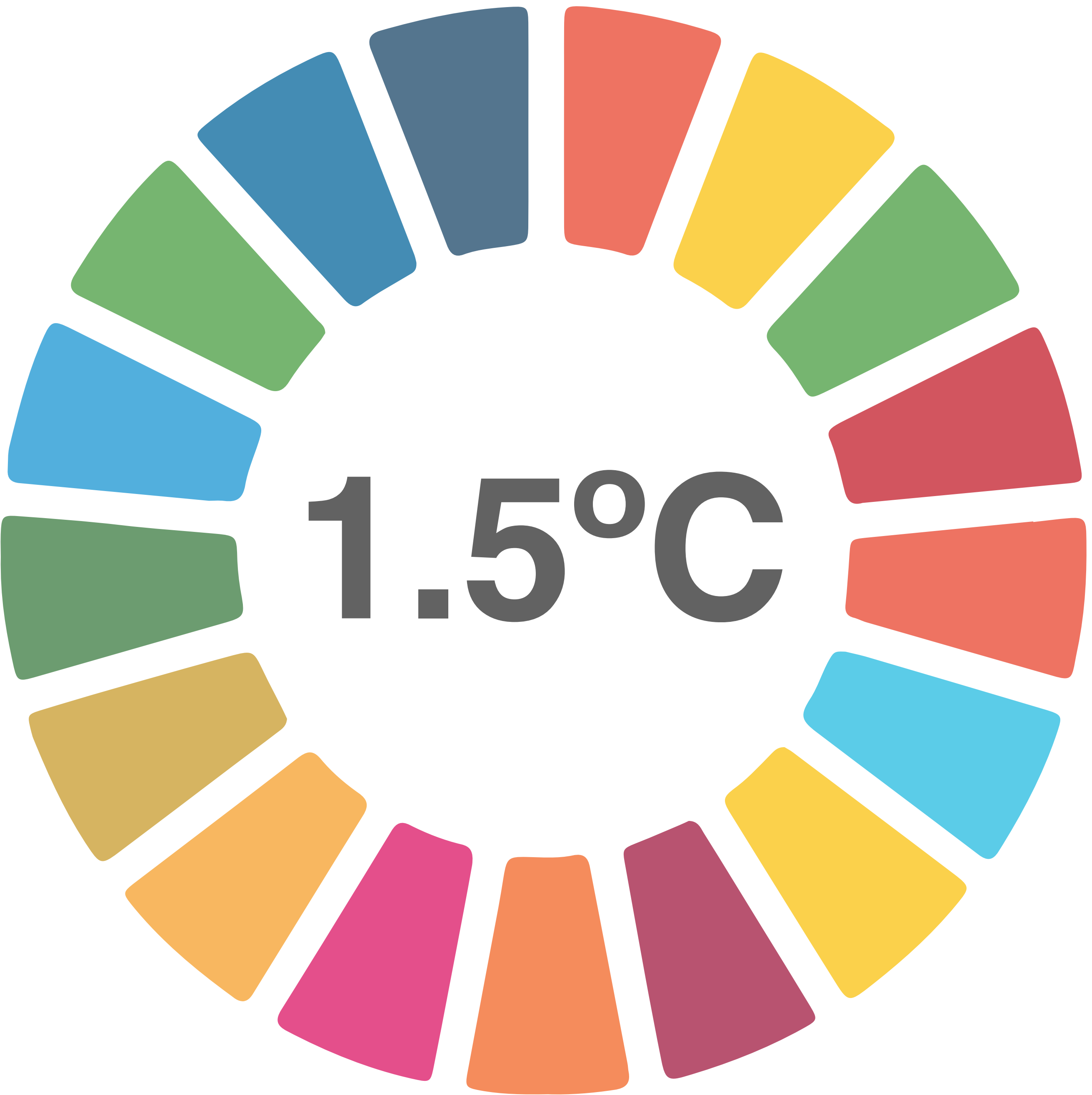
A COMPENDIUM OF SOLUTIONS FOR ACHIEVING THE SUSTAINABLE DEVELOPMENT GOALS **AND** STAYING BELOW 2°C OR 1.5°C

FOCUSING ON:

AGRICULTURE, FORESTRY AND OTHER LAND USE

BUILT ENVIRONMENT

CARBON DIOXIDE REMOVAL



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Track 0, 40 Bermondsey Street, London SE1 3UD, UK

track0.org
@ontrack0

FOREWORD

If implemented as intended, the Paris Agreement that has already entered into force, means nothing less than the only way to both protect the most vulnerable and support the healthy growth of the global economy. We need all hands-on deck to make that happen within half of one human life. It needs innovative and equitable solutions by modern entrepreneurs, forward looking investors, responsible politicians, engaged individuals, and a strong civil society. Globally, in rich and poor countries alike. And in all sectors of the economy and society. There is simply no space or time anymore to allow for some to wait while others are walking ahead.

In parallel, the agreed Sustainable Development Goals (SDGs) by the United Nations pose the challenge beyond climate change into the broader frame for decent livelihood, a safe environment, clear and clean water and energy for all while protecting nature and eradicating poverty. No one should be left behind.

I enthusiastically congratulate Track 0 and CAN for publishing this research paper. It demonstrates a selection of tangible, proven, ambitious solutions in key areas, crosscutting the objectives of the SDG and the Paris treaty. We need more of these exercises, exhibiting practices that work and that can be implemented with multiple advantages, therefore providing many more benefits to society than a narrow cost assessment will reveal. Solutions that work in villages and urban areas, contribute to food security, forest protection and climate change mitigation at the same time.

Science determines that meeting the Paris climate objectives requires the phase out of all fossil fuels by mid-century: a decarbonisation of the energy and industrial sector. Given the global carbon emissions budgets, a move to 100% renewables in the energy sector is the only permissible path. However, a full decarbonisation of these sectors alone is not sufficient to meet the survival targets for poor and fragile communities and ecosystems of 1.5-degree C. About one quarter of global GHG emissions occur in land use, forestry and agriculture. In addition, there is a growing debate on supply-side solutions mainly in the power, industry and transport sector, and to a lesser extent in the build environment and energy efficiency.

The authors have purposely not included solutions from the wider energy supply sector but focused on those two areas, land use and built environment, that arguably receive much less attention in the debate but whose solution potential is enormous, as well as a critical review on some `negative emissions` (Carbon Dioxide Removal) technologies.

In addition, consumption patterns and behavioural changes are two issues very often neglected and are difficult to legislate, but hold great potential. For instance, the authors assess that significantly reducing global food waste, comprising up to half of all harvested food in some rich countries, will reduce about 8% of global GHG emissions while potentially reducing the plight of those almost 1 billion people that still go hungry to bed every day. Furthermore, changing diets to non-ruminant meat and primarily plant-based nutrition is not only healthier and prevents many diseases, it will also free more agricultural land for food security while significantly reducing deforestation – and avoiding up to 14% global GHG emissions.

It would be impossible to meet the Paris climate objective if buildings did not reduce energy consumption significantly, as today those emissions represent one third of all energy emissions. The authors show that energy conservation practices and technologies, from LED lighting to insulation, are growing speedily from Germany to China to effectively reduce energy consumption by 90% and more, both in retrofit and new buildings, private homes and offices alike. If implemented globally, CO2 pollution would be reduced by almost 30%.

Yes, we need to tell the world the story of the threat and the danger of climate change – but more so we need to highlight the growing number of readily-available solutions to avoid a havoc of human civilization. Solutions, that meet a cascade of sustainable development requirements. The good news is these solutions are all available. Policymakers around the globe just need to pick them from the shelf, incentivise and legislate them.

Christiana Figueres
UNFCCC Executive Secretary 2010-2016

ABOUT TRACK 0

Track 0 is an independent not-for-profit based in London providing policy-relevant climate research, and advisory services relating to the long term goal of phasing out greenhouse gas emissions.

Track 0's mission is to translate the globally agreed 2ºC/1.5ºC limit on temperature rise set out in the 2015 Paris Agreement into transformative solutions implementable by everyone. Phasing out emissions to zero is feasible and supported by the science. This goal is recognised in the Paris Agreement, which mandates that everyone work together to decarbonise the global economy by aiming to reach a global peaking of emissions as soon as possible so as to achieve a balance in global emissions in the second half of this century. Scientists say we need to reach net zero emissions by around 2050 for a high chance of limiting temperature rise to below 2ºC/1.5ºC. This means bringing the biggest sources of emissions from fossil fuel combustion and industry down to zero as quickly as possible, starting today. But other sectors and gases have an important role to play.

Track 0 supports countries, companies, cities and individuals that are making a commitment to get to zero emissions on timeframes aligned with science and which contribute to the Sustainable Development Goals.

ACKNOWLEDGEMENTS

This Report contributes to the implementation of the Paris Agreement and the Sustainable Development Goals (SDGs) by examining a wide range of solutions that contribute positively to both. It was written to bridge the literature on the SDGs and climate change policies because too much of this literature remains in single-issue silos. The SDGs literature relating to climate change can be too abstract and unrelated to the key issues and policy debates relating to the Paris Agreement. Our Report aims to rectify these gaps by presenting a wide range of solutions that can help achieve multiple goals. It includes case studies showing how the solutions can contribute to specific SDGs and to pathways that keep global temperatures below 2ºC/1.5ºC and, where possible, we have tried to provide estimates of greenhouse gas (GHG) reduction potential alongside each solution along with a summary of its key features.

We are conscious this Report is a work in progress containing research and analysis others can take forward to refine the discussion and implementation of climate protection and SDG compatible solutions. We believe it provides a useful snapshot of the solutions we have been able to find based on the time and resources available to us. We acknowledge that all below 2ºC/1.5ºC scenarios require rapid decarbonisation of the energy sector and there are a growing number of studies and reports setting out how this can be achieved. We have focused on two key sectors that are, in our view, currently relatively under represented in policy literature - agriculture, forestry and other land use (AFOLU), and the built environment. We have also looked at a number of carbon dioxide removal strategies put forward as solutions, including bioenergy with carbon capture and storage (BECCS) to enable a better understanding of their role and fit with the SDGs.

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EXECUTIVE SUMMARY

There is widespread agreement that the Sustainable Development Goals (SDGs) adopted by the UN in its 2030 Agenda for Sustainable Development cannot be achieved without action to implement the 2015 Paris Agreement.

But not all climate policies contribute equally to achievement of the SDGs. There is insufficient understanding in the climate policy community of how climate and development policies can be integrated to deliver multiple benefits and vice versa.

This Report contributes to the implementation of the Paris Agreement and the SDGs by examining a wide range of solutions that contribute positively to both climate protection and the SDGs. It was written to bridge the literature on the SDGs and climate change policies because too much of this literature remains in single-issue silos. The SDGs' policy literature relating to climate change can be too abstract and unrelated to the key issues and policy debates relating to the implementation of the Paris Agreement. Our Report aims to rectify these knowledge gaps by presenting a wide range of technologies and policy solutions that can help achieve climate goals and the SDGs.

There is already a great deal of literature, and policy agreement, that climate action and the SDGs will require a complete decarbonisation of the power sector and a switch to 100% renewable energy, in combination with access to clean energy for all. We have therefore focused our Report on two key sectors - agriculture, land use change and forestry and the built environment - which, in our view, receive less policy attention but where there are an abundance of SDG friendly solutions that can also contribute to the portfolio of solutions needed to help keep global emissions below 2°C/1.5°C. Each solution is described in our Report succinctly and generally accompanied by one or more proven case studies showing how that solution can contribute to specific SDGs and to pathways that keep global temperatures below 2°C/1.5°C. Where possible, we have tried to provide estimates of greenhouse gas (GHG) reduction potential alongside each solution along with a summary of its key features.

Our report also examines more controversial carbon dioxide removal options that have been put forward as solutions, including bioenergy with carbon capture and storage (BECCS). The majority of these options have not been tested and/or been widely implemented. Our findings suggest they may well fail to deliver at scale in making a realistic and affordable contribution to the Paris Agreement, and their contribution to the achievement of the SDGs would be rather limited or in some cases potentially negative.

