The potential for implementation of Negative Emission Technologies in Scotland

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ABSTRACT

The reduction of anthropogenic greenhouse gas emission rates alone appears insufficient to limit the rise in global temperatures. Negative Emission Technologies (NETs) can be helpful in this critical goal by actively removing CO_2 from the atmosphere. Industrialised countries like Scotland will require NETs to address their climate targets and reach net-zero carbon emissions in a timely manner. However, the implementation of NETs has varied energy, economic and environmental implications that need to be analysed in detail. In this paper, we explore the potential energy and economic costs for implementation of land-based NETs in Scotland. This analysis is based on the calculated averaged costs of the different technologies and the availability of resources for its implementation in Scotland. We found that the country has a maximum technical potential to abate 90–100% of its annual CO_2 emissions by means of land-based NETs, thanks to its low annual emissions and large land area for implementation of NETs. Even in less optimistic scenarios, Scotland is exceptionally well suited for land NETs, which can complement and enhance the potential of more conventional technologies, like renewable energy resources. Our results show that Scotland could lead the transformation towards a carbon-neutral society.

1. Introduction

Global average temperature has increased as a result of cumulative anthropogenic greenhouse gas emissions (especially CO_2) (IPCC, 2014; Peters et al., 2013). The increasing temperature trend is expected to continue unless CO_2 emissions are limited to near zero. To keep emissions under control, parties to the United Nations Framework Convention on Climate Change committed to ambitious CO_2 emission reductions with the signature of the Paris Agreement (UNFCCC, 2015). Scotland set its own CO_2 emission reduction targets of 42% reduction from 1990 levels by 2020 and 80% reduction by 2050 under its Climate Change Act (Scottish Government, 2010; Scottish Parliament, 2009). However, it is likely that emission reduction alone will not be enough to accomplish these targets, based on current CO_2 emission trends and on the reduction efficiencies of the different technologies (IEA, 2017). Most scenarios from Integrated Assessment Models (IAMs) require the implementation of Negative Emission Technologies (NETs) at a large-scale to actively remove CO_2 from the atmosphere (Bouvier et al., 1989; Fuss et al., 2014; Gasser et al., 2015; IPCC, 2014; Rogelj et al., 2016; Smith et al., 2015; Tokarska and Zickfeld, 2015). Studying the potential

and costs of NETs implementation is therefore required to select the most suitable climate targets and work towards their achievement.

This paper builds on two studies on the global potential of NETs by Smith et al. (2015) and Smith (2016). These studies reviewed the characteristics and potential impact of different land-based NETs, including their negative emission potential, energy and economic requirements, water and nutrients (i.e., P, K, N) use, and impact on albedo. The NETs considered in these studies (Smith, 2016; Smith et al., 2015) and also considered in this work, are: (1) Bioenergy (BE) (Creutzig et al., 2015) with carbon capture and storage (CCS) (Boot-Handford et al., 2014; Haszeldine, 2009), together known as BECCS (Fuss et al., 2014); (2) direct air capture (DAC) (Sanz-Pérez et al., 2016); (3) enhanced weathering (EW) of basic and ultrabasic minerals (Taylor et al., 2015); (4) enhancing the sink capacity of forests by means of afforestation and reforestation (AR) (Canadell and Raupach, 2008); (5) soil carbon sequestration (SCS) through change of agricultural practices(Smith et al., 2008); and (6) conversion of biomass to biochar, to be used in soils (Woolf et al., 2010).

Here we make estimates of the potential for NETs in Scotland, adapting the NETs models of the UK by Smith et al (2016). We also

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present a summary of the status of the different technologies in Scotland and indicate the advantages and limitations of the Scottish *status quo* to the implementation of NETs. It is important to realise that this is a scoping study, and the quantities calculated assume 100% efficiency of capture or storage utilisation, although the current efficiencies of capture technologies are around 90% (Leung et al., 2014). In a real-world and certainly in a cost-constrained setting the quantity of exploitable NET may be substantially lower than the technical maximum.

