negative emissions; circular economy; mortgage; carbon capture utilisation, storage; direct air capture; climate crisis; moral & ethical dilemmas; interest free period; biochar; synfuels; photocatalytic; solar chimney power plants.

Introduction

The aim of this paper is to discuss the issues of and review research of *Negative Emissions (NEs)* and its relationship with the *Circular Economy (CE)*. It starts off with a discussion about the background of why there is a need for NEs. Next is an examination of carbon capture sequestration and what carbon can be used for is covered in section 2. Section 3 deals with the various *Negative Emissions Technologies (NETs)*. Followed by section 4 dealing with policy issues that are influencing how to make these technologies work. Who and why to pay for, the costs of externalities and the extra costs that have to be accepted for NEs are described in section 5. The last section discusses the basics of a CE and why NE fits in this economic model. Besides informing readers about NE, the paper intends also to form the basis for discussions and actions about these very important urgent issues.

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List of Acronyms					
CCS	Carbon Capture & Storage	F&D	Fee & Dividend	PCR	Photocatalytic Reactors
CCUS	Carbon Capture Utilisation & Storage	GGR	Greenhouse Gas Removal	PM	Particulate Matter
CE	Circular Economy	GHG	Green House Gas	PoC	Price on Carbon
CS	Carbon Storage	GWP	Global Warming Potential	ppm	parts per million
DAC	Direct Air Capture	IR	Infra-Red	RE	Renewable Energy
EROI	Energy Return on Energy Investment	LE	Linear Economy	SCPP	Solar Chimney Power Plant
ETS	Emissions Trading Scheme	NE	Negative Emissions	UFPM	Ultra Fine Particluate Matter
EV	Electric Vehicle	NET	Negative Emission Technologies		

1. Why is there a need for Negative Emissions?

Green House Gas (GHG) emissions which include CO2 [2], are the focus of this paper, have been rising rapidly since the start of the 1st Industrial Revolution (1stIR). The scientific evidence of this is established and will not be discussed; neither will there be an analysis about the effects of CO2, CH4 or NxO as a greenhouse gases, since they are scientifically accepted. Certainly to improve modeling of earth systems ongoing research is needed on how natural carbon cycles work in more detail (Jones, et al., 2016). This is true for all natural phenomena since they are complex and interrelated, but that does not mean current conclusions from climate modelling are doubtful, but it will help finding the best response to the climate crisis.

A quote that set the scene of the severity of the climate crisis, "*A 2°C world might be insurable*," warned Henri de Castries, former Chairman and CEO of insurance giant AXA, "*A 4°C world certainly would not be*." (Marcacci, 2019; Tooze, 2019). Just an additional reasons to do more about the climate crisis. The natural catastrophes will have very costly financial consequences (Campanharo, et al, 2019; Gebert, 2007; IAG, 2019; IBC, 2012). Articulating the central issue of climate change [3] action differently in a recent address Swedish climate activist Greta Thunberg (Thunberg, 2019), said very succinctly "**You do not have to listen to us children, but listen to the scientists**". The essence of this simple message should be made very clear to politicians. Many may feel uncomfortable hearing these true facts, but employing ostrich strategies and shrugging it off instead of accepting responsibility for our actions, is not an option.

The latest UN Environment Programme's "Emissions Gap Report 2019" (UN, 2019) states in their foreword : *"… **Our collective failure to act strongly and early means that we must now implement deep and urgent cuts**. This report tells us that to get in line with the Paris Agreement, emissions must drop 7.6 per cent per year from 2020 to 2030 for the 1.5°C goal and 2.7 per cent per year for the 2°C goal. The size of these annual cuts may seem shocking, particularly for 1.5°C. They may also seem impossible, at least for next year. But we have to try. … We have to learn from our procrastination. Any further delay brings the need for larger, more expensive and unlikely cuts. We need quick wins, or the 1.5°C goal of the Paris Agreement will slip out of reach. The Intergovernmental Panel on Climate Change (IPCC) has warned us that*

[2] Any mention in this paper of emissions is referring to CO2, unless stated otherwise.
[3] In this paper "climate change" means "anthropogenic climate change", unless stated otherwise.

going beyond 1.5°C will increase the frequency and intensity of climate impacts, such as the heatwaves and storms witnessed across the globe in the last few years. ***We cannot afford to fail****. …" (author's highlights).* These passages and the rest of the report are alarming and show clearly that action needs to be taken now.

It has been established by the IPCC (2018) that to stabilise the climate, the temperature increase should stay below a 1.5°C rise compared to pre-1[st]IR by 2100 . The amount and rate of rising CO2 levels cannot be explained by the argument that climate change is a common occurrence during geological history; actually geological evidence points to the anthropogenic causes of the current climate changes (DePaolo, 2015). Since the start of 1[st] IR the CO2 level has increased from 280 ppm to 415 ppm now. The full impact of CO2 emissions now will not be felt till 30 years after; therefore the climate will be affected in many years to come (De Richter, 2019). It is to be noted that the USA on a historic per capita basis has emitted 10 times more CO2 than China and in relation to India it is 25 times (Hansen, et al., 2019). El Público (2019b) reports that China will not be able to meet their climate targets because of the USA-China trade war. Expansion of fossil fuel burning plants means future CO2 emissions are already committed (Tong, et al., 2019). To reduce the amount of CO2 in the atmosphere to a pre-industrial revolution level just going down to zero emissions is not enough, CO2 has to be taken out of the atmosphere (Kriegler, et al., 2018; Peters & Geden, 2017). This *GHG Removal (GGR)* is called *negative emissions (NEs)* and there are many different techniques to achieve it. Some of these methods falling under the umbrella term "geo-engineering" are such that they cannot be reversed if something goes wrong (De Richter, et al., 2019; Klein, 2019). Taylor, et al., (2016) state "*Large-scale geo-engineering is ethically fraught and poses dangers of both foreseeable and unforeseen consequences*." According to Lenzi et al. (2018) there is no proper ethical evaluation done to date of these types of negative emissions methods. The author of this paper agrees and does not recommend them either because they may have as mentioned uncontrollable and irreversible side effects, while the processes discussed in this paper can be stopped at short notice. For these reasons the paper will not deal with any geo-engineering proposals.

The current increase in CO2 emissions is not only directly from anthropogenic sources, but indirectly by warming of the earth, like from the permafrost under threat. The areas of permafrost are very large, e.g. northern Siberia, and when they thaw out the amount of GHGs emitted will be enormous. In particular the methane released will have a near immediate impact on the climate (Keller, et al., 2018). The long duration and large aerial extent of the unusual bushfires in the arctic during the summer of 2019 are also a result of increased temperatures in these regions, producing GHG emissions. In the Netherlands they are now (2018-2019) in drought conditions and are artificially wetting some peat areas to avoid oxidation and the release of GHGs; these peat areas would otherwise be lost and also it should also help save the natural landscape. The effect of methane emissions by oil and gas will have dramatic impact on the global warming in the very short term (Christen, 2004; Howarth, 2014; Howarth et al, 2012). The ocean is a large carbon sink, the amount it can take up depends on many factors, and for example when oceans warms up less CO2 can be dissolved in seawater (Keller, et al., 2018). Acidification of the oceans will be a side effect of increasing uptake of CO2 (Fuss, et al., 2016), which will have the effect of bleaching on the coral reefs and also affect all the creatures in the ocean that have a skeleton made of CaCO3, the latter is an under-reported issue.