The main insights and findings of this Report are:

No single sector or solution can keep the world on the 2°C/1.5°C pathway. Our Report, in keeping with other scientific assessments, underscores the urgency of action needed to implement a portfolio of solutions in all sectors.

Rapid decarbonisation of the power sector plays a central and critical role in all scenarios. Solutions in the agriculture, forestry and other land use (AFOLU) sector and the built environment sector cannot substitute for or replace the need to phase out fossil fuel emissions as rapidly as possible.

Roadmaps that spell out the scale and timing of decarbonisation at the global level are beginning to emerge but these global analyses need to be down-scaled for specific regions and countries in ways that help national policy-makers align climate policy with SDG compatible solutions.

Based on our qualitative research, we found that solutions that rank the highest in terms of climate protection and SDG-friendliness are concentrated in:
- Agroforestry
- Forest restoration and conversation of biodiversity
- Increasing energy access sustainably and use of smart grids
- Green infrastructure, building with timber and hemp-lime, and Passivhaus standards
- Retrofitting and refurbishment of building stock
- Dietary changes, including reduced meat consumption

Carbon dioxide removal options, in general, contribute far fewer opportunities for positive alignments with the SDGs with many subject to high costs and uncertainties when compared with other solutions.

Significantly avoiding food loss and waste will contribute to securing food security, crucially reduce land use GHG emissions, free land and soils for other multiple and beneficial purposes including biodiversity and therefore fully support the Sustainable Development Goals.

Figure 1: A summary of how the 28 solutions outlined in this Report contribute or potentially contribute to the SDGs

An opaque square denotes positive contribution and a faded square denotes potential positive contribution.

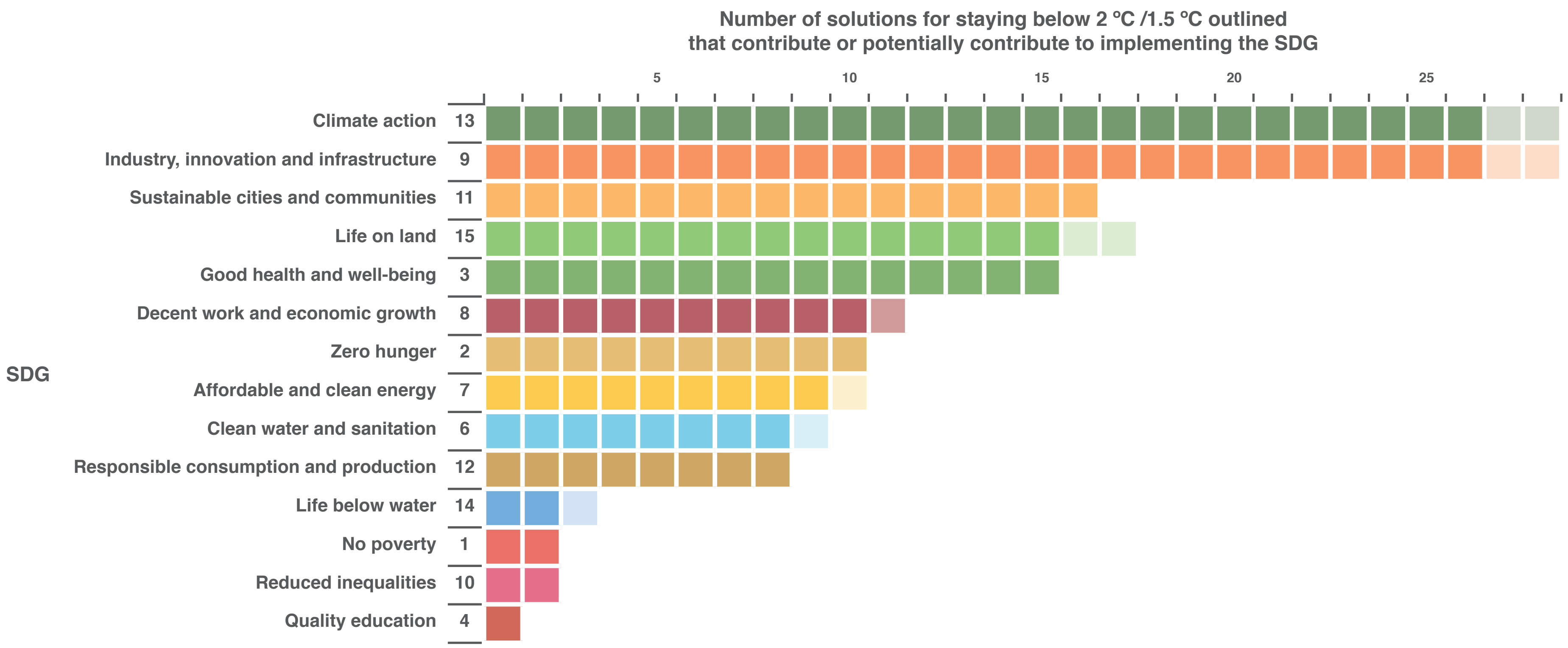


Figure 2: Solutions for staying below 2°C /1.5°C and their compatibility with the SDGs

A summary of how the 28 solutions for staying below 2°C /1.5 °C positively contribute to implementing the Sustainable Development Goals, including negative implications. The ranking of solutions is not based on the absolute size of emissions reductions but on a qualitative assessment by Track 0 of the number of SDGs impacted positively (or negatively) by that solution.

Negative implications	Solution	Positive contribution
	Considering crop wild relatives and plant breeding	2 3 8 9 11 12 13 15
	Increasing energy access sustainably	1 3 4 7 8 9 11 13
8 1	Forest conservation and restoration	1 2 6 8 9 10 13 15
	Agroforestry	2 3 6 8 9 13 15
	Reducing food loss and waste	2 6 9 11 12 13 15
	Sustainable urban planning	3 8 9 10 11 13 15
	Urban agriculture	2 3 9 11 12 13 15
11	Building with timber	3 7 9 11 12 13 15
8	Wetland conservation and restoration	2 6 8 9 13 14 15
	Green infrastructure and urban water management	3 6 9 11 13 15
	Retrofitting and refurbishment	3 7 8 9 11 13
15 13 8 6 2	Afforestation and reforestation	2 6 8 9 13 15
	Dietary changes	2 3 9 12 13 6 8 15
15 6	Biochar	2 6 9 13 15 7
	Building with hemp-lime	3 9 11 13 15
	Building with straw bales	3 9 11 12 13
	Grassland conservation and restoration	8 9 12 13 15
	Improving soil health	2 6 9 13 15
	Passivhaus	3 7 9 11 13
	Smart grids	7 8 9 11 13
	Zero energy and zero carbon building	3 7 9 11 13
13	Building with earth	3 9 11 12 13
	District heating	3 7 9 11 13
	Seagrass bed conservation and restoration	9 13 14 15
	Urban solar	7 9 11 13
15 10 6 2	Bioenergy with carbon capture and storage	7 9 13
15 14 13 9	Enhanced weathering	9 13 14 15
13 6	Direct air capture	9 13

Key to Figure 2

SDGs:

1	No poverty
2	Zero hunger
3	Good health and well-being
4	Quality education
6	Clean water and sanitation
7	Affordable and clean energy
8	Decent work and economic growth
9	Industry, innovation and infrastructure
10	Reduced inequalities
11	Sustainable cities and communities
12	Responsible consumption and production
13	Climate action
14	Life below water
15	Life on land

Categories of solutions for staying below 1.5 °C:

- Agriculture, forestry and other land use
- Built environment
- Carbon dioxide removal

Filled squares:

Coloured squares denote positive contribution to SDGs:

1 2 3 4 6 7 8 9 10 11 12 13 14 15

Coloured numbers denote potential positive contribution to SDGs:

6 7 8 9 13 14 15

Grey squares denote negative implications for SDGs:

1 2 6 8 9 10 11 13 14 15

However, it is important to be clear that our ranking (see Figure 2) of solutions is not based on the absolute size of emissions reductions but on a qualitative assessment by Track 0 of the number of SDGs impacted positively (or negatively) by that solution. We believe this is a useful lens because literature focused only at the size of the GHG reduction potential of different solutions makes climate policy mitigation-centric and insensitive to achievement of the SDGs at a time when climate policy must integrate adaptation to climate impacts and also simultaneously contribute to the achievement of the SDGs.

Having said that it is important to note that some of solutions examined in this Report are sizeable. Dietary changes, for example, could lead to dramatic reductions of between 4.3 and 7.8 $GtCO_2$-eq per year whilst promoting forest conservation and restoration could deliver a mitigation potential of between around 2.3 and 5.8 $GtCO_2$-eq per year (see Table 1). To put these figures in perspective, it is important to note that Decision 1/CP.21 adopting the Paris Agreement stated that least-cost 2°C scenarios would require global GHG emissions to be around 40 gigatonnes in 2020 whereas the aggregate emissions resulting from the Intended Nationally Determined Contributions countries have committed to at Paris lead to a projected level of 55 gigatonnes by 2030 (UNFCCC, 2015).

We hope that future researchers will use the initial findings and analysis in this Report to come up with integrated analyses ranking solutions on their contribution to SDGs combined with their GHG reduction potentials as well as the speed, cost and administrative feasibility of implementing different sets of solutions at the local, national and global scale.

Much more research is needed to help policy-makers and citizens make choices that help us all achieve a climate resilient, SDGs and Paris-compliant world.

Table 1: Summary of estimates for GHG reduction potentials relating to the 28 solutions set out in this Report

Please note: other solutions and estimates may exist but we have only included estimates found in the literature accessed by our research. Where sections are left blank in the Table 1, no estimate could be found by Track 0 as of January 2017. Whilst a comparison of the size of GHG reductions potential of different solutions would be useful for policy-makers, this has not been possible due to time constraints and the difficulty inherent in converting the diverse units of measurement used in the underlying literature.