2. Methods

2.1. NET potential and land requirements

The chosen values for impact of NETs on a per tonne C equivalent (per-t-Ceq.), where 1 t of C equals 3.67 tonnes of CO_2. Removal basis are the same as employed by Smith et al. (2016a,b), full details can be found in Smith et al. (2015) and Smith (2016). The methodology used in this work is derived from the approach described in (Smith et al., 2016b). The impacts of NETs on a per-t-Ceq. were obtained from (Smith et al., 2015), with an expanded focus on land-based options (SCS and biochar) described in Smith (2016). The impact of the different NETs in Scotland are calculated by multiplying each per-t-Ceq. with the available land areas for each technology (Fig. 1).

The areas available for biomass energy crops were defined from the short rotation coppice (SRC) model described in Andersen et al. (2005). The available agricultural area for the Scottish regions is 1.96 Mha for all land not excluded by five primary constraints (soil type, slope, topography, land cover and temperature). This land is divided into three categories, based on their suitability for SCR (Fig. 1a): highly suited land (arable or improved pasture) covers 0.52 Mha, the 26.5% of the total; suited land (semi-natural communities, rough grass) occupies 1.23 Mha, the 61.2%; marginally suited land (scrub or maritime pasture) covers the remaining 0.21 Mha, 10.2% of the total available land. To avoid competition with standard agriculture, our model considers only land that is marginally suited for food production to be used for BECCS feedstock and for feedstock for Biochar. This results in certain underestimation of the potential, as highly suitable land is likely to produce more biomass than the same area of marginally suitable land. Since SCS practices do not change the land use where it is implemented, it is assumed that it can be applied on any land of the SRC model (1.96 Mha) (Andersen et al., 2005).

Renforth (2012) presents a detailed study for EW potential in the UK, that includes the distribution of suitable igneous formations, energy and operational costs and capture potential of igneous rocks in the UK. Scotland hosts 55% of the total UK's rock resource for EW. If all of this rock were quarried (which is extremely unlikely), then 926 Gt of material will be available, with a negative emission potential of 245 $GtCO_2$ (0.264 t C/t rock, on average) (Fig. 1c). However, the EW potential is not only dependent on the availability of land and suitable EW materials, but also to the rate of application of the material to the soil (Taylor et al., 2015). Reported application rates vary from a "low" rate of 10 t rock/ha/yr, applicable to all agricultural land, to a "high" rate of 50 t rock/ha/yr (similar to manure application), not compatible with food production on prime and good quality land (Grades 1, 2 and 3) (Renforth, 2012; Taylor et al., 2015). Hence, the maximum amount of available EW rock is several orders of magnitude greater than the needs of Scotland: even at the high application rate (50 t rock/ha/yr), the available land will be covered with EW material with just 0.098 Gt. Our calculations consider using a low application rate on prime and good quality land (0.52 Mha) and a high application rate on the remaining suitable and marginally suitable land (1.44 Mha), to avoid interaction with the agricultural operations. The potential of EW for reduction in CO_2 emissions is calculated assuming that energy required is derived from conventional fossil fuels, with a conversion rate of 400 gCO_2 kWh^{-1} (Renforth, 2012).

The area available for AR was obtained from the Woodland Expansion Advisory Group (WEAG) 2012 report (WEAG, 2012), which is aligned with the Scottish Government's Land Use Strategy (Scottish Government, 2012) (Fig. 1b). Scotland had 1.39 Mha of woods and forests in 2012, and the target for expansion is an increase of 0.1 Mha over the period 2012-2022. If the Scottish Government commitment of creating 0.1 Mha by 2022 is achieved, woodland will cover 19% of Scotland's territory (WEAG, 2012), compared to just 11% in the rest of the UK (Forestry Commission, 2017).