Carbon Capture, Utilisation and Capture (CCUS) is a topic of review, however it is only dealing with the concept on a general level. So no technical discussion how about these *NE Technologies (NETs)* work in detail. It has to be pointed out that the commercial deployment most NETs on a large scale has not occurred yet (Fuss, et al., 2016). The carbon can be captured at various ways; capture of CO2 can be done in the oil & gas industry at the well head when separating CO2 from hydrocarbon gasses. All this is capturing of CO2 at the source will do is to reduce CO2 emissions and at the very most only to zero at this source point. To remove the CO2 emitted in the past there need to be processes in place that remove it from the atmosphere and is called *Direct Air Capture (DAC)*. It is a generic term for technologies that get the CO2 out of the atmosphere, but encompasses many different techniques, like a S*olar Chimney Power Plant (SCPP)* with photcatalytic panels is a specialised form of DAC.

As said this paper will mainly deal with CO2, but GHGs as methane (CH4) and nitrous oxides (N2O) are also very important factor in the global warming (Sanchez-Pérez, et al., 2016; Sutton, 2011). The importance of reducing the amount of methane is because over a 20 year period it is 84 times more potent than CO2 and so its near instantaneous effect on tropospheric ozone (De Richter et al., 2019). Nitrogen [4] has a beneficial effect on the growth of plants, however for plants thriving on nutrient poor soils this excess of nitrogen will get them replaced with nitrogen loving plants. Nitrogen is produced in agriculture as ammonia and nitrous oxide. Nitrogen is also produced by internal combustion engines. With lot of vehicles and nitrogen producing farms near environmental sensitive areas a potential problem arises with excess nitrogen. Processes have to be put in place to avoid a situation as in The Netherlands as a result of a European Court ruling that the Dutch nitrogen policy has not been carried out properly, this has now enormous impact on development of residential areas near nature areas have been put on hold (Bij12, 2019; Natuurmonumenten, 2019; RvON, 2019). The Dutch national broadcaster just relayed an announcement (10 November 2019) that their government has lowered the speed limit on the freeways from 130 km/h (a signature policy for the liberals in government) to 100 km/h which would save enough NxO start up the building projects again.

Fugitive methane emissions from the large LNG industry in WA are a major problem (Boogaerdt, 2019b; Boothroyd, et al., 2016; CCWA, 2019; Howarth, 2014). Near these facilities equipment should be installed to capture the fugitive methane. This month research from Canada and The Netherlands was released about using satellites to detect methane pollution (Varon, et al., 2019). The advantage of using satellites is that the data collection is uniform all over the globe and so data can be compared.

2. Carbon Capture Utilisation and Storage (CCUS)

As was stated earlier bringing CO2 emissions down to zero is not enough, CO2 needs to be removed, the question is what to do with the captured CO2 (Markusson, 2012). There are various ways to do this. One of them is to sequester the CO2 in the ground; another is to use the CO2 as a resource to create products like biochar and synfuel, which are talked about later. The IPCC restricts the definition of carbon removal to free atmosphere, while it should include carbon removal from any source; including fossil fuel plants (Gasser, et al., 2015). Nature can

[4] When nitrogen is mentioned in this paper it is to represent N_2 or NxO.

capture carbon in its own way, which could be achieved amongst others by planting trees that will store carbon during their lifetime. Figure 1 is a diagram by Keller, et al. (2018) that displays the various types of carbon flows.

Recent reports on extinction threats show that a need for maximize afforestation to abate this threat, that will mean reducing the land use for agriculture (Goldsmith & Del Campo, 2012). Even the use of forest residues for biofuels depletes the organic matter in the forests; however on the other hand it reduces the fuel loads which are a bushfire hazards which increases in a warming and drying climate. Afforestation especially in marginal agricultural areas should be aimed for. These marginal areas are often the same where the expansion of agriculture occurs; they are also often more susceptible to droughts and loss of topsoil due to dust storms changing farming practices help to mitigate it (McDonald, et al., 2019). Afforestation with mono cultures for plantation purposes may have advantage of fast growing and easy management, but lack biodiversity enhances the risk of diseases and pests (Kay, et al., 2019). So the concept of “strip cultivation” (Wageningen, 2019) could be adapted to forestry where let say a 50m wide strip is used for monoculture plantation separated by interconnected 50m strips of ‘native’ (regenerated) bush land that provide diversity in plant and insect species. Here maybe the native bush ‘strips’ can provide forest floor residue that can be used for biochar production. This biochar can then be applied to the monoculture strips to enhance plantation growth potential and avoids depletion of nutrients. One of the biggest opportunities for CO2 sequestration is by increasing the carbon content of the in general poor soils in WA. This can be done in the form of changing agricultural practices to ”regenerative farming” (Massy, 2019). Resulting in an increase of carbon content in soils and so storing carbon and improving yields (FAO, 2005; Hepburn, et al., 2019). If biochar generated from CO2 by DAC methods is added to the soil there will be an improvement in soil quality and the carbon will be stored for some thousands of years.

In emissions reduction discussions in general the focus is related to the electricity generation sector. Malischek, et al. (2019) point out that industry is liable for a quarter of the CO2 emissions and they continue to say that industry is central to prosperity and employs about 25% of workforce; however it is also a difficult sector to abate emissions (similar for shipping and aviation). The largest emitters of industry are the “cement”, “chemical” and “steel” sectors. There are enterprises in these industries that are interested in manufacturing low carbon products using CO2 as an input resource. A different example is the Whyalla Steelworks, South Australia, which plan to have their electricity to be generated by *renewable energy (RE)*. Malischek, et al. (2019) give the example of Apple Inc. being involved with aluminium producers Alcoa and Rio Tinto to look at ways to reduce CO2 emissions from their production processes.

Cement production churns out ½ t CO2 for each ton of cement, this industry should be required to carry out CCS in their production processes by 2030 at the latest. The extra cost for cement would encourage the use of alternative of more sustainable building materials. If plantation wood is used this is still a form of carbon storage for the length of the existence of it as a building material. Concrete footpath repairs are another example where the use of cement can be reduced. In recent underground power projects, holes were cut in the existing concrete footpaths. Under the likely requirement to restore footpaths to their original status sections, slabs 10 times larger than the original hole were removed and replaced by fresh concrete, instead of repairing the footpaths. Resulting in extra CO2 emissions from the extra concrete and machinery used. In addition there are the extra costs of waste and labour.

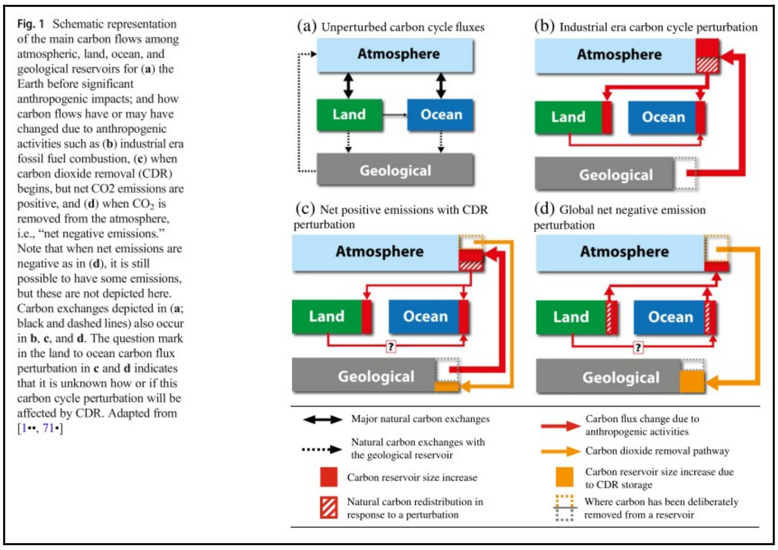

Fig. 1 : Diagram copied from (Keller, et al., 2018).

Aside from CCUS it is important to all types of energy generation the amount of water usage is kept to a minimum. With a warming climate and a growing global population water is a precious resource and water security a major issue and that a large part of the world population, two-thirds, experience water scarcity of at least one month a year (Grafton, 2017).