		Solution	GHG reduction potential estimates
1	A.1	Improving soil health	Potential storage through soil carbon sequestration is estimated at around 0.7 GtC-eq per year (Smith, 2016). An often used 20-year saturation time would lead to 14 GtC soil carbon storage and an optimistic 50-year saturation time would lead to 35 GtC (IPCC, 2006; Hansen et al., 2016).
2	A.2	Dietary changes	Global transition to more plant-based diets, which are in line with standard dietary guidelines could reduce food-related GHG emissions by between 29% and 70% or 3.3 and 8.0 $GtCO_2$-eq compared with a reference case in 2050 (Springmann et al., 2016). Compared to a business as usual scenario the following GHG reduction potentials have been estimated for range of dietary changes when compared to a 'business as usual' scenario (Stehfest et al., 2009; Smith et al., 2013): **Diet** — **GHG reduction potential ($GtCO_2$-eq per year)** Healthy (as defined by Harvard Medical School) — 4.3 No ruminant meat — 5.8 No meat — 6.4 Purely plant-based — 7.8
3	A.3	Reducing food loss and waste	Global GHG emissions relating to food loss and waste, including associated land use change, are estimated at around 4.4 $GtCO_2$-eq per year (FAO, 2015a).
4	A.4	Crop wild relatives and local plant breeding programmes	None found
5	A.5	Urban agriculture	None found
6	A.6	Agroforestry	Carbon sequestration of between 12 and 228 Mg per ha, with 95 Mg per ha as a median, which could equate to storage of between 1.1 and 2.2 PgC over the next 50 years given the global area suitable for the practice (Albrecht and Kandji, 2003).
7	A.7	Forest conservation and restoration	It has been estimated that the total elimination of deforestation by 2030 could deliver a mitigation potential of between around 2.3 and 5.8 $GtCO_2$-eq per year (Smith et al., 2013). It has been estimated that afforestation, reduction in deforestation and forest management could have a mitigation potential of between 1.9 and 5.5 $GtCO_2$-eq per year in 2040 (FAO, 2016a).
8	A.8	Grassland conservation and restoration	Global rehabilitation of overgrazed grasslands has been estimated to potentially sequester around 45 TgC per year, largely through cessation of overgrazing and implementation of a moderate level of grazing (Conant and Paustian, 2002). Various improvements to grasslands have been estimated to sequester between 0.11 and 3.04 MgC per ha per year, with a mean of 0.54 MgC per ha per year (Conant, Paustian and Elliott, 2001).
9	A.9	Wetland conservation and restoration	Peatlands cover just 3% of the Earth's surface, but store 30% of all soil carbon (The Global Peatland Initiative, 2002). Drained peatlands are responsible for around 5% of global anthropogenic CO_2 emissions (Joosten, 2015). Over the past 800 years or so mangroves have been estimated to sequester around 1.5 tonnes of carbon per hectare annually (Eong, 1993). It is estimated that mangrove deforestation generates emissions of between 0.02 and 0.12 PgC per year (Donato et al., 2011). Mangroves in the tropics have been calculated to contain on average 1,023 MgC per hectare (Donato et al., 2011). Restoration of salt marshes is thought to be one of the most successful ways to capture carbon (Trulio, 2007), estimated at around 55 times faster than tropical rainforests (Macreadie et al., 2013).
10	A.10	Seagrass meadow conservation and restoration	Global carbon burial estimated at between 48 and 112 TgC per year (Kennedy et al., 2010). If restoration does not occur and seagrass meadows continue to be destroyed they are likely to become a significant source of carbon (Greiner et al., 2013), representing a CO_2 emission potential of between 131-523 $MgCO_2$ per ha (Pendleton et al., 2012).
11	B.1	Retrofitting and refurbishment	A 2°C/1.5°C pathway would require renovation rates leading to a 90% reduction in fuel and heat demand of 3-5% of floor space per year (Climate Action Tracker, 2016b).
12	B.2	Zero energy and zero carbon buildings	In general, the annual usage and production of energy in zero energy buildings is balanced, not taking into account energy used in construction (Hernandez and Kenny, 2010). Zero carbon buildings are highly energy efficient buildings that produce on-site, or procure, enough carbon-free renewable energy to meet building operations energy consumption annually (Architecture 2030, 2016).
13	B.3	Passivhaus	Passivhaus design allows for energy savings related to space heating and cooling of up to 90% compared to typical building stock and over 75% compared to average new builds (Passive House Institute, 2015c).
14	B.4	Green infrastructure and urban water management	None found
15	B.5	Sustainable urban planning	None found
16	B.6	Building with earth	None found
17	B.7	Building with timber	None found
18	B.8	Building with hemp-lime	None found
19	B.9	Building with straw bales	None found
20	B.10	Increasing energy access sustainably	None found
21	B.11	Smart grids	None found
22	B.12	District heating	None found
23	B.13	Urban solar	None found
24	C.1	Afforestation and reforestation	Estimated removal of between 1.1 (mean) and 3.3 (maximum) GtC-eq per year in 2100 (Smith et al. 2015). It has been estimated that afforestation, reduction in deforestation and forest management could have a mitigation potential of between 1.9 and 5.5 $GtCO_2$-eq per year in 2040 (FAO, 2016a).
25	C.2	Bioenergy with carbon capture and storage (BECCS)	Estimated removal of 3.3 GtC-eq per year in 2100 (Smith et al. 2015).
26	C.3	Biochar	Using biochar to improve soil fertility has been estimated to provide the potential carbon storage of between 0.7 and 1.8 GtC-eq per year (Woolf et al., 2010; Smith, 2016). The potential carbon storage relating to intensive, industrial-scale biochar carbon storage is not currently known (Hansen et al., 2016).
27	C.4	Direct air capture (DAC)	Estimated removal of 3.3 GtC-eq per year in 2100 (Smith et al. 2015).
28	C.5	Enhanced weathering	Estimated removal of between 0.2 (mean) and 1.0 (maximum) GtC-eq per year in 2100 (Smith et al. 2015).

INTRODUCTION

The Paris Agreement commits Parties to limit global temperature rise above preindustrial levels to “well below 2ºC… and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change” (UNFCCC, 2015). The benefits and opportunities of staying below the 2°C/1.5°C limits have been documented in a number of post-Paris research papers (McKinnon, Schaeffer and Rocha, 2016).

In order to achieve this temperature goal, Paris also sets out a long-term emissions reduction goal, which commits Parties to aim for net zero greenhouse gas (GHG) emissions in the second half of the century (UNFCCC, 2015). For a high chance of keeping to Paris, the net zero trajectory implies CO2 emissions be phased out first and well before 2050 (Hare et al., 2016). Directed by the Paris Agreement, the IPCC is to provide a special report in 2018 on “the impacts of global warming of 1.5ºC above pre-industrial levels and related global GHG emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty” (UNFCCC, 2015; IPCC, 2017).

This Report aims to provide an enhanced understanding of a wide range of possible technologies and strategies that can help keep the world on the below 2°C/1.5°C pathway mandated by the Paris Agreement. The core focus of the Report is to highlight solutions that maximise compatibility with pathways needed to stay below 2°C/1.5°C goal and help achieve as many of the Sustainable Development Goals (SDGs) as possible.

The Report examines both positive and negative aspects of various solutions and provides case studies to illustrate practicability and highlight success stories. The research has drawn from various scientific assessments of the Paris Agreement below 2°C/1.5°C target that have been developed since the IPCC Fifth Assessment Report (IPCC, 2014), and from other peer reviewed sources relevant to each of the topics covered.

The three main kinds of solutions examined in the Report are grouped under three categories:
- Agriculture, forestry and other land use (AFOLU)
- Built environment
- Carbon dioxide removal (CDR)

Decarbonisation of the power sector is a vital aspect of staying on the below 2°C/ 1.5°C trajectory but in our view has been relatively well covered in the literature so in our Report we focus on specific solutions in the power sector that are directly related to the built environment. This is an important reorientation of focus because by 2050, 66% of the world’s population is expected to be living in urban areas (UN DESA, Population Division, 2015). Energy use in buildings and for building construction represents more than one-third of global final energy consumption and contributes to nearly one-quarter of GHGs emissions worldwide (GABC, 2016; IEA, 2016). Getting climate and SDGs friendly solutions adopted in this sector is critical given the long lifespan of buildings and infrastructure.

AFOLU was also selected as a sector where a large number of solutions exist, which could together represent part of the steps that could be rapidly implemented to achieve the SDGs and also help the world stay below 2°C/1.5°C.

The role that CDR technologies will play in emission reduction scenarios is being increasingly analysed with some controversial claims that these kinds of interventions will help us stay on track for the below 2°C/1.5°C objective. These claims are interrogated in our Report, which includes an assessment of a range of carbon dioxide removal technologies in terms of their compatibility with the SDGs.

To put our findings and analysis in context, we include over the page a summary of recommended global strategies recently identified by Climate Action Tracker (2016a) and by the Stanley Foundation (2016) as required to limit global temperature increase to below 2°C/1.5°C (see Table 2). We concur with their findings in full but only cover a number of their recommended steps in this Report given our more focus on AFOLU, the built environment and CDR options. The Table below shows their recommended 10 steps, highlight in yellow the subset covered in this Report.

Table 2: Recommended global strategies required to limit global temperature increase to below 2°C/1.5°C

From Climate Action Tracker (2016a) and the Stanley Foundation (2016), with those covered in this Report highlighted in yellow.

The 10 most important short-term steps to limit warming to below 2°C/1.5°C outlined by Climate Action Tracker (2016a)	Policy interventions and strategies that could help drive the pursuit of a below 2°C/1.5°C trajectory outlined in the Stanley Foundation (2016) conference report
100% zero and low carbon power by 2050	Decarbonise the power sector, with the goal of doubling the share of renewable energy by 2020 from 2015
No new coal plants, reduced emissions from coal power by at least 30% by 2030	Scale up circular economy strategies
Last fossil fuel car sold before 2035	Expand the coverage of carbon pricing
Develop and agree on 1.5°C compatible visions for aviation and shipping	Transform biological land use from a carbon source to a carbon sink
All new buildings fossil-free and near zero energy by 2020	Support research and development to identify medium-and long-term solutions for challenging sectors, particularly steel, cement, aviation, and agriculture
Increase building renovation rates to 5% by 2020	Transition to a low-carbon transport sector, with the goal of eliminating manufacturing of vehicles with internal combustion engines by 2030
All new installations in emissions-intensive sectors low-carbon after 2020	Modernise existing building stock to ensure the sustainable construction of new structures
Reduce emissions from forestry and other land use to 95% below 2010 levels by 2030, stop net deforestation by the 2020s	
Establish and disseminate best practice, reduce emissions, and increase research related to commercial agriculture	
Begin research and planning on CO_2 removal	

Paris Agreement and 1.5°C

Limiting global warming to 2°C at most, with an option to review this target after scientific review so it was closer to the safer threshold of 1.5°C, was something initially agreed upon at the United Nations Climate Change Conference (UNFCCC) in Cancun, 2010 (UNFCCC, 2011). The inclusion of a reference to 1.5°C five years later in the Paris Agreement was a major success both for planetary safety and for science-based policy. The 1.5°C language was based upon progressive improvements in the science of understanding both the risks associated with climate change and the means of cutting greenhouse gas emissions (Hare, 2015). The inclusion of the 1.5°C target was largely driven by the small island countries and the 48 members of the Climate Vulnerable Forum, who made the "1.5°C to survive" goal a central part of their political strategy during the Paris Agreement negotiations.

Schleussner et al. (2016) have recently highlighted significant differences between the impacts associated with a warming of 1.5°C and those associated with 2°C. This variability includes notable risks related to heat-related extremes, water availability, sea-level rise, heavy precipitation intensity and the future of tropical coral reefs (see Figure 3). The research has shown that limiting warming to 1.5°C would, as stated in the Paris Agreement, significantly reduce the risks and impacts associated with climate change. Focus on further investigation into impacts related to 1.5°C warming and possible transformation pathways in order to limit warming and accommodate the expected changes is now necessary (Schleussner et al., 2016) and the window to achieve the 1.5°C goal is rapidly diminishing (Rogelj et al., 2015).

This report aims to highlight solutions that can keep global temperatures below 2°C/1.5°C as well as achieve the SDGs.

Figure 3: Key differences in climate impacts between a warming of 1.5°C and 2°C above pre-industrial levels

(Outlined in Schleussner *et al.* (2016) and Schleussner *et al.* (2016a))

1.5°C of warming		2.0°C of warming
Heatwaves		
Duration of up to **1.1 months**		Duration of up to **1.6 months**
Water availability		
9% reduction in availability annually (in the Mediterranean)		**17%** reduction in availability annually (in the Mediterranean)
Heavy rainfall		
5% increase in intensity		**7%** increase in intensity
Global sea-level rise		
40 cm rise by 2100 relative to 2000		**50 cm** rise by 2100 relative to 2000
Fraction of coral reef cells at risk of long-term degradation		
90% in 2050		**98%** in 2050

Sustainable Development Goals

The United Nations (UN) adopted the Sustainable Development Goals (SDGs) on 1 January 2016 as part of the commitment to the 2030 Agenda for Sustainable Development (UN, 2015). The seventeen inter-related SDGs (see Table 3) incorporate a vision of development that balances environmental, social and economic imperatives for current and future generations. We hope our Report can make a concrete contribution to how alignment of climate policies and policies to achieve the SDGs can take place in practice.

Table 3: List of the 17 Sustainable Development Goals from Transforming our world: the 2030 Agenda for Sustainable Development

(UN, 2015)

1	**No poverty** - End poverty in all its forms everywhere
2	**Zero hunger** - End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	**Good health and well being** - Ensure healthy lives and promote well-being for all at all ages
4	**Quality education** - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	**Gender equality** - Achieve gender equality and empower all women and girls
6	**Clean water and sanitation** - Ensure availability and sustainable management of water and sanitation for all
7	**Affordable and clean energy** - Ensure access to affordable, reliable, sustainable and modern energy for all
8	**Decent work and economic growth** - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	**Industry, innovation and infrastructure** - Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation
10	**Reduced inequalities** - Reduce inequality within and among countries
11	**Sustainable cities and communities** - Make cities and human settlements inclusive, safe, resilient and sustainable
12	**Responsible consumption and production** - Ensure sustainable consumption and production patterns
13	**Climate action** - Take urgent action to combat climate change and its impacts* * Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change
14	**Life below water** - Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	**Life on land** - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	**Peace, justice and strong institutions** - Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	**Partnerships for the goals** - Strengthen the means of implementation ad revitalise the Global Partnership for Sustainable Development

The SDGs are not legally binding in the same way as the Paris Agreement. Nevertheless, all countries are expected to take ownership and establish a national framework for achieving the 17 Goals and to align their development and finance strategies accordingly over the next 15 years. Whilst countries have the primary responsibility for follow-up and review with regard to the progress made in implementing the Goals and targets, it is clear that the SDGs will also guide all work by the UN system. A broad range of stakeholders - civil society, the private sector, development banks and others - are expected to contribute to the realization of the 2030 agenda.