Finally, DAC activities have likely small land requirements compared with the rest of NETs, so the calculation of its potential is not constrained by land availability. The location of DAC equipment will depend on the method used for capture and energy sources for regeneration of capture medium, and especially to be close to the transport of CO_2 to the geographic location storage or method of CO_2 utilisation. The DAC potential was calculated according to current fossil fuel energy factors and assuming a conventional grid (Socolow et al., 2011), but it is sensitive to the changes in the supply sector.
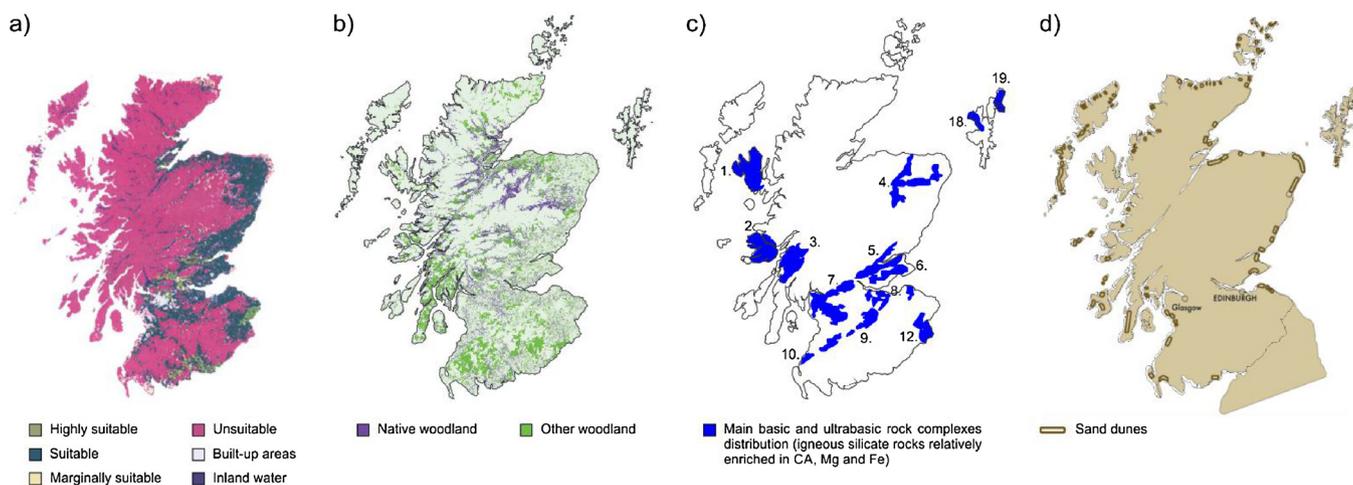

Fig. 1. Geographical distribution of the different elements used in the negative emission assessments. a) Short rotation coppice suitability map, from Andersen et al. (2005), used to determine available land for BECCS, SCS, Biochar and EW; b) current woodland areas in Scotland, from WEAG (2012); c) main basic and ultrabasic rock complexes in Scotland, from Renforth (2012) (number codes can be found in Renforth (2012); d) location of major Scottish dune systems, from Brampton et al. (2000).

2.2. Economic cost calculations

The economic cost of implementation of the different NETs is variable, and depends on the characteristics and requirements of each technology, the scale of implementation, the resources needed (including the energy required) and the operation costs. The economic cost of each NET is calculated in units of carbon removed from the atmosphere ($ tCeq^{-1}). The costs for BECCS are obtained from the six IAMs calculated in Calvin et al., (2013). These IAMs include a range of different policies, both at regional and global scale and with different types of resources and applications in several energy sectors (e.g. nuclear, coal, oil, gas) with and without CCS, resulting in a mean price of $132 per t Ceq (Smith et al., 2016a). AR costs are estimated to range between $65–108 per t Ceq for 2100, with a mean cost of $87 per t Ceq. The cost of SCS and biochar were obtained from Smith (2016). SCS, in the form of cropland and grazing land sequestration range from $-165 to $40 t Ceq. Biochar estimates for the UK (from Shackley et al., 2011) range from $-830 to $1200 t Ceq, with a mean of 185 $ t Ceq. The cost of EW is obtained from the "preliminary estimate" carried out in Renforth (2012). Estimated costs of EW range from $88 to $2120 per t Ceq, with a mean of $1104 per t Ceq, although the author explicitly indicates that there are still great uncertainties related to these values. Further details on the cost calculations can be found in Smith et al. (2015 and 2016a,b) and references therein.