Capturing CO2 at the source, which should be done in the oil & gas industry, at industrial smoke stacks or from fossil fuel fired power stations, is coorect thing to be done, followed by the sequestration of the CO2 in suitable geological traps. These are examples of abatement technologies, not negative emissions. Then the enterprises that are to capture the CO2 are not necessarily at a location where the geology is suitable for sequestration. In the Netherlands there are suggestions to use the existing gaspipe distribution lines, which will be redundant after a switch to electricity, to transport CO2 to the sequestration sites. A manor to get money back from this stranded asset. Some indicative costs for carbon capture are researched by Budinis, et al. (2018) range from US$20 - US$110 / ton (2015), while transport costs ranges from US$1.3 / t (2015) for onshore pipelines to US$15/t (2015) for offshore pipelines. Even though CCS may not be permanent in geological time frame, it is a good temporary (10,000 years?) solution until better technologies are available.

2.1 Bio-Energy Carbon Capture Storage (BECCS)

Bio-energy is from a GHG perspective at best carbon neutral and better than fossil fuels. The IPCC 5th report appears to emphasize bio-energy, which is a surprise because of the low cost of photovoltaics (Creutzig, et al., 2017). A very large negative for bio-energy is the amount of water needed for the production of biomass. A comparison of water usage between energy types is shown in Table 1, which data are copied from Amaroux (2014) and the table shows very clearly the extremely large amounts of water needed for bio-energy and modelling by others supports this (Séférian, et al., 2018). These large volumes seem in first instance not credible, but are related to the total of "Virtual Water" (Hoekstra, 2008; Renault, 2002). Wikipedia defines Virtual water trade (also known as trade in embedded or embodied water) as to the hidden flow of water if food or other commodities are traded from one place to another.

Energy production Type	**Water requirement (liter/MW h)**
Oil extraction	10 – 40
Oil refining	80 – 150
Coal integrated gasi fi cation combined cycle	950
Natural gas combined cycle power plant	200 – 3,000
Nuclear plant closed loop cooling	950
Geothermal power plant in close loop tower	1,900 – 4,200
Enhanced oil recovery (EOR)	7,600
Nuclear power plant open loop cooling	94,000 – 27,700
Ethanol from corn (irrigation volume)	2,270,000 – 3,670,000
Soybean biodiesel (irrigation volume)	13,900,000 – 27,900,000

Table 1. Energy production water usage adapted from Amaroux (2014).

Concluding from Table 1 it is clear that water usage of biofuels made from specifically grown crops is extreme and therefore these types of biofuels should be avoided as an alternative to fossil fuels. This is also not an efficient way of using the land (Boogaerdt, 2016). However according to some researchers *Bio-Energy Carbon Capture and Storage (BECCS)* is the most cost effective way to remove CO2 (Tokarska & Zickfeld, 2015), but they have not shown to take externalities, like virtual water, into account when modelling. The externalities, will be so large that BECCS is likely not a sustainable option (Urgenda, 2019). To use wheat straw in BECCS appears to be a waste of resource because straw can be ploughed back into the soil to reduce the depletion of the soils. Nevertheless in certain cases "growing" biofuel can be an overall benefit and particularly because the water input is low. A scheme, like the one in WA for Mallee (an *Eucalyptus*) growing where only the new the shoots are harvested helps the CO2 emissions as well as stop/reverse land degradation due to salination problems (WA Gov, 2019). Hopefully this Mallee fuel has fewer pollutants than fossil fuels. Currently the research appears to be focussed on creating an aviation fuel from it (McGrath, et al., 2015). There is a need for R&D in to mini-distillers, so this biofuel can be produced and used locally by regional communities. This would also have socio-economic benefits to the regional economy, and the externalities of transport of this biofuel are near zero.

Bio-energy production has also the problem that it is probably will be shifted to areas where it is easiest (politically) grown, likely Africa. Quoting Winchester & Reilly (2015) "... *That is, as agricultural markets are linked via international trade, incentivizing bioenergy will lead to deforestation in unprotected areas, regardless of the location of bio-energy production. This suggests that promoting bio-energy based on the location of production or even the type of bio-energy, as in many renewable energy policies, is a poor instrument to prevent emissions from land use change. Instead, the issue should be addressed directly by protecting forested areas or pricing emissions from land-use change ...*". Besides the water problem a major issue is the amount of agricultural land that is needed to grow them (Boogaerdt, 2016). The land should be use for afforestation and reforestation instead which would also benefit the reduction of CO2 emissions by storage. This has become even more important after the extensive bushfires in the Amazon in 2019.

A topic that that was not investigated for this paper is the use seaweed and microalgae as a potential for sequestering CO2 and/or as input for bio-energy. For information to the reader a few references on this subject are Goli et al. (2016), Moreira & Pires (2016) and Sondak et al. (2017).

2.2 Carbon Capture & Storage (CCS)

The concept of *Carbon Capture and Sequestration (CCS)* has been around for quite some time and has been implemented at various places overseas. CCS is a method using various processes like post-combustion, pre-combustion and different separation techniques (Budinis et al, 2018). As said CCS cannot be conducted anywhere, it is geology specific and so existing oil and gas fields are potential targets for GHG sequestration since they likely contain suitable geology. In Western Australia's south-west pilot studies have been carried out near the town of Harvey (Hortle, et al., 2014; Sharma, et al., 2017; Stalker & Van Gent, 2014; Zhang, et al., 2015). The sequestration on Barrow Island by Chevron has just started, due to technical problems is so years behind [5]. Sequestration process is energy intensive and expensive since the CO2 has to be compressed to supercritical liquid, which is very corrosive, in order to be pumped down at depth (minimum of 800 m). Another issue with CCS is the ongoing liability of monitoring (Platt, et al., 2018). Hovorka (2017) states that "... *Lack of a method for defining how much monitoring is enough can depress confidence in CO2 storage by creating uncertainty, and elevate costs by motivating collection of large amounts of monitoring data 'just to make sure'* ...". The oil and gas industry is in a good position to use CCS as a business opportunity, especially when combined with DAC (Roberts, 2019). The government has to encourage investments into these projects. The Australian government should put money in establishing CCS projects in order to achieve the Paris targets.

2.3 Direct Air Capture (DAC)

Direct Air Capture (DAC) is a process to capture CO2 directly from the air, it has the potential to have a large impact on lowering CO2 levels (Chen & Tavoni, 2013; Marcucci, et al., 2017). A DAC facility is not location specific since CO2 is uniformly distributed in the atmosphere all over the globe, for example CO2 emitted in the USA can end up in the Sahara where it is captured; it actually does not matter where the CO2 originated only that is captured (Broehm, et al., 2015; Wohland, et al., 2018). The advantage of DAC is that the energy required can be created by RE, like solar and wind, wherever it is available. So DAC can be used as decentralised approach for NEs. It also can be switched on or off very quickly (Wohland, et al., 2018), the latter is useful when carrying out demand management on the electricity grid during times of peak demand and have DAC only running at times of low demand. DAC could also be part of the solution for constrained RE production because now during curtailment time the generator could be paid to run DAC instead. This also means that there will be no problem with overcapacity of RE, since there are very large amounts of CO2 need to be captured. Even on household scale it could

5 Making this operation one of the biggest emitters of GHG in Australia (CCWA, 2019; Reputex, 2018).

work, when DAC systems are small and cheap enough for individuals to purchase. All this would stabilise the electricity grid. In urban areas DAC could pump their captured CO2 via existing, but now redundant gaspipe network to where it can be sequestered or used as a resource in manufacturing. Some DAC systems produce water as a by-product, from an energy point of view they try to get as little as possible water because generation of water costs energy (Breyer, et al., 2019; Fasihi, et al., 2019). In remote communities to have DAC that produces water is an advantage, where likely there is never enough clean water. It actually could be done wherever access to clean water is at a premium and might partially be an alternative to a desalination plant. A concern about DAC and other NETs is that they may use a lot of energy. Sure it is important to use as little as possible energy for DAC, but if the energy comes from RE it is not such a concern. Overtime the systems will become more energy efficient, due to economically driven innovations and so in the long term the cost for DAC will come down (Broehm et al. ,2015; Fasihi, et al., 2019). Additional functions for DAC could be a combination with filters to clean the air, so in Perth, for example, it may also help with improving air quality during backburning or bushfires and also to reduce the impact of smog.