Unlike the Millennium Development Goals, which they replaced, the SDGs elevate the requirement for environmental sustainability and taking action in relation to climate change is a goal in itself (SDG Goal 13) as well as being integrated into the detail of the majority of other goals. The Paris Agreement “aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty” (UNFCCC, 2015). Research to support alignment between climate protection and the SDGs could not be more timely and critical as countries are preparing implementation and financing frameworks for both Paris and the SDGs.

Our Report makes a concrete contribution to how in practice alignment of climate policies and policies to achieve the SDGs can take place. It does so by analysing how many of the SDGs can be impacted, positively and negatively, by a wide range of climate protection solutions and strategies. Whilst qualitative in nature, we hope our analysis will help identify suitable policy mixes at a local, national and global level.

A.

AGRICULTURE, FORESTRY AND OTHER LAND USE SOLUTIONS

The IPCC Fifth Assessment Report outlined that Agriculture, Forestry and other Land Use (AFOLU) were responsible for just under one quarter of anthropogenic GHG emissions, around 10-12 GtCO2-eq per year (IPCC, 2014). These emissions are generated largely from deforestation and agricultural emissions in relation to livestock, soil and nutrient management. Anthropogenic forest degradation, forest fires and agricultural burning also make significant contributions. Agriculture specifically is the main contributor of the greenhouse gases methane and nitrous oxide in the AFOLU sector (Carlsson-Kanyama and Gonzalez, 2009). Analysis has shown that even small changes in crop and forest varieties can make a significant difference in carbon sequestration potential (Thomson et al., 2008).

Agriculture is the main driver of changes in land use, including the clearing of forests and grasslands to create croplands, pastures and plantations (Joosten, Tapio-Biström and Tol, 2012). An analysis of countries' Nationally Determined Contributions showed that crops, livestock, fisheries and aquaculture, as well as forestry were featured in 94% of all countries' goals set out to meet national mitigation and adaptation targets (FAO, 2016).

In the following section, we explore the following solutions:

A.1 Improving soil health
A.2 Dietary changes
A.3 Reducing food loss and waste
A.4 Crop wild relatives and local plant breeding programmes
A.5 Urban agriculture
A.6 Agroforestry
A.7 Forest conservation and restoration
A.8 Grassland conservation and restoration
A.9 Wetland conservation and restoration
A.10 Seagrass meadow conservation and restoration

In doing so, we highlight the potential surrounding mitigation, carbon sequestration and opportunities relating to the SDGs.

A.1 Improving soil health

The potential for soils to mitigate greenhouse gas emissions is a very important solution that could be applied on a large scale across the world and potentially at low cost (Paustian et al., 2016). After oceans, soils are the second largest carbon store (European Environment Agency, 2016).

The potential carbon storage available through soil sequestration is estimated at around 0.7 GtC-eq per year (Smith, 2016). The soil carbon saturation point is often estimated at 20 years and a more optimistic estimate is 50 years (IPCC, 2006), which would lead to 14 GtC-eq and 35 GtC-eq respectively (Hansen et al., 2016). Soils that are not managed well can be a source of carbon dioxide release into the atmosphere (FAO, 2015b). Soil carbon loss due to land-use change between 1860 and 2010 has been estimated to be between 109 and 227 $PgCO_2$-eq (Smith et al., 2016a). Agricultural management practices that threaten soil health include current cropping practices, use of agrochemicals, current irrigation practices, current livestock management practices and agriculture in wetlands (Smith et al., 2016a).

For much of history little has mattered more to human communities than their relationship with soil because it is where most of their nutrition and energy supply originated. Some of the earliest written documents discovered have been agricultural manuals that had the intention of organising, preserving and imparting soil knowledge. Over the past two centuries, human actions have sped up rates of soil erosion and re-routed nutrient flows. Current agricultural production patterns and waste management practices strip soils of nutrients, creating an on-going challenge for efforts to maintain soil fertility (McNeill and Winiwarter, 2004).

Freibauer et al. (2004) highlight that efficient carbon sequestration in agricultural soils requires a permanent change in management practices and adaptations that take local soil and climate into account. Over one third of the world's land area is agricultural land (World Bank, 2016). This makes it an important focus in using soils as sinks, and carbon sequestration on agricultural lands could be substantial if there is widespread implementation of new management strategies (Kane, 2015).

Carbon is continuously moving through the soil food web, changing forms when it is incorporated into different organisms or converted into different compounds. Carbon in soil is classified by soil scientists into pools in relation to the length of time the carbon remains in the soil; there is the fast pool, slow pool and stable pool (Kane, 2015).

The size of the three pools varies in different soils, but generally the stable pool remains relatively constant and the size of the slow and fast pools are both sensitive to management (Kane, 2015).

As the stable pool is generally static, it is in the slow and fast pools that soil carbon is effectively increased, by increasing the net balance of carbon that enters the soil relative to what is lost. Land management practices can strongly increase the amount of carbon entering the soil by:
- decreasing the level of soil disturbance, which enhances the physical protection of soil carbon in aggregates;
- increasing the amount and quality of plant and animal inputs;
- improving the diversity and abundance of soil microbes; and
- maintaining year-round plant cover on soils (Kane, 2015).

It is also necessary to consider other GHGs in relation to soils. Methane (CH_4) and nitrous oxide (N_2O) are two potent greenhouse gases that are regularly emitted from soils (Kane, 2015). Research around these emissions is new, but some factors are known to strongly influence emissions of either gas (Kane, 2015). Practices that saturate the soil with nitrate, which are found in conventional agriculture, lead to higher N_2O emissions (Kane, 2015). CH_4 emissions are high in the production of paddy rice as the fields are generally flooded during production (Kane, 2015). One concrete way this could be lessened is if fields were drained mid-season when flooding is less necessary for production (Wassmann et al., 1993).

The recent Status of the World's Soil Resources report (FAO, 2015b) demonstrated that around 33% of soils globally are either moderately or highly degraded due to compaction, chemical pollution, erosion, acidification and salinisation of soils. This highlights the need to concentrate on the health of soils and establish how to achieve sustainable soil management practices across the world.

For an example of potential for increasing soil carbon levels see **Australia - potential for increasing soil carbon levels** in section A.1 of the Case Studies.

Spotlight on improving soil health - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Potential storage through soil carbon sequestration is estimated at around 0.7 GtC-eq per year. An often used 20-year saturation time would lead to 14 GtC-eq soil carbon storage and an optimistic 50-year saturation time would lead to 35 GtC-eq.	IPCC, 2006 Hansen et al., 2016 Smith, 2016

Spotlight on improving soil health - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER
- Increased soil carbon content improves soil structure, soil quality and soil nutrient cycling.

SDG 6 - CLEAN WATER AND SANITATION
- Increased soil carbon content leads to improvements in water holding capacity.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE
- Improving soil health on a global scale would require research, collaboration, education and communication along with continued monitoring and development of soil management practices.

SDG 13 - CLIMATE ACTION
- After oceans, soils are the second largest carbon store. Soils that are not well managed can be a source of CO2 released into the atmosphere.
- Permeable soil stores more water, which can help keep temperatures down in heatwaves.

SDG 15 - LIFE ON LAND
- Healthy soil can also help with flood regulation and prevention.
- Increased soil carbon reduces levels of soil erosion.
- Sustainable soil management would help combat desertification, mitigate effects of drought, preserve biodiversity and preserve the provision of ecosystem services.

Sources: Derner and Schuman, 2007; Kambale and Tripathi, 2010; Sethi et al., 2010; Kane, 2015; FAO, 2015b; European Environment Agency, 2016; FAO, 2016

Source: Raúl Hernández González (image cropped). Tierra fértil, escenas de la huerta.

A.2 Dietary changes

Meat consumption is a major factor in relation to methane (CH4), nitrous oxide (N2O) and carbon dioxide (CO2). The total GHG emissions from livestock supply chains is very large and has been estimated at around 7.1 GtCO2e a year (Gerber et al., 2013), which accounts for just under 15% of the global total (Wellesley, Happer and Froggatt, 2015).

For this reason, reducing the amount of meat consumed has been put forward by the IPCC in its Fifth Assessment Report (IPCC, 2014). Meat consumption as a strategy to reduce GHG emissions has also been examined by a growing number of leading think tanks post Paris, including the Heinrich Böll Foundation and Friends of the Earth Europe (Chemnitz and Becheva, 2014), Zero Carbon Britain (Blake, 2014), Chatham House (Wellesley, Happer and Froggatt, 2015), and the World Resources Institute (Ranganathan, 2016).

Reduced meat consumption would rank as a fast and very significant contribution to GHG reductions and to positively achieving the SDGs. Eating less meat would not only reduce GHG emissions, it would also lead to a significant reduction in land and water use. Beef protein specifically requires several times the amount of land and water compared to vegetable proteins, such as cereals. Globally current diets consist of around 15% meat but approximately 80% of agricultural land is dedicated to animal grazing or the production of feed and fodder for animals. (Smith et al., 2013).

Over the last century, big changes have occurred within food systems, which has led to the majority of food items being produced and distributed in complex and lengthy supply chains (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Westhoek et al., 2016). Consumers do not have easily accessible information relating to what they consume and the consequences of food production (Westhoek et al., 2016). The environmental impacts associated with food production and consumption are not often represented to consumers (Leach et al. 2016). Raising awareness could be a key aspect of encouraging and allowing for change to current food systems (Wellesley, Happer and Froggatt, 2015; de Boer, de Witt and Aiking, 2016; Westhoek et al., 2016). A better synergy between environmental and health education could be one means of raising the acceptability of dietary changes, such as a reduction in meat consumption (Carlsson-Kanyama and Gonzalez, 2009).

More research is required to fill knowledge gaps surrounding sustainable and healthy food production and consumption. Specific areas that require more research include fishing, sustainable levels of meat consumption, the impact of dairy production, the impacts of high sugar, high fat and high salt processed foods, and the broader social and economic dimensions of sustainable diets (Fischer and Garnett, 2016).

It also needs to be recognised that multinational businesses are increasingly influencing what is grown and what people eat (Ranganathan et al., 2016). Decisions made by large agri-businesses, manufacturers and retailers are having an increasing influence on the availability of different foods (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

The global convergence of dietary norms incorporating large amounts of meat threatens the capacity to achieve a number of SDGs, including those related to hunger, health, water management and terrestrial ecosystems as well as climate change (Ranganathan, 2016). For these reasons, reduced meat consumption is a significant climate and SDG friendly solution.

Livestock

Currently animal husbandry, aquaculture and fisheries have a big influence on the environment, with feed production and animal husbandry having the most significant environmental impacts (Nijdam, Rood and Westhoek, 2012). The livestock sector is a significant climate change polluter and is responsible for just under 15% of total global GHG emissions (Wellesley, Happer and Froggatt, 2015).

A global transition to lower meat consumption is already recommended for health reasons (Stehfest et al., 2016) and reducing both meat and dairy consumption is key to meeting science-based climate action targets (Hedenus and Wirsenius, 2014; Stehfest et al., 2016). A 2016 study found that the projected required agriculture in relation to meat and dairy-free diets gave GHG emissions of less than a tenth of business as usual measures and an 80% reduction in land use (Röös et al., 2016).

It is important to bear in mind cultural and social values associated with meat when discussing the idea of eating less meat. There is a great deal of scepticism around the link between meat consumption and climate change, as well as potential resistance to messaging around its significance. Due to these factors, it is important for communication to take a staged and considerate approach (Macdiarmid, Douglas and Campbell, 2016).