3. Results

3.1. Negative emissions potential

Table 1 summarises the results for negative emission potential of the different NETs in Scotland, as well as other impacts in water use, energy requirement, nutrient (N, P and K) requirement, albedo and bottom-up estimates of cost.

The negative emissions potential for BECCS, implemented on the 0.52 Mha of highly suitable land, is 1.56–6.24 Mt C-eq./yr. Biochar potential, also implemented on 0.52 Mha, is 0.60–3.9 Mt C-eq./yr. The SCS could be implemented on 1.96 Mha, delivering 0.06–1.96 Mt C-eq./yr. AR implemented on 0.1 Mha would deliver the smallest NET contribution, with 0.34 Mt C-eq./yr. EW, implemented at an application rate of 10 t rock/ha/yr on prime and good quality land (0.44 Mha) and at 50 t rock/ha/yr on the remaining land (1.52 Mha) would result in 1.2–4.8 Mt C-eq./yr.

The potential of DAC for atmospheric carbon removal is promising (Keith, 2009; Lackner et al., 2012), although this technology is still at a very early stage of development, and therefore its potential is not considered directly in this work. While the associated energy costs are claimed to be high (House et al., 2011), technology efficiency and innovation in capture processes will likely reduce its cost. As an example, Climeworks currently claims operation costs of US$500-600 per ton of CO_2 captured, which makes it already competitive compared to some taxes or rival offset proposals (Bourzac, 2017). Other estimations range from as low as $30 to as high as $1000 per ton of CO_2 (Marcucci et al., 2017), giving a notion of the current uncertainty associated with this technology. For comparison of impacts, DAC was modelled with the same level of implementation as BECCS, i.e., 0.6–2.4 Mt C-eq./yr. As well as BECCS, DAC technology is constrained by (and thus might compete with BECCS for) storage potential, but several studies on storage potential suggest that there is sufficient CO_2 storage capacity for Scotland's future CCS needs (Bentham et al., 2014; SCCS, 2009). Nevertheless, there are still major uncertainties about the potential for the upscaling of DAC to meet the current mitigation targets.

3.2. Implementation costs

The modelling results allow the energetic and economic costs of implementation of the different NETs to be investigated (Fig. 2). The bottom-up costs calculated here do not account for cost reduction associated with the experience curve, nor the effect of economies of scale, but constitute a reasonable approximation to the expected costs of the different NETs.

EW is the most economically expensive technology in terms of cost per Mt CO_2 yr^{-1} abated, with an entry cost of $US 25/t CO_2 and an upper estimate of $US 1600/t CO_2 abated. These results are expressed in terms of net CO_2, including the derived emissions from the energy needed to and costs incurred in its generation. There is a great economic cost variability in EW related to the energy usage during the mineral comminution, which is reported as 39–2327 kW h tCO$_2$$^{-1}$ for basic rocks and 13–497 kW h tCO$_2$$^{-1}$ for ultrabasic rocks, assuming national transport (Renforth, 2012). This, in combination with the differences in application rates are responsible for the wide range of cost observed in EW. Upper estimates of Biochar and DAC economic costs are also high ($US 330 and $US 570/t CO_2, respectively), but Biochar has the potential for cost negative implementation (Hammond et al., 2013; Smith et al., 2016b), with a cost range of -230 to 330 $US 100/t CO_2. SCS has also potential for negative cost of implementation, with a mean cost of -35 $US/t CO_2. BECCS and AR have relatively low costs, and lie within the order of magnitude estimated in the AVOID programme (McGlashan et al., 2010) (i.e., in the order of magnitude of $US 100/t CO_2). Note that BECCS cost is a predicted one, since the industry does not yet exist at the size scale.