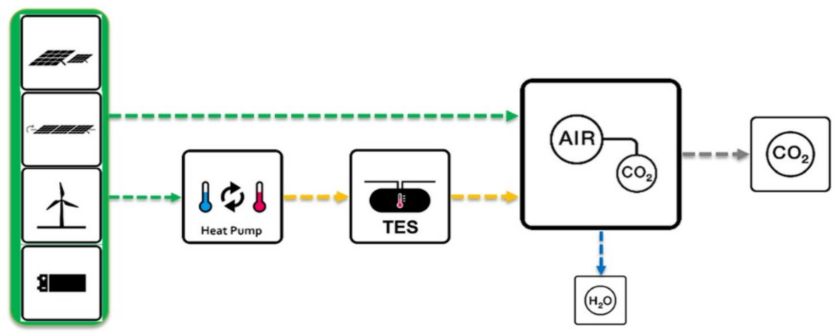

Fig. 1 The hybrid PV-wind-battery-DAC value chain

Value chain of a DAC set up, copied from Breyer et al. (2019)

The small scale DACs specific for agricultural methane and nitrogen could be placed at intensive farming areas. In urban areas with large amounts of traffic or high levels of fugitive methane from gas pipes DACs could scrub out these compounds (Howarth, 2014).

2.4 Enhanced Weathering

Enhanced weathering is a way to speed up the natural weathering process of rocks. It is a process that changes the soil chemistry which could increase the nutrient availability. The application of finely ground alkaline rocks like basalt to depleted soils could increase the nutrient accessibility in acidic soils and capture of CO2 (Taylor, et al., 2016). If biochar (see section 3.2) is added the soil structure could even be further improved (Keller, et al., 2018; Taylor, et al., 2016). A potential problem is that enhanced weathering products reach rivers they could increase their alkalinity, which is a negative for the river, however when reaching the ocean it could improve the uptake of carbon (Fasihi, et al., 2019; Keller, et al., 2018; Strefler, et al., 2018). Many areas that are drought stricken and where part of the topsoil has been blown away (think about the famous images of Dust Bowls in the USA during the 1930s). During dust storms and torrential rains large parts of the productive topsoils are blown or washed away, the left over soil profile could be improved by extra weathering. In addition enhanced weathering could be a tool used at minesites to help rehabilitation of waste dumps and pitfaces. Starting with trials of enhance weathering at minesites, especially abandoned ones, easy to monitor and does not disturb new areas should be great research projects. A negative could be that a changing the soil-type will change the type of native vegetation growing in the region. This is not a problem if it is only applied to cropping areas.

A problem with enhanced weathering proposals so far are that very large amounts of rock have to be crushed and transported, both processes using large amounts of energy. The environmental impact regarding the removal, shifting and dumping of these rocks have not been addressed in literature searched on this subject. So enhanced weathering may not be a sustainable option yet to be carried out on large scale. However, doing it as mentioned around abandoned and existing minesites, where right rocktypes may be available on site, could well be an excellent way of testing these theories and way of improving rehabilitation at these minesites. And at quarries for bluemetal a lot of fine dust is produced, this material could be used as a soil enhancer in areas close to the quarry.

Scientists also look at sequestering CO2 into basaltic rocks where it will create carbon containing minerals; tests are done in Iceland, and are looking at peridotite rocks in Oman (Krupp, et al., 2019; Matter, et al., 2016). In Australia work is done to sequester CO2 in old minesite tailings (Harrison, et al., 2011; Oskiersky, et al., 2013).

3. CO2 as a Resource

Instead of treating CO2 as a waste product as in CCS, it should be used as a resource, the use of it creates new innovative industries, in part already happening in China, Germany and USA (Amouroux, et al., 2014). The DAC captured CO2 could be used as a resource to enhance crop growth in glasshouses, as demonstrated by Climeworks in Switzerland (Climeworks, 2019). Sun Drop farms in South Australia are a great candidate to incorporate this in their carbon neutral setup (Sundrop Farms, 2019). The resource of CO2 and other GHGs can be the input for other products.

3.1 Biochar

Biochar is the charred product of biomass heated without oxygen in a process known as pyrolysis; it is expected to be stable for thousands of years not weathering quickly. Biochar could be created from biomass waste and from DAC processes with a RE energy input. A high proportion of carbon from the biomass remains within the newly created biochar. It can be added to soils without breaking down (Oldfield, et al., 2018; Stewart, et al., 2013; Thomazini, et al., 2015a&b). One thing is certain biochar improves soils; Pratt & Moran (2010) describe that in South America more than 2000 years ago biochar was used to improve soils (“Terra Preta”) which have much higher yields than the surrounding areas without biochar. The ancient soils in WA’s wheatbelt, the sandy soils of the Swan Coastal Plain in WA and many other places can certainly use some extra organic material which also helps with the soil moisture content. This should also be seen as a measure to improve food security in a drying climate.

If biochar can stabilise the leaching of 'P' (phosphor) from soils and so stop the runoff into rivers that would be an excellent outcome (Oldfield, et al. 2018). The recycling of 'P' is essential; if it goes down rivers and end up in sea it is lost for ever. All living plants and creatures depend for growth on 'P'. The number of geological phosphor deposits is limited. Beneficial effects of biochar additions to soil may also result from reducing other GHG emissions, such as NO2 and CH4 (Stewart, et al., 2013). Urban waste can be composted on a large scale; this could be combined with biochar before it is distributed to farms. The combined product should be part of soil improvement programs and also form part of their CO2 abatement requirements for farmers. Soils are a very large reservoir for carbon storage and so form an important carbon sink. In the soils carbon can be stored in three ways : i) in the form of organic material from plants, ii) the weathering of rocks and iii) the forming of carbonate matter (Pires, 2019). Adding the use biochar would be the fourth way. A concern raised about biochar is to ensure that the production of biochar is more carbon intensive than what it replaces, as happened with some of the biofuels (Pratt & Moran, 2010). When REs are used to produce biochar via DAC this is not a problem, it would be a win-win. Biochar may also be used to stabilise slime dumps at minesites, or may be even for a part of neutralising toxic waste at minesites, by amongst others make them less mobile (Qiao, et al., 2018; Yin, et al., 2017). It is not the same, but possibly could work in a similar fashion as synroc does for nuclear waste (Ringwood, 1982). Overall it can be said biochar used in soils is a form of carbon sequestration.

Biochar is not as flammable as the biomass it is derived from (Goldsmith & Del Campo, 2010; Li, et al.,2018; Zhao et al., 2014). With a drying climate the amount of forest floor debris will increase as a fuel source for bushfires. If this biomass from the forest floor can be converted to biochar and redistributed back on to the forest floor, it would maintain or enhance the fertility of the soil and possibly reduce the fire risk or the forest floor biochar could be used by surrounding farmers. So there is a need for the development of mobile biochar plants.

Soils get darkened by increased amount of biochar, this is a negative since it means a decreasing albedo effect. This in turn increases the heat absorption (Williams, 2016) and this is also the case by afforestation. However this negative effect is not a reason for not to reforest or using biochar.