It is important that different forms of animal husbandry are not pooled together, but that varying practices are evaluated and compared in relation to their environmental impact. This is because different systems provide both different functions and impacts (Rivera-Ferre et al., 2016). Grazing animals should not be seen as altogether negative, different methods of management can have benefits. Integrated cropping and grazing systems can reduce soil erosion, build up nitrogen and organic carbon content and build up microbial and fungal diversity, which altogether leads to improved soil structure, increased nutrient cycling and allows for soils to be a net sink, as opposed to a net source of GHG emissions (Teague et al., 2016).

Apart from reduced meat consumption other mitigation options discussed in relation to livestock include manure management and improved feed digestibility (Herrero et al., 2016).

Overconsumption, transport and consumption patterns

There are other aspects of diets globally, apart from consumption of animal-based foods that can be considered in relation to climate mitigation and development goals. There are currently two and a half times as many overweight than undernourished people in the world and there is a global trend towards overconsumption. Targeting this would also have considerable benefits in relation to health improvements (Ranganathan, 2016).

Hadjikakou (2016) highlights the need to tackle over consumption of discretionary food and drink (food and drink not necessary to provide the nutrients the body needs) both in relation to human health and the environmental impacts of the products, especially considering that consumption of discretionary food and drink has been on the rise in recent decades. Specifically, ultra-processed food and drink is becoming increasingly popular (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

One significant barrier is that official international guidelines with recommendations surrounding the extent of processing do not exist. However, there are some good national guidelines. For example, the 2014 Brazilian Food Guide highlights that high-quality diets consist of minimal amounts of ultra-processed foods (Global Panel on Agriculture and Food Systems for Nutrition, 2016; PAHO, 2015). In this case, examples of ultra-processed foods include sweet, fatty or salty packaged snack products, ice cream, sugar-sweetened drinks, chocolates, confectionary, chips, burgers, hot dogs, poultry nuggets and fish nuggets. However, other forms of processing, such as canning and freezing vegetables, can increase food availability and help preserve foods and thus reduce food waste (PAHO, 2015).

Transportation of food makes a large and direct contribution to GHG emissions and this movement of food is often referred to as “food miles” (Vermuelen, Campbell and Ingram, 2012). Price and inconvenience are common barriers to consumers buying locally produced food (Chambers et al., 2016).

The way that people consume is also changing, with food consumption outside of domestic and community settings becoming a growing phenomenon (Goggins and Rau, 2016). The impacts of a change in place of consumption and people’s general relationship with food needs to be considered alongside what is being consumed, as all these aspects are interrelated. Brazil’s food-based dietary guidelines encourage communal eating, cooking skill sharing and making food and eating an important aspect of daily life (Fischer and Garnett, 2016). This advice highlights recognition of a shift in the place of food in people’s lives and potential for better connection with food and with people through food. Knowledge surrounding the broader social and ethical dimensions in relation to food consumption and diet is something that needs to be built upon (Fisher and Garnett, 2016).

For an example of a dietary change initiative in Germany see **Germany - German environment minister banning meat at official functions** in section A.2 of the Case Studies.

Spotlight on dietary changes - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Global transition to more plant-based diets, which are in line with standard dietary guidelines could reduce food-related GHG emissions by between 29% and 70% or 3.3 and 8.0 $GtCO_2$-eq compared with a reference case in 2050. Compared to a business as usual scenario the following GHG reduction potentials have been estimated for range of dietary changes when compared to a 'business as usual' scenario:	Stehfest et al., 2009 Smith et al., 2013 Springmann et al., 2016

Diet	GHG reduction potential ($GtCO_2$-eq per year)
Healthy (as defined by Harvard Medical School)	4.3
No ruminant meat	5.8
No meat	6.4
Purely plant-based	7.8

Source: Jeremy Keith (image cropped). Tomatoes.

Spotlight on dietary changes - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- The provision of high-quality diets for all is needed in order to address malnutrition and under nutrition.

SDG 3 - GOOD HEALTH AND WELL BEING

- A global transition to lower meat consumption is already recommended for health reasons.
- There is currently a global trend towards overconsumption.
- There is a need to tackle over consumption of discretionary food and drink.

SDG 6 - CLEAN WATER AND SANITATION

- Current water use is tied to current consumption patterns, which needs further research to be better understood.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- There are social and economic dimensions to current consumption patterns, which need further research to be better understood.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Substantial scientific research is required and called for in relation to the impacts of current consumption patterns.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION

- Current water and land use, as well as animal welfare, are tied into current consumption patterns and there is potential to reduce water and land use and consider animal welfare in relation to what we eat.

SDG 13 - CLIMATE ACTION

- Feed production and animal husbandry have significant environmental impacts.
- The livestock sector is already responsible for almost 15% of total global GHG emissions.
- Reducing both meat and dairy consumption is key to meeting science-based climate action targets.
- Transportation of food makes a large direct contribution to GHG emissions.

SDG 15 - LIFE ON LAND

- Current land use is tied to current consumption patterns, which needs further research to be better understood.

Sources: Nijdam, Rood and Westhoek, 2012; Vermuelen, Campbell and Ingram, 2012; Hedenus and Wirsenius, 2014; Wellesley, Happer and Froggatt, 2015; Fischer and Garnett, 2016; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Hadjikakou, 2016; Ranganathan, 2016; Röös et al., 2016; Stehfest et al., 2016

A.3 Reducing food loss and waste

Around 1.3 billion tonnes of food are lost or wasted globally per year (Gustavsson et al., 2011), which translates to around one in every four food calories being produced for humans to eat not being consumed (Lipinski et al., 2013). Food loss and waste, including associated land use change, is responsible for an estimated 4.4 $GtCO_2$-eq per year (FAO, 2015a).

Food loss is food that spills, spoils, bruises, wilts or is otherwise lost before reaching the consumer. It is the unintended result of an agricultural process or a technical limitation in relation to transport, storage, packaging or distribution (Lipinski et al., 2013).

Food waste is food that is of good quality and fit for human consumption but that is eventually discarded instead (Lipinski et al., 2013).

We conclude that redirecting food waste should be a major component of strategies to stay below 2°C/1.5°C. The reduction of food loss and waste requires changes throughout the entire food system and within practices, technology, behaviour and policy (Lipinski et al., 2013), and these changes would also benefit the achievement of several SDGs.

Causes of the current extent of food waste

Loss and waste of food happens throughout food supply chains, which extend from agricultural production through to consumption. In low-income countries, the main causes of food loss and waste include: technical limitations in harvesting; having to store and cool food in difficult climatic conditions; and availability of infrastructure to transport food. This means food is mostly lost in the early and middle stages of the supply chain. In contrast, in medium- and high-income countries a significant wastage occurs at the processing, distribution and consumption stages, which largely relates to lack of coordination between sections of the supply chain, as well as consumer behaviour. Studies have revealed that there are significant data gaps surrounding understanding of the extent of and reasons behind food loss and waste. Further research is urgently required to build knowledge and help establish pathways away from the levels of food loss and waste that exist today. One aspect that needs to be assessed is the impact of growing international trade on food losses. (FAO, 2015a; Gustavsson et al., 2016)

Food waste legislation

The issue of food waste has begun to be targeted by new legislation. In France in 2015 a law was passed that requires supermarkets to prioritise the re-distribution of food destined to become waste and to deal with any waste more responsibly (Schiller, 2015; Chrisafis, 2016). In Italy in 2016 a law was adopted that means businesses only need to record donations once a month, don't risk penalty for giving away food that is passed its sell-by date and will pay less waste tax if they re-direct food away from waste streams (BBC News, 2016). In the UK an inquiry was launched in July 2016 into food waste in England, which includes looking into redistribution, how voluntary initiatives contribute and if there is a need for legislation (UK Parliament, 2016). More detail of these examples can be found in section A.3 of the Case Studies.

Food waste initiatives

Community initiatives are increasingly focusing on tackling the problem of food waste. These include food waste supermarkets, food waste cafés, a mobile phone app advertising left over food and community fridges. Examples of these can be found in section A.3 of the Case Studies.

Local food storage in silos

In order to meet food security demands, varieties of plants have been developed through breeding programmes that produce high yields and that are resistant to pests, diseases and abiotic stresses (Bediako, Nkegbe and Iddrisu, 2004). Many of these new varieties have poorer storage characteristics than traditional crops and traditional storage practices were developed in the context of local environments, climate and social conditions and in relation to the specific characteristics of varieties grown (Rhoades et al., 1991; Bediako, Nkegbe and Iddrisu, 2004). Traditional storage techniques have sometimes become inadequate due to an increase in volume of production and change in the storage needs of varieties grown (Bediako, Nkegbe and Iddrisu, 2004).

Post-harvest storage improvements need to be appropriate, accessible and affordable to smallholder farmers, so that they can help increase food availability and reduce waste through spoilage (Bediako, Nkegbe and Iddrisu, 2004).

Existing initiatives surrounding food loss and waste including food waste legislation, community based projects and extending the use of local food storage silos can be found in section A.3 of Appendix X. See the full list of case studies below:

- **France - food waste law**
- **Italy - food waste law**
- **UK - food waste inquiry**
- **International - the Real Junk Food Project**
- **Denmark - selling and using food waste**
- **International - food waste app, Too Good To Go**
- **Spain - community fridges**
- **Ghana - mud silos**
- **Afghanistan and Kenya - metal silos in, Food and Agriculture Organization of the United Nations (FAO) projects**

Spotlight on reducing food loss and waste - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Global GHG emissions relating to food loss and waste, including associated land use change, are estimated at around 4.4 $GtCO_2$-eq per year.	FAO, 2015a

Spotlight on food loss and waste - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER
- One in every four food calories being produced for humans to eat is currently not being consumed.

SDG 6 - CLEAN WATER AND SANITATION
- Reducing the amount of water wasted in connection with food that is lost or wasted.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure associated with progression of initiatives to reduce food loss and waste.
- Research into food loss and waste and reduction methods.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Improving waste management.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION
- Reducing food loss and waste.

SDG 13 - CLIMATE ACTION
- Reducing food waste will reduce the current estimated 3.3 billion tonnes of CO_2 equivalent per year that food waste is responsible for.

SDG 15 - LIFE ON LAND
- Reducing the amount of food waste and related packaging going to landfill.

Sources: Gustavsson et al., 2011; Lipinski et al., 2013; Goodwin, 2015

ALTERNATIVE AGRICULTURAL PRACTICES

Alternative agricultural practices are currently seen as unconventional (Kane, 2015). A common challenge globally is the dissemination of technology and farming practices with the annual adoption rate of new agricultural technologies and farming practices being very low (Schwoob, Treyer, and Dobermann, 2016). Reasons for this include diversity of environments and distance between farmers, combined with weak links between practitioners and institutions promoting new ways of farming (Schwoob, Treyer, and Dobermann, 2016).

The aim of this section is to demonstrate the opportunities created by a variety of alternative agricultural practices.

A.4 Crop wild relatives and local plant breeding programmes

Crop wild relatives (CWR) are wild plant species that are related to crops. They are a valuable genetic resource for crop breeding and adaptation of crops to a changing climate. The ranges and survival of CWR are threatened by land use change, climate change, intensification of agriculture and invasive species (Global Crop Diversity Trust, 2016). Maintaining CWR is vital to attaining the SDGs because they enhance resilience and long-term food production.

There are two methods of CWR conservation: in situ and ex situ. In situ conservation is in the plant's natural habitat. Ex situ conservation is outside the natural habitat and includes gene banks, field collections and botanical gardens. A combination of both in situ and ex situ conservation is required, because each approach provides something the other does not. Ex situ conservation improves access to CWR for use in research and crop breeding and aids in preservation of species. In situ conservation is necessary to enable continued evolution of species for adaptive traits and the maintenance of population-level genetic diversity (Global Crop Diversity Trust, 2016).

An example of a local plant breeding programme, The Bread Lab established by Washington State University in the USA, and the opportunities it offers can be found in section A.4 of the Case Studies in **Washington State University, US - The Bread Lab**.

Spotlight on crop wild relatives and local plant breeding programmes
- GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (image cropped). ICRISAT's work on crop wild relatives.