Table 1

Summary of the NETs potential modelled, including areas, negative emission potentials, water, energy and nutrient (N, P and K) requirements, albedo, and bottom-up estimates of economic cost in Scotland. EW may supply nutrients such as P and can have variable impacts on albedo depending on the mineral used, though these effects are not quantified. See text for further details. *DAC potential is not constrained by area, so impacts are assessed at same level of implementation as BECCS (i.e. 0.6–2.4 MtCeq/yr). ** EW – high rate of application (50 t rock/ha/yr) applied only to non-Grade 1–3 land = 1.44 Mha; low rate of application (10 t rock/ha/yr) applied to available Grade 1–3 land = 0.52 Mha. High and low rock application rates from Taylor et al. (2015).

| Technology	Area applied	Negative Emission Potential		Water use		Energy required		Nitrogen		Phosphorus		Potassium		Albedo		Cost	
	Mha	Low Mt C-eq./yr	High Mt C-eq./yr	Low km3/yr	High km3/yr	Low PJ/yr	High PJ/yr	Low ktN/yr	High ktN/yr	Low ktP/yr	High ktP/yr	Low ktK/yr	High ktK/yr	Low unitless	High unitless	Low B$US/yr	High B$US/yr
BECCS	0.2	0.6	2.4	1.20	6.00	−23.16	20.88	6.6	48	0.48	48	3.42	52.8	0	0.04	0.08	0.32
AR	0.1	0.34	0.34	0.40	0.80	0	0	0.68	1.7	1.36	1.7	0.136	1.0608	0.002	0.62	0.02	0.04
SCS	1.96	0.0588	1.96	0.00	0.00	0	0	4.704	156.8	1.176	39.2	0.882	29.4	0	0	−0.01	0.08
Biochar	0.2	0.23	1.5	0.00	0.00	−11.5	−30	6.9	45	2.3	15	16.1	105	0.08	0.12	−0.19	1.80
DAC	0.6*	2.4*		0.04	0.26	1.56	109.92	0	0	0	0	0	0	0	0	0.96	4.99
EW	0.2/1.76**	1.4	2.2	0.00	0.00	4.3	100.8	0	0	0	0	0	0	0	0	0.13	12.84
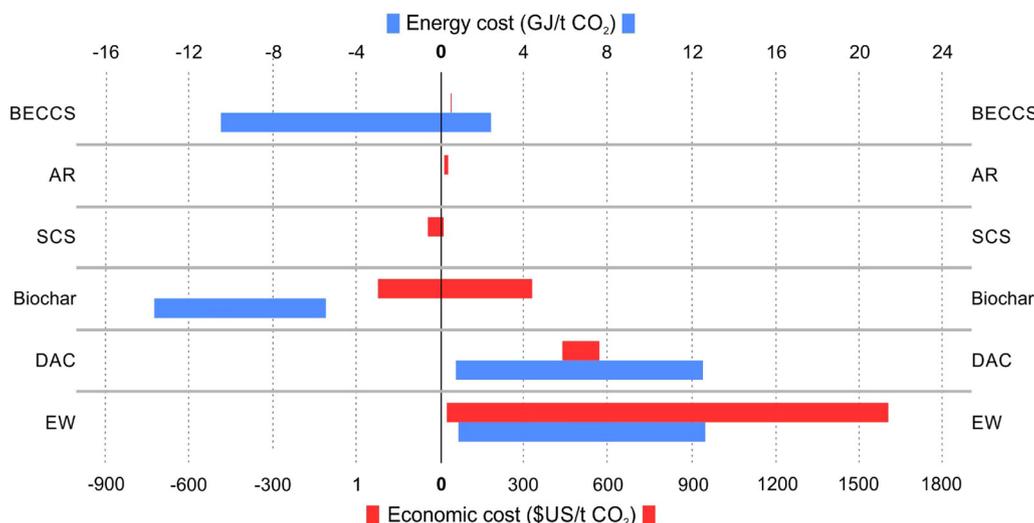
Fig. 2. Estimates of energy (in GJ t CO_2^{-1}, in blue) and economic cost (in \$US t CO_2^{-1}, in red) of the implementation of the different NETs in Scotland.