3.2 Synfuels

Synfuels are synthetically derived hydrocarbons that are till now have been created from fossil fuels. Most well-known and proven process is the Fischer–Tropsch from 1925, modifications may have to be made to use CO2 as resource. Because it is synthetically made the product is more pure, without the contaminants like sulphur or nitrous oxide as in fossil fuels, this means when they are used, in theory, the only pollutants are CO2 and soot. In addition because they are pure there likely will be less wear and tear on engines and improve fuel efficiency. It is likely that the scrubbing of the exhaust fumes would be less intensive, resulting in lower costs of manufacturing and operation. Ideally there is a move away from fossil fuels now straight away, but the realistic timeframe for that will however be at least 30 years. Therefore if any fossil fuel can be replaced by synfuel, created with RE via DAC, is good because at least be carbon neutrality can be reached. In this way large parts of the industry could be made carbon-neutral within 10 years.

A distinction between the origin of the synfuels has to be made, the ones derived form fossil fuels are "blue' or "brown" synfuels depending if the source was natural gas or coal respectively. While synfuel derived from atmospheric CO2 with energy input from RE is a "green" synfuel [6]. This is in line with the differentiation of "blue", "brown" and "green" qualifier of hydrogen production.

Electricity generation can relatively easy change over to a RE type. Vehicular transport can be changed to *Electric Vehicles (EVs)* without to many problems. Air and sea transport will not be that easily transformed. The availability of synfuel will make it possible for air and sea transport to become carbon neutral. Replacing the very dirty bunker fuel in ships would be a great benefit. This is not an endorsement of just replacing fossil fuel with synfuels and for the rest business as usual (BAU); green synfuels are to be used as transition fuels. These synfuels can also be used by backup and peak demand plants in the electricity generation.

A problem with any internal combustion engine is that the efficiency is low, at most 38%, the rest is wasted as heat, unless heat exchangers are used to capture this heat. All this heat adds to heating up the atmosphere. So far, no reference was found in literature about the total amount of heat dispersed in to the atmosphere. To capture all this heat research is to be directed to infra-red-voltaic panels, for these panels the major challenge is to improve their efficiency (Economist, 2012). They can be used in cities to capture the heat build-up during the day. Methanol, derived from atmospheric CO2 by energy supplied by RE is 11% more fuel efficient than petrol (Specht, et al., 1998). The internal combustion engine could benefit from the addition of methanol to the synfuel. When the term efficiency is used only the final output is referred to. *Energy Return on Energy Invested (EROI)* is a secondary qualifier that shows the amount of energy that was needed to generate the unit of energy in the first place. Applying EROI reduces even further the efficiencies of fossil fuels if it include the energy lost by venting or other fugitive emissions. The move to synfuel gas via DAC reduces the amount of fugitive emissions which make the natural gas industry such a large pollutant [7].

3.3 SCPP and Photocatalytics of non-CO2 GHGs

A *Solar Chimney Power Plant (SCPP)* is a system that uses thermal airflows generated by solar radiation. There are four components to a SCPP, namely 'energy storage facility', 'chimney', 'solar collectors' and a 'wind turbine'. Figure 2, copied from Cao et al. (2013), shows these components. The concept of its workings is that solar energy heats up the ground, than the thermal convection pushes this warmer air up the chimney. This draft is able to power an electricity generating turbine (Chergui, et al., 2016; Gholamalizadeh & Kim, 2016; Islamuddin, et al., 2013.). In addition the panels of photocatalytic material can be installed in the SCPP. These panels can according De Richter (2019) *"… Change in the rate of a chemical reaction or its initiation under the action of ultraviolet, visible, or infrared radiation in the presence of a substance—the photocatalyst—that absorbs light and is involved in the chemical transformation of the reaction partners. …".* The advantage of photocatalysts is that the chemical reactions occur at room temperatures. Methane gets oxidized by the photocatalytic

[6] In this paper when "synfuel" is used it means "green synfuel", unless stated diferently.

[7] When fugitive emissions are included in total emissions of natural gas, its GHG emissions can be higher than coal (CCWA, 2019).

process, effectively reducing *Global Warming Potential (GWP)* by 90%. Nitrous Oxide levels can be reduced in a similar fashion (De Richter, 2019).

The first pilot plant built in 1982 at Manzares in Spain by a German consortium. The solar collector has a radius of 122m, the chimney is 194m high with diameter of 10m. It was designed to have 50kW electricity generation (Gholamalizadeh & Kim, 2016). According to Cao et al. (2013) SCPPs along slopes are more cost efficient than the standalone SCPPs, their schematic design is shown in Figure 2. Advocates of SCPP say it is easy to collect large amounts of solar radiation, to have relative cheap thermal storage and the natural wind regime can be used at collection. The pilot plants at Manzares (Spain) and Kerman (Iran) show it is possible to run them around the clock with no intermittence (Gholamalizadeh & Kim, 2016; De Richter et al., 2019). This technology has great potential especially in desert areas with high solar irradiation. In urban areas a SCPP variant of a photocatalytic solar tower proposed by Negishi & Sano (2014) could be installed in combination with DAC processes described in section 2.2.

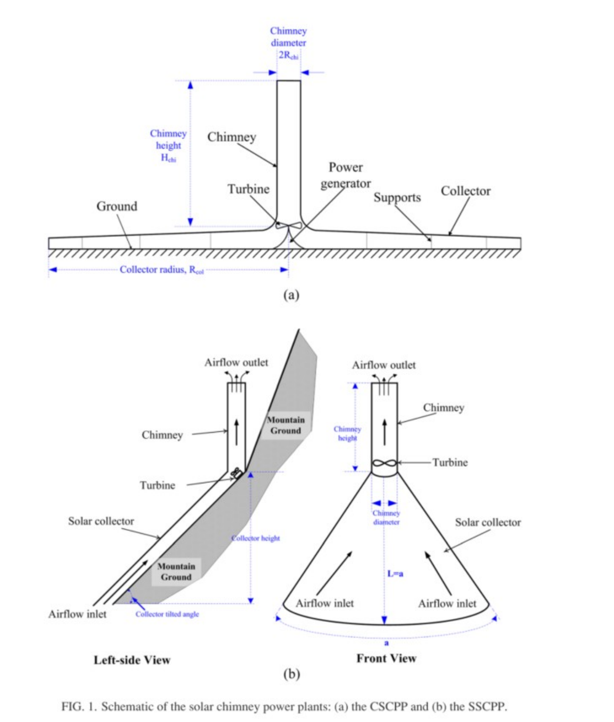

Figure 2 : From Cao, et al., 2013 shows diagrams of SCPP as standalone and along hill slope.

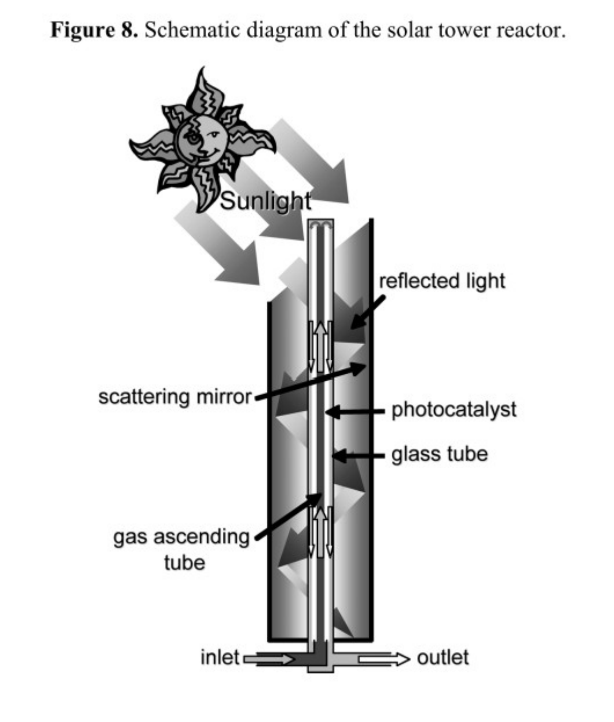

Figure 3 : From Negishi & Sano (2014) shows a diagram of photocatalytic solar tower reactor.