Spotlight on crop wild relatives and local plant breeding programmes
- Sustainable Development Goals

SDG 2 - ZERO HUNGER

- The development and selection of plant varieties that are adapted to specific environments is an important part of creating a resilient food system.

SDG 3 - GOOD HEALTH AND WELL BEING

- Decentralisation creates potential for an increase in food quality and the focus of local plant breeding programmes can be on nutritional value.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- It creates a hub of activity and development local to the growth of the related crops.
- Diversifying crop development is beneficial to the famer, soil and community.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Research and development in relation to crop wild relatives and local plant breeding.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Increases cultural connection to production and consumption, enhancing regional diversity, and helps protect natural heritage.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION

- The momentum of local agriculture movements requires participation from and communication between farmers, breeders and those working with food, which could increase the capacity for transformation in food production.

SDG 13 - CLIMATE ACTION

- They are a valuable genetic resource for crop breeding and adaptation of crops to a changing climate.

SDG 15 - LIFE ON LAND

- In situ conservation is necessary to enable continued evolution of species for adaptive traits and the maintenance of population-level genetic diversity.
- Related crops are less reliant on pesticides.

Sources: Brouwer, Murphy and Jones, 2016; Global Crop Diversity Trust, 2016; Patagonia, 2016

A.5 Urban agriculture

There are a wide range of methods of urban agriculture including community gardens, allotments, growing at home in gardens, on roofs, on balconies or on window sills, growing on walls and on roofs and even utilising underground space. Urban agriculture often makes efficient use of small spaces and limits post-harvest transport of crops.

It is important to consider the full life cycle of crops grown in urban environments because the type of crop and cultivation method can have an impact on the environmental and economic costs of urban growing (Sanyé-Mengual et al., 2015). It is particularly important to avoid urban agriculture practices that require large energy inputs (Goldstein et al., 2016). In one study, open air, soil-based production of vegetable-like fruits, such as tomatoes and aubergines, proved the most environmentally friendly option for roof top farming (Sanyé-Mengual et al., 2015).

Some of the opportunities offered by urban agriculture are highlighted by cases in Cuba since 1989, details of which can be found in section A.5 of the Case Studies in **Cuba - urban agriculture**.

Spotlight on urban agriculture - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Seattle Parks

Spotlight on urban agriculture - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- Development of self-sufficiency and food security.

SDG 3 - GOOD HEALTH AND WELL BEING

- Practicing urban agriculture has a clear impact on diet and benefits for both physical and mental health.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Demonstrates that food growing and raising animals can be achieved on scale within the urban environment.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Widespread community engagement, improvement to local environments, greater care for local environments and much greater self-sufficiency.
- Increasing number of green and public spaces.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION

- Significant increase in fresh produce that originates from the city, use of organic compost and use of simple irrigation systems.

SDG 13 - CLIMATE ACTION

- Demonstration of transformation of food production within an oil-scarce environment.
- Reduced need for transport and refrigeration and a reduction in use of pesticides and fertilisers.

SDG 15 - LIFE ON LAND

- Increase in urban vegetation.

Sources: Bellows, Brown and Smit, 2004; Clouse, 2014; Danish Architecture Centre, 2014

A.6 Agroforestry

Agroforestry is when both trees and agricultural or horticultural crops are grown on the same area of land. Agroforestry systems are designed to provide both tree and other crop products whilst also focusing on the interactions of the different components. Research over the last 20 years has demonstrated that this form of growing can be more productive, profitable and sustainable than forestry or agriculture monocultures (Agroforestry research trust, 2016). The carbon sequestration potential of agroforestry systems has been estimated at between between 12 and 228 Mg per ha, with 95 Mg per ha as a median, which could equate to storage of between 1.1 and 2.2 PgC over the next 50 years given the global area suitable for the practice (Albrecht and Kandji, 2003). As a result, there are significant benefits for implementing the SDGs and for lowering GHG emissions from agriculture.

The opportunities offered by agroforestry are highlighted by cases in southern France and northern Peru, details of which can be found in section A.5 of the Case Studies X in:

- **Montpelier, southern France - agroforestry**
- **San Martin, northern Peru - agroforestry**

Spotlight on agroforestry - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Sources: University of Missouri College of Agriculture, Food and Natural Resources (image cropped). Horticulture & Agroforestry Research Center, New Franklin.

Spotlight on agroforestry - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- Increased and diversified yields.

SDG 3 - GOOD HEALTH AND WELL BEING

- Planting multi-strata native tree varieties leads to higher quality produce.

SDG6 - CLEAN WATER AND SANITATION

- Improved water quality.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Greater resilience to changing markets.
- Using local knowledge to generate management plans that can be implemented at low cost and with locally available materials.
- Increased household income levels.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Research into, and monitoring and development of, agroforestry techniques

SDG 13 - CLIMATE ACTION

- Increased resilience and reduced demand for agricultural land.

SDG 15 - LIFE ON LAND

- Greater biodiversity
- Reduced soil erosion and improved soil quality

Sources: Evidence and Lessons from Latin America, 2012; European Climate Adaptation Platform, 2014

CONSERVATION AND RESTORATION PRACTICES

A focus on the health of ecosystems and biodiversity not only increases carbon storage capacity of habitats but also generates adaptation opportunities, increasing resilience to a changing climate (Conservation International, 2015). Globally the conservation and restoration of ecosystems could result in the storage of an estimated 220 to 330 $GtCO_2$-e, which requires action now (Götze et al., 2016). Land use change has been dominated by deforestation and the conversion of grasslands to cropland and grazing land (Smith et al., 2016a). The conservation and restoration practices covered here relate to forests, grasslands, wetlands and seagrass meadows.

A.7 Forest conservation and restoration

The Sustainable Development Goals include the target of halting global deforestation by 2020 (UN, 2015). The total elimination of deforestation by 2030 could theoretically provide a mitigation potential of between around 2.3 and 5.8 $GtCO_2$-eq per year (Smith et al., 2013).

Forests cover about 4 billion hectares, or 31% of the earth's land surface, compared to 5.9 billion hectares in pre-industrial times. In the past, deforestation was mainly in the USA and Europe; today, the largest deforestation rates are observed in tropical rainforest regions. The place of forests within the carbon cycle means that actions affecting forests have a large impact on GHG emissions, which makes reducing deforestation and forest degradation, and forest conservation and restoration, important aspects of climate change mitigation (UN-REDD, 2015).

Direct drivers of deforestation and forest degradation include agriculture, mining, infrastructure development, urban expansion, forest fires and timber extraction. Indirect drivers of deforestation and forest degradation (on both an international and national level) include markets, commodity prices, population growth, policies, financial incentives and subsidies (UN-REDD, 2015).

Research into forest areas of Vietnam, Indonesia and Nepal found that incentives for promoting deforestation remain much greater than those for preventing it. A range of deforestation-free business solutions have been tried and tested, but they remain isolated cases, struggling against business incentives that promote deforestation. This includes the high price of palm oil and non-native timber. This situation highlights the need for support to those working to create businesses that are deforestation-free and low impact (Dudley et al., 2016).

Degraded forests can recover naturally over time and forest restoration can be defined as enabling or accelerating that recovery (Kartha and Dooley, 2016). The potential for restoration varies dependent on the extent of fragmentation and biodiversity loss (Kartha and Dooley, 2016). Intact forest ecosystems containing a variety of different tree species alongside old growth and deadwood not only store considerably more carbon and are more resilient to climate change but also increase biodiversity and provide a livelihood to millions of people (Götze et al., 2016). They are also less vulnerable than monocultures to forest fires and pests (Pearce, 2016).

It is important to better understand both how local communities rely on forests as well as how forests can help build the resilience of local communities, including that to climate change (Suzuki, 2012). Porter-Bolland et al. (2011) found that community managed forests presented lower and less variable annual deforestation rates compared to state-protected areas across the tropics. Stevens et al. (2014) demonstrate that Indigenous Peoples and local communities with legal forest rights maintain or increase the carbon storage of the forest and lower carbon dioxide emissions and deforestation. Their report recommends that Indigenous Peoples and local communities should be provided with legal recognition of rights to their forest and that governments should help to protect these rights.

Opportunities offered by participatory forest management can be found in **Lulanda Village, Southern Tanzania - participatory forest management**, which highlights a range of benefits and limitations of the project.

Source: Akos Kokai (image cropped). Looking from the garden to Wilton's Bush Reserve, Wellington, New Zealand.

Spotlight on forest conservation and restoration - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	It has been estimated that the total elimination of deforestation by 2030 could deliver a mitigation potential of between around 2.3 and 5.8 GtCO2-eq per year. It has been estimated that afforestation, reduction in deforestation and forest management could have a mitigation potential of between 1.9 and 5.5 GtCO2-eq per year in 2040.	Smith et al., 2013 FAO, 2016a

Spotlight on forest conservation and restoration - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 1 - NO POVERTY

- Forests are important for aiding in combatting rural poverty.
- If restrictions are placed on forest access it is necessary to consider the impact of loss of access to local communities, such as the need for firewood and building materials.

SDG 2 - ZERO HUNGER

- Forests are important for ensuring food security.

SDG 6 - CLEAN WATER AND SANITATION

- Forests are important for ecosystem services, including clean water and storm-water control.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Forests and forest products make a significant contribution to the lives of rural communities.
- Jobs created in relation to conservation and restoration programmes.
- It is necessary to consider livelihoods lost through management practices and to establish alternatives in this case.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with sustainable forest management practices.

SDG 10 - REDUCED INEQUALITIES

- Encouraging legal recognition of and protecting the rights of Indigenous Peoples and local communities is vital to forest conservation and restoration.

SDG 13 - CLIMATE ACTION

- The place of forests within the carbon cycle mean that actions affecting forests have a large impact on GHG emissions, which makes forest conservation and restoration important aspects of climate change mitigation.

SDG 15 - LIFE ON LAND

- Forests are important for conservation of biodiversity.
- Forests have an important role in the regulation of temperature and fresh water flows.

Sources: Angelsen, 2011, cited in Suzuki, R., 2012, p. 6; Stevens et al., 2014; UN-REDD, 2015; FAO, 2015; FAO, 2016, Painemilla et al. 2010

A.8 Grassland conservation and restoration

In grassland ecosystems almost all carbon is stored in the soil, and this soil is the largest of all terrestrial carbon storage (Jones and Donnelley, 2004). It has been estimated that carbon stored in grassland soils probably accounts for more than 10% of total biosphere stores (Eswaran, Vandenberg and Reich, 1993 and Nosberger, Blum and Fuhrer, 2000, both cited in Jones and Donnelley, 2004, p.424).

Grasslands can act as a sink or source of atmospheric CO_2 depending on land use, grazing intensity and climate (Frank, 2002). Different grassland management techniques have differing effects on carbon sequestration (Maia et al., 2009). Grasslands lose carbon more quickly than they store it, which highlights the importance of successful management to preserve the carbon sink (Smith, 2014). Management of grasslands, including tilling, causes carbon to be released (Minnesota Board of Water and Soil Resources, 2010) and conversion of grasslands to arable land can decrease carbon stock by, on average, 60% (Paustian, Collins and Paul, 1997; Guo and Gifford, 2002).

Opportunities offered by regenerative grazing can be found in section A.8 of the Case Studies in **South Dakota, US - regenerative grazing**.

Spotlight on grassland conservation and restoration - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Global rehabilitation of overgrazed grasslands has been estimated to potentially sequester around 45 TgC per year, largely through cessation of overgrazing and implementation of a moderate level of grazing. Various improvements to grasslands have been estimated to sequester between 0.11 and 3.04 MgC per ha per year, with a mean of 0.54 MgC per ha per year.	Conant, Paustian and Elliot, 2001 Conant and Paustian, 2002

Source: Larry Smith (image cropped). Bison grazing at sunrise in Wichita Mountains Wildlife Refuge, SW Oklahoma.

Spotlight on grassland conservation and restoration - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Increased production and related increased financial income.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with grassland conservation and restoration.
- Research into effective sustainable grassland management.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION

- Regenerative grazing removes the need for feeding areas and associated waste and contamination.