In terms of energy costs, DAC and EW have significant energy requirements, in the range of 1–13 GJ/t CO_2 abated. The energy impact of SCS and AR is negligible. BECCS has a high potential for negative energy cost and the greatest energy range (-10.5 to +2 GJ/t CO_2). Biochar can produce energy during its production by pyrolysis, making its energy cost entirely negative (-14 to −5 GJ/t CO_2). It can also be combined with BECCS, where BECCS produces energy and captures the CO_2 while biochar is formed in the process when run at low temperatures (Woolf et al., 2010).

4. Discussion and conclusions

4.1. Total potential

The negative emissions potential of the studied NETs in Scotland range from 0.06 Mt C-eq./yr (low estimate for SCS) to 6.23 Mt C-eq./yr (high estimate for EW) (Fig. 3). AR presents the smallest increment between low and high estimate, only 0.3 Mt C-eq./yr, whereas BECCS (and potentially DAC) has the greatest increment, 4.68 Mt C-eq./yr.

BECCS, AR and biochar use the same land and biomass resource, making them incompatible in terms of combined implementation. The maximum negative emission potential is reached by the implementation of BECCS, SCS and EW, with a possible combined abatement capacity of 8.3–36.8 Mt CO_2. Total CO_2 emissions in 2014 in Scotland

Fig. 3. Negative emission potential (in Mt CO_2^{-1} yr^{-1}) of the different NETs in Scotland. The green bar is the combined negative emission potential of BECCS, SCS and EW. The dashed line is total CO_2 emissions in Scotland in 2014 (41.89 Mt CO_2^{-1}).

were 41.89 Mt CO_2 (or 11.42 Mt C-eq./yr). Thus, the maximum combined potential of BECCS, SCS and EW could remove up to 89.8% of the annual emissions of Scotland. If a small contribution from DAC is added (less than half of its assumed), the combined potential of NETs could abate over 100% of the annual CO_2 emissions, making Scotland a carbon-neutral country in territorial emissions (i.e. not including embedded emissions in imported goods or services). The high potential of NETs in Scotland contrasts with that calculated for the UK, where the NETs potential ranges from 7.6 to 32.1% of the total annual emissions (Smith et al., 2016b). Scottish potential is enabled by the relatively low emissions and large land area for implementation of NETs. Together with its NETs potential, Scotland has the lowest CO_2 territorial emission per capita of the UK's home nations (England, Wales, Scotland and Northern Ireland), with 5.7 t of CO_2 in the UK vs 7.7 t of CO_2 in the UK excluding Scotland (Department of Energy and Climate Change, 2016) and a lower emission per capita than the EU as a whole (8.73 t of CO_2 per capita in the EU, Eurostat, 2017). This, in combination with the remarkable potential for renewable energy (e.g. Alldritt and Hopwood, 2010; Anandarajah and McDowall, 2012; Neill et al., 2017) suggest that Scotland could, therefore, lead transformation toward a carbon-neutral Europe.

Projections of the potential for negative emissions from imported and exported resources are not included in this work. Scotland is a net energy exporter, exporting energy to the rest of the UK and other nations, mainly as a result of its hydrocarbon resources (Scottish Government, 2014). Heat accounts for more than half of Scotland's energy use (Scottish Government, 2017) and the Scottish Government aims to achieve a target of 11% of Scotland's heat energy from renewable sources by 2020 (Scottish Government, 2011). In 2015, biomass (primary combustion and combined heat and power) accounted for 86% of the total renewable heat capacity (Flynn, 2016), and this proportion is expected to increase to meet the Government's renewable heat commitment. Whether Scotland becomes a net renewable energy importer or exporter in the future, and depending on the resulting energy/emissions balance, the negative emissions potential of Scotland might change accordingly.