4. Policy

Energy supply is essential for socio-economic and environmental sustainability. A framework called Shared-Socioeconomic Pathway (SSP) has been developed to model various scenarios of what happens when a particular energy route is taken (Bauer, et al., 2017; Beck, & Mahony, 2018; Gütschow, et al., 2018; O'Neill & Kriegler, 2017). The SSPs with most RE get the best results. A fundamental issue is that whatever a human does it will produce anthropogenic carbon emissions not necessarily from burning fossil fuels (Rogelj, et al., 2015). For that reason the negative emission policy will be with us for a long time and may be forever.

Climate Change is in general abstract and complex, and therefore more difficult to apprehend with time frames long into the future. The politicization of this issue makes it also harder for people wanting to do something about it. Quoting Markowitz, & Shariff (2012) "*… Unlike financial fraud or terrorist attacks, climate change does not register, emotionally, as a wrong that demands to be righted. ...*". When discussing climate change people often focus on small items that are difficult to achieve, or sit on the fence because some actions in the past may have had negative side effects and forget the broader picture. No doubt mistakes will be made when combating climate change, but that is not a reason not to take action. Waiting till the current uncertainties have been resolved, means a reduction in innovation, lost opportunities and missing out on long-term GGR (Lomax, et al., 2015). There is a moral dimension to the action on climate change, since we are, if we want to or not, passing on the environment to the next generations (Boogaerdt, 2019b&c). The ethical question is what type of environment we want our children to inherit? We are possibly too optimistic about solving complex natural problems of nature with technical solutions, basically an unjustified arrogance (Lenzi, 2018). What has been stated so far may appear quite depressing, however O'Neill & Kriegler (2017) find improvements in international cooperation, more inclusiveness trends, partly due to increased evidence and the accounting of the costs of environmental degradation.

Wind and solar can be used basically anywhere on the globe. Classic carbon storage, the pumping of CO2 underground, can only be done in limited areas. Therefore according to Vögele & Rübbelke (2013) carbon sequestration is only a transitional technology providing a 50 year window to move away from fossil fuels. Reaching the Paris target by 2050 is only possible with electrification by RE and to substitute fossil fuels used during this period with synfuels. DAC could be the main supplier of CO2 for the production of synfuels (Broehm, et al., 2015; Fasihi, et al., 2019).

It has to be mentioned again that abatement in the short-term of CO2 is an essential part of meeting climate target of 1.5°C, but it is not enough (Fuss, et al., 2016; Peters, 2018; Van Vuuren, et al., 2018). Therefore it is necessary to increase the amount of research in and implementation of the NETs in regards to biophysical and socio-economic aspects (Broehm, et al., 2015; Fuss, et al., 2016). The more CO2 is mitigated from now on the lesser amount of CO2 has to be part of the negative emissions, an enormous cost saving over time. To reach international consensus and action on how to combat climate change are very difficult. However, a success story is the Montreal Protocol of 1984 regarding Chlorofluorocarbons (CFCs) phase-out management plan. At the time the hole in the Ozone layer was getting larger and larger and recently it was recorded that the hole was shrinking as a result of action taken following the ratification of the protocol. The phasing out of CFCs was modeled to cost $235 Billion implementing in Canada, but would create over a period of 60 years period a $459 Billion economic benefit (De Richter, et al., 2019).

Each jurisdiction should be responsible for its own legacy emissions, in Australia this should ideally be approached on a national basis. WA should do its share regardless of whether or not other states', territories' or federal governments are doing their share. This is an issue of moral obligation (Kelleher, 2015; Lenzi, et al., 2018; Lenzi, 2018; Mittler, 2014). It is to be noted that the USA on a historic per capita basis has emitted 10 times more CO_2 than China and in relation to India it is 25 times (Hansen, et al., 2019). For Australia these figures would likely be similar. Policy should focus on solutions, that is setting up a framework in which solutions can be created. The problem is known and understood. Always there will be a need to learn more in order to be more effective in executing solutions (Massy, 2019).

Now it is time to pay the debt created by past generations, since we have the technology to create negative emissions. It comes down to according Ruscio (2014) *"… the value-laden question, which is what do we owe to future generations? The verb is important. 'Owe' implies an obligation, a duty, which further implies an ethical question, which further implies an ethical answer or at least an ethical analysis ...".* Morally we cannot leave it for the next generations, who will pay in part for it anyway and already have to deal with the effects of climate change (Nelson, 2013). The motivations of right and wrong are powerful forces in behaviour, but climate change it is not clear cut because the complex and abstract notion of climate change. In addition to the abstract nature of climate change these financial incentives play a role. Rau & Oberhuber (2017) state that "... *Knowledge is no incentive for change. Financial incentives are that. No one turns around his business plan because they think their grandchildren will be better off ...*". In a way this is at odds what parents often do, namely they make sacrifices for the betterment of their children's future of better lives and opportunities. With this in mind the hardest part will be persuading politicians to create legislation and regulations that make it happen. Besides relying on regulations form governments of not polluting there is also a need for financial incentives, which would spur innovation (Zakkour, 2014). It will not be easy to achieve NEs, but as Krupp, et al. (2019) state "... *Hard does not mean impossible, however, and the transformative power of human ingenuity offers an endless source of hope. ...*". Business invests when they see a market opportunity and as a way to grow. If these opportunities do not exist, government stimuli like tax relief will not be effective (Mazzucato, 2018; Platt, et al., 2018). To kickstart NETs' "public good" has to be taken into account when setting out government policies and rethinking the capitalism of the Linear Economy (Boogaerdt, 2018; Mazzucato, 2018). Maybe in order to get this partially social policy of NE accepted, is to engage the community with the collaborative principles (Angelstam, et al., 2013; Axelson, et al., 2013; Boogaerdt, 2016; Hartz-Karp, 2012; Mittler, 2013; Mulgan, 2017; O'Neill & Kriegler, 2017; Riahia, et al., 2017).

Besides technical issues with DAC there are also opponents who argue that the DAC technologies encourage "business as usual" approach (Krekel, et al., 2018), this would be valid argument against all NETs. Government regulations are essential to counter act BAU to occur. A *Price on Carbon (PoC)* can stop this BAU attitude, since with an ever increasing PoC is an incentive to change habits. It has also to be pointed out again that NEs should not be seen as an alternative to emissions reductions. For DAC to be successful not just technical scientific issues are to be solved, there needs to be a stable system of carbon credits or fees. They will also be an essential part for the market for CO_2-product and development of synfuel (Broehm, et al., 2015). As pointed out in section 2.2, DAC could be used by RE generators to compensate for the losses of income during imposed curtailment of electricity generation. In other words there has to be a policy and a financial mechanism that incentivises generators to install DAC. This could be done in part by creating 'NE-Credits'/'DAC-Dividends' for businesses or governments that are not able to do run DAC themselves.

When new technologies are developed it is done on a relative small scale as pilot projects. After that stage further development should go in both the direction of upscaling and downscaling, so that there could be possibilities for DAC at private homes, business or small scale operators, they would need a system of what to do with captured CO2. An option for a system could be that the DAC has easily exchangeable containers, which can be collected by a service provider. Just like exchanging gas bottles outside the metro area. Or, the CO2 may be pumped through unused existing gaspipes, this service provider can at their plant sequester the CO2 or maybe make biochar from it or even another product. In addition to capturing carbon these urban-DAC-systems can filter *particulate matter (PM)* from the air. These particulates mostly have their origin from fossil fuels, from bushfire smoke, but also as biogenic volatile organic compounds (Saunders, 2011). PMs are causing health problems; pollution studies tend to quote PM10 and PM2.5, but the *ultra-fine particulate matter (UFPM)* are also of great concern (Cahill, et al., 2016.; El Público, 2019a; Jim & Chen, 2008; Varotsos, et al., 2012; Wang, et al, 2010).