SDG 13 - CLIMATE ACTION

- Decrease in carbon released from the soil, increased carbon sequestration and increased resilience to climate variability.

SDG 15 - LIFE ON LAND

- Increased soil productivity.

Sources: Eswaran, Vandenberg and Reich, 1993, cited in Jones and Donnelley, 2004,, p.424; Nosberger, Blum and Fuhrer, 2000, cited in Jones and Donnelley, 2004, p.424; Jones and Donnelley, 2004; Patagonia, 2016

A.9 Wetland conservation and restoration

Wetlands are areas of land where for all or part of the year water either covers the soil or is present at, or near to, the surface of the soil. They can support both aquatic and terrestrial species and the prolonged presence of water establishes conditions that support the growth of specially adapted plants and the development of characteristic wetland soils. Wetland habitats vary widely because of differences in soil, vegetation, topography, climate, hydrology and levels of human disturbance (United States Environmental Protection Agency, 2016). Here, peatlands, mangroves and salt marshes will be considered.

Peatlands

Since the beginning of the Holocene, around 11,500 years ago, peatlands have withdrawn huge amounts of CO_2 from the atmosphere (Joosten, 2015). They cover just 3% of the Earth's surface, but store 30% of all soil carbon (The Global Peatland Initiative, 2002). The carbon is essentially locked up in peatlands due to the slow, often negligible decomposition processes within them (FAO, 2016b). Peatlands account for over half of all wetlands and are home to a wide range of habitats and species (The Global Peatland Initiative, 2002).

Draining of peatlands has been occurring for centuries for productive purposes, including grazing, forestry, agriculture and peat mining, and over this time 15% of peatlands have been drained globally (Holden, Chapman and Labadz, 2004; Joosten, Tapio-Biström and Tol, S., 2012). Although this accounts for just 0.4% of global land area, these drained peatlands are responsible for 5% of global anthropogenic CO_2 emissions (Joosten, 2015). When drained, peatland becomes a net source of GHGs (Biancalani and Avagyan, 2016) including CO_2 and N_2O (Joosten, 2015). Large amounts of CH_4 are also emitted from the drainage ditches (Joosten, 2015). Unlike emissions associated with deforestation, which are largely immediate, emissions from drained peatlands continue over decades or centuries, for as long as the peatland remains drained and keeps oxidising (Jossten, Tapio-Biström and Tol, S., 2012).

Drainage of peatlands not only increases GHG emissions but also leads to lowering the height of the land surface, which is known as land subsidence, and in newly drained areas this can be up to 50 cm per year (FAO, 2016b). Drainage reduces water quality in downstream aquatic ecosystems, leads to vegetation cover changes, causes a loss in biodiversity and increases the frequency of fires (FAO, 2016b). There can also be an associated increase in saltwater intrusion, droughts and soil erosion, which all lead to a reduction in agricultural productivity (FAO, 2016b). Many peatlands that have been drained for use in agriculture have been abandoned because of decreasing productivity along with increasing soil degradation and cost of drainage (Biancalani and Avagyan, 2016).

Under the wet conditions required for peat formation some dead plant material is decomposed in the absence of oxygen, which results in the emission of the GHG methane (CH_4). This means peatlands are a major global source of CH_4, which is a much stronger greenhouse gas than CO_2. However, CH_4 has a short atmospheric residence time of 12 years and is rapidly removed from the atmosphere by oxidation, while atmospheric CO_2 continues to be absorbed. As a result, in the long-term, well-managed and natural peatlands reduce GHG emissions (Joosten, 2015).

The use of wet and re-wetted peatlands for agriculture and forestry is a developing concept often referred to as Paludiculture, which offers a range of potential opportunities for use of wet peatland (Schröder et al., 2015). When considering peatland management, it is essential to address social issues, including access to and use of natural resources for local communities (Biancalani and Avagyan, 2016).

It has been highlighted that failing to recognise the consequences of current land use practices on peat soils will mean that future generations will be faced with an irreversibly altered and dysfunctional landscape that is a burden locally and globally, on both the environment and society (Wijedasa et al., 2016).

Source: Ninara (image cropped). Peatland in Northern Finland, Jänissuo, Oijärvi, Ii, Oulun lääni.

Mangroves

Mangroves are salt tolerant trees that form coastal forests found in tropical and subtropical intertidal sheltered shores, often within estuaries and on riverbanks (IUCN, 2007; Patil et al., 2012). Where mangroves can grow is dependent on both factors affecting the relationship between land and sea, including sea level rise, sedimentation and shoreline erosion, and factors affecting the extent of tidal inundation, including human land use changes such as the creation of dykes (Warner et al., 2016). They are characterised by their aerial roots, which take in oxygen, and they are able to survive in saline waters (Patil et al., 2012). Mangroves are known to be resilient to changes and are able to make small adjustments to adapt themselves (Alongi, 2012).

Mangrove forests are a highly productive habitat and they store proportionally more carbon below ground in pools amongst the soil and dead roots (Alongi, 2012). Over the past 800 years or so mangroves have been estimated to sequester around 1.5 tonnes of carbon per hectare annually (Eong, 1993). Deforestation rates of mangrove forests is high, with roughly 1-3% lost annually (Alongi, 2012) and it has been estimated that mangrove deforestation generates emissions of between 0.02 and 0.12 PgC per year (Donato et al., 2011). Mangroves in the tropics have been estimated to contain on average 1,023 MgC per hectare, with ground carbon storage in just the uppermost metre having been estimated to be 2 to 4 times that contained in the biomass (Donato et al., 2011).

It has been estimated that if deforestation of mangroves in Indonesia were halted then emissions from the land-use sectors there would be reduced by around 10-31%, which highlights that mangrove conservation should be a high-priority component to climate change mitigation portfolios. (Murdiyarso et al., 2015)

Salt marshes

It is believed that the restoration of salt marshes is one of the most successful ways to capture carbon (Trulio, 2007), estimated at around 55 times faster than tropical rainforests (Macreadie et al., 2013). Carbon is well stored in salt marshes due to the regular and predictable tidal saturation of the soil, which creates anaerobic conditions that limit the decay of biomass (Whittlesey et al., 2013).

This is partially because salt marshes have the advantage of having no saturation point for their storage of carbon, because over time they grow vertically and increase density by compressing downwards, with the addition of new sediment and biomass at the surface (Crooks et al., 2011; Mcleod et al., 2011; Whittlesey et al., 2013). Due to extreme conditions, few plants are adapted to grow in the high saline conditions, this results in low levels of competition and in turn high productivity of the salt-tolerant, hardy, plants (CEC, 2016). Salt marshes are able to produce 8,000 tonnes of biomass annually, continually locking carbon in the soil below the surface (Mitch and Gosselink, 2000; Trulio, 2007). Salt marshes also act as a line of defence again storms and a sink for pollutants, stopping them from reaching the sea or transferring to the land (CEC, 2016).

The transformation of land in drainage basins to agricultural land threatens the growth of salt marshes, as the fertilisers and pesticides used increases the nitrogen levels reaching the salt marshes (CEC, 2016). This increase in nitrogen causes saltmarsh root growth to decline, which in turn decreases the growth of the soil on the salt marshes (CECE, 2016). Additional policy measures to support protection and restoration of salt marshes are needed to enhance their sequestration potentials.

Existing examples of peatland and mangrove forest restoration along with a study into salt marshes can be found in section A.10 of the Case Studies. See the full list of case studies below:

- **Ruoergai Plateau, China - peatland restoration**
- **Mekong River Delta, Vietnam - mangroves**
- **San Francisco Bay, US - salt marshes**

Source: Daniel Hartwig (image cropped). Mangroves.

Spotlight on wetland conservation and restoration - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Peatlands cover just 3% of the Earth's surface, but store 30% of all soil carbon. Drained peatlands are responsible for around 5% of global anthropogenic CO2 emissions. Over the past 800 years or so mangroves have been estimated to sequester around 1.5 tonnes of carbon per hectare annually. It has been estimated that mangrove deforestation generates emissions of between 0.02 and 0.12 PgC per year. Mangroves in the tropics have been estimated to contain 1,023 MgC per hectare, with ground carbon storage in just the uppermost metre having been estimated to be 2 to 4 times that contained in the biomass. Restoration of salt marshes is thought to be one of the most successful ways to capture carbon, estimated at around 55 times faster than tropical rainforests.	Eong, 1993 The Global Peatland Initiative, 2002 Trulio, 2007 Donato et al., 2011 Macreadie et al., 2013 Joosten, 2015

Source: Jack Flanagan (image cropped). Salt marsh.

Spotlight on wetland conservation and restoration - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- Mangroves can be a source of food.

SDG6 - CLEAN WATER AND SANITATION

- Peatlands help control flooding and purify water.
- Healthy peatlands improve water security.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Paludiculture offers a range of potential opportunities for use of wet peatland.

- It is important to establish alternative options for local communities to support themselves e.g. when reducing land area for pasture.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with wetland conservation and restoration practices.
- Research into effective sustainable wetland management.

SDG 13 - CLIMATE ACTION

- Peatlands store 30% of all soil carbon.
- When drained peatland becomes a net source of GHGs including CO_2, N_2O and CH_4.
- Mangroves have been estimated to sequester around 1.5 tonnes of carbon per hectare annually.
- Salt marshes have no saturation point for their storage of carbon and may be able to adapt to sea level rise.

SDG 14 - LIFE BELOW WATER

- Mangrove forests provide nurseries for fish and sediment storage.
- Salt marshes act as a sink for pollutants, stopping them from reaching the sea.

SDG 15 - LIFE ON LAND

- Peatlands are important for the conservation of biodiversity and provide habitat for a range of endangered species.
- Drainage of peatlands leads to land subsidence.
- Mangroves protect against coastal erosion.
- Salt marshes act as a line of defense again storms and a sink for pollutants, stopping them from transferring to the land.

Sources: Spalding et al., 1997; The Global Peatland Initiative, 2002; Ellison, 2008; Alongi, 2009; Crooks et al., 2011; Mcleod et al., 2011; Whittlesey et al., 2013; Cris et al., 2014; Schröder et al., 2015; Biancalani and Avagyan, 2016; CEC, 2016; FAO, 2016b; Joosten, 2016

A.10 Seagrass meadow conservation and restoration

Seagrasses are angiosperms (a large group of plants that are able to produce flowers (Merriam-Webster, 2017) that live within the marine environment (Duarte, 2002; Duarte, Kennedy, et al., 2013) and are found along the shores of all continents except Antarctica (Hemminga and Duarte, 2000). Seagrass meadows sequester high levels of carbon (Duarte et al., 2005), with global carbon burial in seagrass meadows estimated at between 48 and 112 TgC per year (Kennedy et al., 2010). The accumulation of sediment rich in organic matter is so effective that it is able to raise the sea floor by 1mm annually (Kennedy et al., 2010). It is this sediment accumulation that causes carbon to be buried and stored (Duarte et al., 2005; Kennedy et al., 2010; Fourqurean et al., 2012). However, anthropogenic activity, increasing ocean temperatures and decreased ocean water quality (Duarte, 2002; Duarte et al., 2005) are causing seagrass meadows to decline by 5% annually (Orth et al., 2006a; Waycott et al., 2009; Mcleod et al., 2011). If restoration does not occur and seagrass meadows continue to be destroyed they are likely to become a significant source of carbon (Greiner et al., 2013), representing a CO_2 emission potential of between 131-523 $MgCO_2$ per ha (Pendleton et al., 2012).

An example of seagrass meadow restoration can be found in section A.10 of the Case Studies in **East Coast Virginia, US - seagrass meadows**.

Spotlight on seagrass meadow conservation and restoration - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Global carbon burial estimated at between 48 and 112 TgC per year. If restoration does not occur and seagrass meadows continue to be destroyed they are likely to become a significant source of carbon, representing a CO_2 emission potential of between 131-523 $MgCO_2$ per ha.	Kennedy et al., 2010 Pendleton et al., 2012 Greiner et al., 2013

Source: James St. John (image cropped). Thalassia testudinum, South Pigeon Creek estuary, San Salvador Island, Bahamas

Spotlight on wetland conservation and restoration - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with seagrass meadow conservation and restoration practices.
- Research surrounding seagrass meadow conservation and restoration.

