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The potential for implementation of Negative Emission Technologies in Scotland

Juan Alcalde[a,b,c,*], Pete Smith[b,d], R. Stuart Haszeldine[e], Clare E. Bond[a,b]

[a] *Department of Geology and Petroleum Geology, University of Aberdeen, Aberdeen, UK*
[b] *ClimateXChange, Edinburgh, UK*
[c] *Barcelona-CSI, Institute of Marine Sciences - CSIC, Barcelona, Spain*
[d] *Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen, UK*
[e] *School of Geosciences, University of Edinburgh, Edinburgh, UK*

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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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[*] Corresponding author at: Department of Geology and Petroleum Geology, University of Aberdeen, Meston Building, King's College, Aberdeen, AB24 3FX, UK.
E-mail address: juan.alcalde@abdn.ac.uk (J. Alcalde).

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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 to 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.

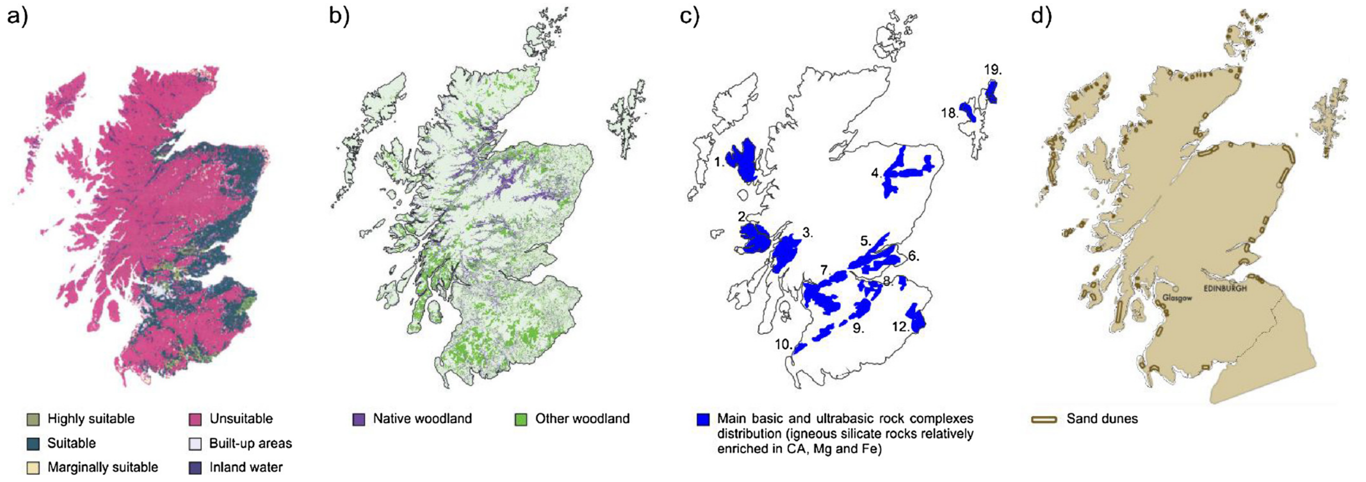

Fig. 1. Geographical distribution of the different elements used in the negative emission assessments. a) Short rotation coppice suitability map, from Andersen et al. (2005), used to determine available land for BECCS, SCS, Biochar and EW; b) current woodland areas in Scotland, from WEAG (2012); c) main 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).