The Australian Financial Review wrote "*… According to experts, it's also a sobering preview of how climate change, accelerated by human behaviour (and exacerbated by political corruption), will not just complicate Venetian's unique and fragile life but wash it away entirely. ...*" (Bellware, 2019). These fleeing Venetians are basically climate refugees. With increasing severity of natural disasters, like floods and droughts and rising sea levels we have to be prepared for an influx of "climate refugees". In policy discussions it is also important to look at the climatic influence on crop yield. Lower yields due to increased temperatures or more frequent droughts and floods will push several hundred million more people into poverty in the developing world (Krupp, et al., 2019). This will result in mass migration. Even though it is a federal responsibility climate refugees will also have their impact on WA. Unfortunately Australia's latest white paper on foreign policy only scantly refers to this, while it was made aware of the importance of this major issue by at least one submission (FP, 2017).

There is a cost associated with CO2 abatement, there is the cost of avoiding pollution and CCUS is the cost of cleaning up pollution. That is the cost to the economy (Nápoles, 2011). What about the pollutions by the emitters of the past? The answer is the taxpayer, and that is nothing new because we already do that for recent pollution created by companies that went bankrupt or were not accounted for cleaning up their pollution. To achieve that there needs to be regulatory framework that ensures that the pollution is reduced, and including incentives to do this pollution abatement. Incentives come in the form of fines or Price on Carbon (Malischek, et al., 2019). The introduction of a Price on Carbon is essential to combat GHGs and is supported by many economists (Rhodes, et al., 2014). ETS schemes work well, but have the negative side namely a lot of the money generated ends up in the hands of the financial institutions that are doing the trading. A price on carbon in the form of a Fee & Dividend scheme as promoted by Citizens' Climate Lobby (CCL, 2019) is a fairer option. A fee is put on carbon emissions; the fee is increased every year by a fixed amount, this makes it easy for companies to budget for. The money raised, the Fee, is distributed equally as a Dividend amongst the population (Tooze, 2019). This dividend is likely to offset more than the cost increases of the products bought and services used. A version suitable for Australia which incorporates border adjustments was researched by the University of NSW (Holden & Dixon, 2018).

Air-Clean-Dividends (AC-Dividends) could be applicable to the CCUS and SCPP facilities. Air-Cleaning is where particulates are filtered out of the air. The Fee & Dividend a price is put on carbon, paid by the polluter and the dividend is paid the citizens, while AC-Dividends could work in the reverse. The organisation or individual get money (dividend) for the captured CO2 and other pollutants. This dividend is paid for by the taxpayer or in part by the polluters that have not captured the these pollutants. Initially, that is from now, the dividend is high. Over time when technology improves and the costs go down, the dividend will go down until one time in the future when the NEs are not any more required. This process would incentivize DAC technologies to be taken up. There will be opposition from other NETs because they will see the scheme biased towards DAC and CS. That criticism is fair but the reason for choosing DAC & CS is because the Carbon-capture can easily be measured. This AC-Dividend system could be setup in parallel with a DAC-Dividend.

Besides the earlier mentioned causes of methane emissions, further research in removal of CH4 is very important. Let oil & gas industry pay for it as part of their abatement program, especially since the industry skips regularly their social responsibility regarding GHG emissions (Boothroyd, et al., 2016; Schneising, et al., 2014), while they receive fossil fuel subsidies (IMF, 2019).

In discussions about NE and the climate crisis in general, they often cover different technological and scientific topics. A problem arises when outsiders often do not understand what these technologies mean, but still have what Karimi, et al. (2016) call a “pseudo opinion”. For example everyone seems to have an opinion on “baseload” in the electricity sector, but very few know really what it means in relation to supply and demand curves (Boogaerdt, 2019a). The new technologies discussed here are not an insurance policy but a gamble to achieve then required outcome in the long-term (Anderson & Peters, 2016). Taking these comments into account it is important to use many different strategies and technologies to achieve the negative emissions targets. Australia with excess solar, wind and space could sell Air-Clean Dividends and DAC-Dividends to countries that are not so lucky. Carrying out mitigation strategies now will save money later benefits the environment.

To many the task of reducing GHGs appears too large, but if the population as a whole with help of the government, carry out many relative small steps the result will be significant. Urgenda, a Dutch organization for innovation and sustainability in the Netherlands, has prepared a list of 40 point action plan for the individual or government that when implemented will have the impact of reducing GHGs by 10 - 15 Mt CO2 per year (Urgenda, 2019).

A policy framework should set a timeframe when environmental accounting of externalities is fully embedded in the reporting. The costings should be simple, based on how the GST works, including credits to avoid double payments and can easily be computerised.

4.1 Who pays for it all and what are the costs?

The first criticism about any NET, all environmental issues for that matter, is “what will it cost” and “who is going to pay”. Whatever we do in life has a cost associated with the action or the non-action. These costs may have been incurred in the past or currently or could be expected to occur in the future. Similarly we could argue about benefits reaped in the past, enjoying them now or in the future. An analogy is receiving a decent superannuation in the future when retiring, while paying for it now; or if children inherit the house of their parents, which still has a mortgage on it, no one questions the need for mortgage payment. To get a monetary benefit there has to be a cost input. In this field there are no miracles that produce a benefit without an input (costs). There are various permutation are laid out in Table 2.

	BENEFITS		COSTS
1	In the Past	a	In the Past
		b	Now
		c	In the Future
2	Now	a	In the Past
		b	Now
		c	In the Future
3	In the Future	a	In the Past
		b	Now
		c	In the Future

Table 2. Benefit and Cost matrix

Paying for current emissions as a concept is straight forward. As indicated there is a need to remove CO2 from the atmosphere, but who bears the costs for these negative emissions? Now it has to be established who is and was responsible for them. As a society, at least in the developed world, we have benefited since the start of the 1st IR of the progress away from an agrarian society, to achieve this there has been an ever increasing amount of CO2 emitted, during this 200 years period. So all past generations pushed the problem of CO2 emissions forward, because they did not have the technology to avoid these emissions to deal with it, neither would they initially have anticipated it to be a problem. In other words they unknowingly borrowed time and the cost of abatement from future generations, and this continues today. In the meantime their actions have created enormous wealth and comfort for at least the developed world. Now it is time to pay the debt created by past generations, since we have the technology to create negative emissions. It comes down to quoting Ruscio (2014) "*… the value-laden question, which is what do we owe to future generations? The verb is important. 'Owe' implies an obligation, a duty, which further implies an ethical question, which further implies an ethical answer or at least an ethical analysis ...*". Morally we cannot leave it for the next generations, who will pay in part for it anyway and already have to deal with the effects of climate change.

In the case of carbon emissions benefits, see table 2, we are dealing with in the past and now (scenarios 1 & 2), but for the costs now and in the future (scenarios b & c). It is like buying goods on credit with an interest free period. At the time when CO2 emissions started to increase there was no timeframe set for the repayments, there would not have been any notion for a need of payments at the time anyway. In the financial sector, when risks are high the costs are higher. Translated into the climate crisis scenario the longer action on CO2 reduction is postponed the higher the risks of higher temperature increases. In financial terms it means much higher costs for mitigation later on. However the financial crunch has come now and society has to start paying "interest and capital" back to nature. *The <u>interest</u> is being the costs* *of mitigating CO2 and the negative emissions strategy. The* <u>*capital*</u> *is removing the CO2 from the atmosphere to pre-industrial levels*.