Scotland's current emission reduction targets under the Climate Change (Scotland) Act of 2009 (Scottish Parliament, 2009) are aimed for an 80% reduction by 2050, but these targets are being revised in 2018 and are very likely to increase to a 90% reduction, or even net zero emissions by 2050. Given that some sources of greenhouse gases are difficult to abate (e.g. aviation fuels and agriculture), some negative emissions will be necessary to meet these targets. This will provide impetus for Scotland to create a policy environment in which some
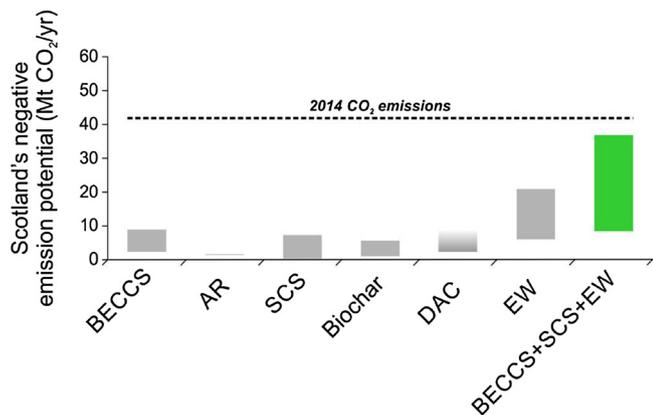
NETs can be implemented. This study outlines the potentials of each available and impacts of each NET, so that the Scottish Government and civil society can consider the pros and cons of each technology.

4.2. Individual NETs considerations

Global-scale NETs analyses have identified a number of technical issues concerning the NETs modelled in this work that may limit or expand their negative emission potential (Smith et al., 2015). The negative emission potentials calculated in this work must therefore be taken with care, as there are still important uncertainties related to the different NETs that can limit their implementation. Here, we detail some of these issues, further assessments should be undertaken to evaluate their specific impacts.

BECCS and AR would compete for land, water, nutrients and potentially albedo impacts. The capacity of AR is limited by the current Government's woodland strategy (i.e., 0.1 Mha in 10 yrs), but this figure could easily be stretched with relatively minimal effort, and the Government has committed to revise (and probably increase) it in the future (WEAG, 2012). The carbon abatement capacity of AR is only limited to 40 years, and thus BECCS will be required to permanently store the associated biomass. The selection of species used in the AR processes can also produce changes in albedo, modifying the net climate forcing impact of woodland in Scotland, but choosing smart trees (e.g. broadleaf deciduous trees) could circumvent that problem.

The deployment of BECCS will be greatly dependent on technological development, land availability, economic scope and implementation of dedicated policies (Creutzig et al., 2015), and the necessary equilibrium between energy bioenergy, food supply and environmental impact is still debated (Haberl et al., 2013). Most techno-economic assessments involve using BECCS to reach atmospheric CO_2 targets (Fuss et al., 2014; IPCC, 2014), but the cost and technical design of the CCS portion of BECCS is slowing down the implementation of this technology globally (Herzog, 2011). Studies suggest that adopting an appropriate infrastructure strategy (for example with the use of shared transport and storage; Brownsort et al., 2016; Stewart et al., 2014) can greatly reduce costs. In addition, large scale Utilisation by CO_2-Enhanced Oil Recovery (EOR) activities (Stewart and Haszeldine, 2015) can likely store CO_2 securely for millennia (Alcalde et al., 2018), and can also create income to reduce costs that would encourage stakeholders to implement CCS, through an element of EOR. However, the effectiveness of implementing CCS in combination with CO_2-EOR depends on various factors that add caveats to its negative emission potential, such as the source of the injected CO_2, the amount of CO_2 produced in the combustion of the produced oil, the scale of implementation, and the continuation of storage after the cessation of EOR activities (e.g. Armstrong and Styring, 2015; Bennett et al., 2014; Ettehadtavakkol et al., 2014; Hornafius and Hornafius, 2015). Nevertheless, Scotland has a CO_2 storage capacity beyond its needs in both active and abandoned hydrocarbon reservoirs, and significant hydrocarbon-legacy infrastructure that could help open the door to a new economic market based on export of the UK's CO_2 storage capacity.