5. Environmental Accounting

When talking about costs of pollution, NEs, global warming etc., after deciding who pays for them there is the issue of how do we account for all these expenses including GHGs. There are two points here, first how do we account for all the emissions and second how can they be incorporated in the "standard" financial accounting practices. The first point deals in a large part with the costs of externalities. Externalities can be defined as market failures that arise when there is an in-balance between social costs and private costs, or as unintentional and unbalanced losses or gains in the welfare of a party resulting from the activity of another party (Unerman et al., 2018). Externalities are a broad concept over a wide range of issues. Some researchers (Eidelwein, et al., 2018) divide them into various classes, like Greenhouse Gases, Air Pollution, Soil Use, Water Consumption, Soil or Water Pollution and Solid Waste.

Environmental costs are not often borne by the polluter; more formally said they are not internalised. To quote Eidelwein, et al. (2018) "... *Internalization of externalities refers to all measures (public or private) that guarantee that unpaid benefits or costs are taken into account in the composition of goods and services prices* ..." and even if externalities are a result of failing markets, they are an integral part of the market economy (Unerman, et al., 2018). In most cases markets continue to ignore externalities, because no penalties are linked to them. Relationships between internalities and externalities are depicted in figure 4. After methods have been worked out how to account for GHGs, both positive- and negative-emissions, mechanisms can be designed how to incorporate them in to the current accounting methods.

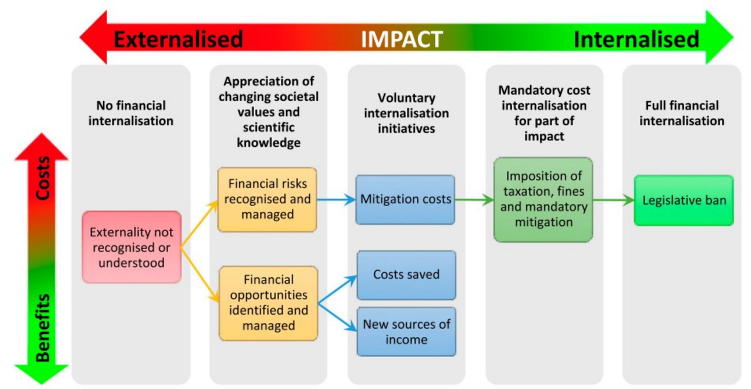

Figure 1. Internalising externalities continuum.

Figure 4. Internalising Externalities Continuum. (copied from Unerman, et al., 2018)

From a policy perspective a 'Price on Carbon', independent of its form, is like mortgage cost, in this case a CO2-Debt repayment and paying for NEs is a CO2-Debt repayment from an accountant's viewpoint. Using an analogy, it is no different from a company taking over another company including its debts, in this case the debts being the costs of NE. At face value synfuel may be more expensive that fossil fuel, but when externalities are taken into account the value comparison will be different. No publications have been found so far that compares the cost of synfuels with the cost of fossil fuels that include the costs of externalities. The cost of synfuels or other products by DAC will be much higher than the same products from the same industry source (Chen & Tavoni, 2013), who expect synfuels to be 3.5 times more expensive that fossil fuels. This would be without taking into account the cost leveller of a price on carbon and other costs of externalities. Therefore a F&D scheme where the fee increases every year makes the ratio ('DAC-costs' / 'Carbon-fee') smaller over time. Advantage of RE for CO2 abatement is that the "fuel" price is fixed, actually wind, sun and waves are free, this will enormously help with financial planning.

The accounting profession needs to carry out more research in what to include and how to report on externalities. Because as a profession they will have a responsibility of reporting on environmental activities (Yakhou, 2012). This will have to be done in a transparent fashion; there is an increasing need for disclosure and reporting on environmental externalities. Current accounting standards have to be adjusted to incorporate these externalities (Yakhou, 2012). The research may come up with totally different ways of assessing how and what to account for, as the current system appears not amenable to the changed circumstances.

When raising the issue of economic viability, costs in relation to the environmental issues, economic growth and GDP will be mentioned, often with dogmatic ideological zeal. GDP itself is a flawed concept which was alerted to by the designer of the concept in the 1930s (Boogaerdt, 2018; Van Den Bergh, 2010). In general the concept of 'economic growth' needs to be looked as well (Boogaerdt, 2017; Daly, 2009), it may need adjustment in the current circumstances.

6. Circular Economy [8]

The current economic system that we are part of is called the *Linear Economy* (LE) for the following reasons. It is linear, because raw materials get collected, manufactured into a product which get sold to a consumer who dumps it after use. By some called "take, make, dispose". In other words natural resources are used for just for temporary benefits in the meantime creating waste and depleting the resources. A *Circular Economy* (CE) is an economic system where the waste from production to the final consumption stages of disposal, is minimised and becomes a resource and has the ultimate goal of zero waste. This resource can then be used as input for the same or different products. As pointed out in section 3 "treating CO2 as a resource" is an integral part of CE.

One of the main problems with the LE is that it does not account for externalities. From a neo-liberal perspective externalities should not be part of the economic model because it interferes simply with the profitability model of opportunistic short term gain with exclusion of any social responsibility. It will be difficult for neo-liberals to accept that their model will come to a crashing halt, when resources run-out or when pollution becomes so bad that health care costs become so exorbitant that only a few afford it and as result people are dropping off like flies. Tooze (2019) writes "*... that is precisely what the fossil fuel interests have been lobbying hard to prevent. This resistance may make sense from the industry's narrow point of view, but by blocking proactive decarbonisation and clinging to a vision of fossil fuelled future, it also maximises the risk of a large-scale build-up of stranded assets. It is the old dilemma of*

[8] For a more in depth discussion about the Circular Economy read "Circular Economy in the TiR" by Humphrey Boogaerdt (2018).

conservative politics: By resisting progressive adjustment, they are courting a revolution. For the financial system that is bad news. …". A related issue is raised by Rau & Oberhuber (2017) namely "*... power and responsibility are too far apart. The producer has the power, but not the responsibility for the consequences of his actions. He passes it on to the consumer. Where power and responsibility come together, things are going well ...*". In CE this changes because the producer takes more responsibility of the product. This were part of the externalities get internalised. Fortunately in some jurisdictions like the EU and China are regulating a move to more sustainable investment models (El País, 2019). Even though it is not exactly CE, it is a way towards it. Transitioning from LE to CE is changing from an open system that does not account for externalities to a nearly closed looped, one that includes externalities. Inherently the CE is more environmentally friendly; and with its ultimate goal of zero waste (EMF, 2019). There will be business opportunities in CE. Business leaders have to start thinking more innovative and accepting that fossil fuels are never a part of the CE, because they are not a renewable resource.

Environmental pressure will make CE acceptable for economic and political reasons in order to survive as a society. At its core the CE is an economically and politically palatable response to aspirations for sustainable growth in the context of mounting pressures on global resources. According González Ordaz & Vargas-Hernández (2017) the CE has positive impacts on economic development and business while contributing in social responsible way.

Conclusions

To achieve the target to stay below 1.5°C warming by 2100, reaching zero emissions by 2050 is essential but not enough. Negative emissions have to be created, by carbon capture, utilisation and storage. This can take various forms like afforestation, biochar, enhanced weathering, newly invented products, solar chimney power plants or underground storage. Using CO2 as a resource is a part of the Circular Economy model. The conventional way of thinking about economic growth and entitlements will have to change in order to cope with the climate crisis.

It is essential to have government policies in place as soon as possible to encourage R&D and investments in NETs, without them the climate targets will be missed. More funds have to be made available for research into stripping out the carbon from CO2. While carrying out this transition there will be great business opportunities for forward looking business leaders.

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