SCS and biochar provide negative emission potential at negative or low energy and economic cost. However, the sink potential of SCS is time limited, since the potential reaches zero when the soil approaches a saturation equilibrium (Smith, 2012), usually around 20 years (IPCC, 2006). Biochar is also time-dependent, but the time scale for equilibrium is greater ($\sim$100 yrs), making it a more stable and secure mitigation option.

DAC and EW have high economic, water, and energy costs, but their negative emission potential is also high. DAC's negative emission upper limit is still unknown, and further studies should be undertaken to quantify it. The world's first commercial plant opened in Switzerland in 2017 and the developers claim that DAC could capture up to 1% of global emissions at a current price of $600/ t CO_2 (Bourzac, 2017; Marshall, 2017), but other studies suggest that it will be difficult to overcome the high costs (in the order of $US 1000 per Mt of CO_2 abated, according to (House et al., 2011).

EW, on the other hand, is relatively better known than DAC, but also costly. Scotland has a high potential for EW, but application rates make the process of implementing EW expensive (Taylor et al., 2015). Another option for EW could involve spreading EW material in tidal areas. Beaches occupy around 8% of the coastal length in Scotland (depending on tidal phase) (Rennie, 2005), occupying around 0.05 Mha (Angus et al., 2011) (Fig. 1d). Studies suggest that waves can accelerate the dissolution of EW material in tidal areas by maintaining fresh reactive surfaces of the minerals (Hangx and Spiers, 2009; Hartmann et al., 2013). The small area occupied by beaches might not have a strong impact on the EW potential compared to EW in agricultural land, but if the dissolution velocity is high enough, beaches could be regularly spread with suitable minerals increasing abatement impact. However, this option would likely create a negative social response, so its application onto beaches in Scotland could be very limited and would require extensive debate. It would be potentially much more viable to emplace olivine into offshore rapid currents on the marine shelf (Renforth et al., 2015), but there are still important challenges to be investigated before this technology is ready for implementation (Montserrat et al., 2017). This all needs fuller consideration by offshore marine dumping treaties, and the runoff effects on trace and major elements in the ocean geochemical chains.

All of the NETs relying on biological sequestration will be subject to sink saturation, i.e. the net removal of greenhouse gases from the atmosphere will decline to zero over time (20–100 years) as trees reach maturity and as a new equilibrium is approached for soil carbon. All biological sinks are also reversible, and all of the carbon sequestered can be lost if management is reversed. The longer-term potentials of AR and SCS are therefore time limited – so annual potentials can only be sustained for 20–100 years.

Finally, there are important limitations regarding the social acceptability of NETs (Buck, 2016). Studies regarding social perception of NETs confirm that the public are broadly supportive of efforts to reduce greenhouse gas emissions but are mostly unaware of the different potential technologies and their characteristics. This behaviour has been documented for CCS (Howell et al., 2014; Shackley et al., 2004) and for EW (Pidgeon and Spence, 2017), but it is probably extensive to other technologies. Public perception is seen as a major barrier to the development of NETs and analogue technologies (Buck, 2016). Thus, outreach efforts should be made to transfer the knowledge on NETs to the civic society, which can in turn improve their understanding of these technologies, and potentially increase their social and political acceptability.

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