SDG 13 - CLIMATE ACTION

- Seagrass meadows sequester high levels of carbon.

SDG 14 - LIFE BELOW WATER

- Seagrass meadows increase sediment deposition.
- They are productive ecosystems, providing habitat for a wide range of species.

SDG 15 - LIFE ON LAND

- Seagrass meadows decrease coastal erosion.

Sources: Duarte and Chiscano, 1999; Duarte et al., 2005; Kennedy et al., 2010; Fourqurean et al., 2012; Greiner et al., 2013; Hejnowicz et al., 2015

B.

BUILT ENVIRONMENT SOLUTIONS

The IPCC Fifth Assessment Report outlined that between 1970 and 2010 GHG emissions from the building sector doubled to reach 9.18 GtCO2-eq, representing 19% of global GHG emissions in 2010 (IPCC, 2014). Buildings are the largest consumers of energy worldwide and the global population is growing, which will lead to increasing rates of construction (IEA, 2013). Energy use in buildings and for building construction represents more than one third of global energy consumption and contributes to nearly one quarter of GHG emissions worldwide (IEA, 2016).

Changing the design of urban environments and using sustainable materials can dramatically reduce GHG emissions, as well as reduce pollution and commuting time, and enhance the quality of life of urban residents. The International Energy Agency (IEA) estimates that the building sector offers the largest cost-effective GHG mitigation potential, with net cost savings and economic gains possible through implementation of existing technologies, policies and building designs (IEA, 2016).

These developments are critical because over the next decade, it is predicted that the construction industry will see an annual growth of 4-6% (Garcia, 2016, cited in FAO, 2016a, p. 87). Governments are beginning to recognise that they must accelerate investment in net-zero and low carbon buildings, including ways to change building methods and materials, if the building sector is to play a role in implementing the Paris Agreement (IEA, 2016). This will require architects, planners, designers and the construction industry to engage in working to reduce levels of GHG emissions in relation to the built environment. Without their support, new building materials, ways of designing and methods of construction will not become prevalent in old or new buildings. As the majority of new construction will take place in developing countries, efforts must be made to ensure the skills and resources are enabled to allow for the sharing, development and use of new technologies and new ways of building in these countries.

It is important to consider both existing buildings and construction methods. A good overview of the challenges and opportunities is set out in the Global Alliance for Buildings and Construction in it's 2016 Global Status Report (IEA, 2016).

In this section, three aspects of the built environment are explored in relation to both energy use and the SDGs: low energy design, sustainable building materials and energy provision.

In the following section, we explore the following solutions:

B.1 Retrofitting and refurbishment
B.2 Zero energy and zero carbon buildings
B.3 Passivhaus
B.4 Green infrastructure and urban water management
B.5 Sustainable urban planning
B.6 Building with earth
B.7 Building with timber
B.8 Building with hemp-lime
B.9 Building with straw bales
B.10 Increasing energy access sustainably
B.11 Smart grids
B.12 District heating
B.13 Urban solar

LOW ENERGY DESIGN

Retrofitting and refurbishment, zero energy and zero carbon buildings, Passivhaus design, green infrastructure, and sustainable urban planning can make an enormous contribution to below 2ºC/1.5ºC-compatible emissions reduction pathways.

B.1 Retrofitting and refurbishment

Global building stock is projected to grow from 223.4 billion m² in 2015 to 415.2 billion m² in 2050 (GABC, 2016). This means that in 2050, 46% of the world's building stock will be new and 54% will be "existing" and eligible for retrofitting/refurbishment to higher performance standards (GABC, 2016). Climate Action Tracker (2016b) highlight the urgency of the need to quickly increase changes within the building sector as a 2°C/1.5°C pathway would require renovation rates leading to a 90% reduction in fuel and heat demand of 3-5% of floor space per year.

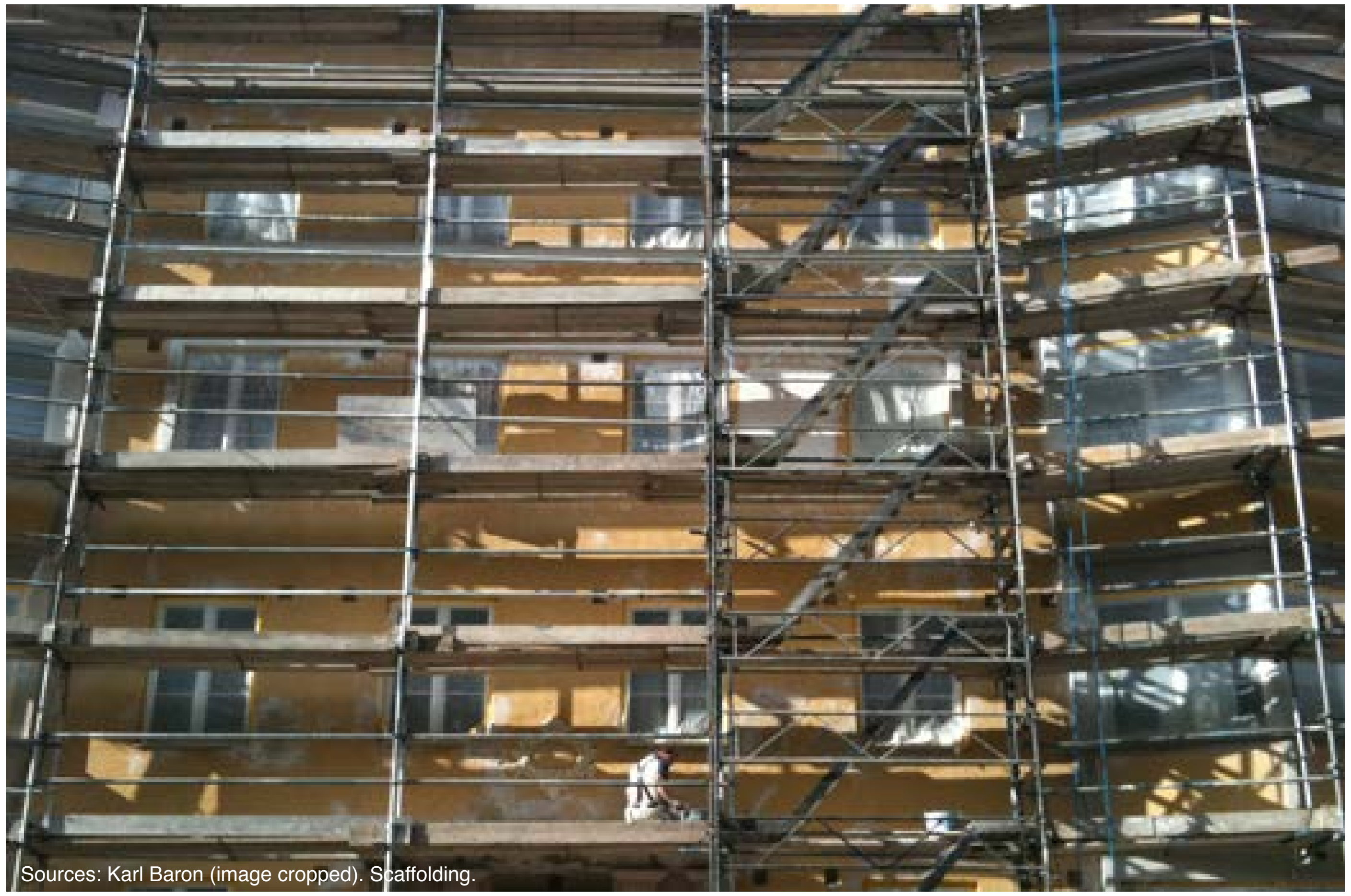
Retrofitting refers to the addition of a component or feature (Eames et al., 2014) whereas refurbishment refers to repair activity (Cambridge English Dictionary, 2016). Refurbishment with reducing energy use in mind focuses on thermal efficiency and sustainability in buildings and includes work in relation to air-tightness, thermal bridges, solar gain and low energy technologies and appliances (Mohammadpourkarbasi and Sharples, 2013).

Refurbishment and retrofitting often result from a desire to save energy and money whilst, depending on climatic conditions, also making the house warmer or cooler. Additional benefits are gained, as a building that is underperforming in its heating ability can lead to damp, which causes health problems and dust mites (Baker, 2001). Challenges to retrofitting include the unwillingness of the owners to pay for any changes (Ma et al., 2012) and certain property types being much more difficult to retrofit, such as buildings with solid walls or no loft (Department for Communities and Local Government, 2006). There are many old buildings globally that are protected for their aesthetics and historical importance and there are often difficulties in enhancing the energy efficiency of these (Johansson, Hagentoft and Kalagasidis, 2014).

The following case studies can be found in section B.1 of the Case Studies:
- **Lebanon - Casa Batroun**
- **Bulgaria - The National Programme for Energy Efficiency in Residential Buildings**

Spotlight on retrofitting and refurbishment - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	A 2°C/1.5°C pathway would require renovation rates leading to a 90% reduction in fuel and heat demand of 3-5% of floor space per year.	Climate Action Tracker, 2016b



Sources: Karl Baron (image cropped). Scaffolding.

Spotlight on retrofitting and refurbishment - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING

- Health and quality of housing are inextricably linked: a reduction in damp conditions, improved thermal insulation and improved ventilation all create a healthier environment.

SDG 7 - AFFORDABLE AND CLEAN ENERGY

- Retrofitting and refurbishment lead to energy and related money savings.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Job creation.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with retrofit and refurbishment projects.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Improving housing.

SDG 13 - CLIMATE ACTION

- Reducing energy consumption associated with the built environment: eco-refurbishment includes work in relation to air-tightness, heat bridges, solar gain and low energy technologies and appliances.

Sources: Baker, 2001; Ma et al., 2012; Mohammadpourkarbasi and Sharples, 2013; Georgiev, 2015; BPIE, 2016; FOE, 2016

Built environment solutions
B.2 Zero energy and zero carbon buildings

In 2013 the global buildings sector consumed over 120 EJ, which accounts for more than 30% of the total final energy consumption for all sectors of the economy and three-quarters of which can be attributed to the residential sector. In some regions electricity consumption by buildings has increased by over 500% since 1990 and when considering upstream power generation, the building sector is responsible for just under one-third of global CO_2 emissions. (IEA, 2016)

Climate Action Tracker (2016b) outlines that a 1.5°C pathway would require all new buildings to be zero energy by 2020-2025. The definition of zero energy buildings (ZEBs) has been varied (Torcellini et al., 2006) and it would be necessary to establish an international standard for ZEBs (Marszal et al., 2011). There is also a lack of standardised calculation for assessing ZEBs; however, assessment methods have been created for those voluntarily wishing to apply standards to their building (Marszal et al., 2011), including BREEAM (BRE, 2016), Leadership in Energy and Environmental Design (LEED) (LEED, 2016) and the Living Building Challenge (International Living Future Institute, 2015).

In general, a building classified as zero-energy or net-zero-energy is one in which the annual usage and production of energy is balanced, not taking into account energy used in construction (Hernandez and Kenny, 2010). In recent years ZEBs have shifted from concept to achievable reality (Marszal et al., 2011). ZEBs must produce their own energy (Goodier, 2011), but it is also understood that generally ZEBs need to be connected to the national grid, to ensure that there is an energy supply at all times (Torcellini et al., 2006) and to remove the need for on-site electricity storage (Hernandez and Kenny, 2010).

While ZEBs are applicable in low rise and sub-urban areas where there is enough roof or site area to produce on-site renewable energy, they are limited in application in denser urban areas. In this case, Architecture 2030 has developed a new definition for Zero Net Carbon buildings, or “a highly energy efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually” (Architecture 2030, 2016).

The following case studies can be found in section B.2 of the Case Studies:
- **International - Living Building Challenge (LBC)**
- **New Delhi, India - Indira Paryavaran Bhawan**

Spotlight on zero energy and zero carbon buildings - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	In general, the annual usage and production of energy in zero energy buildings is balanced, not taking into account energy used in construction. Zero carbon buildings are highly energy efficient buildings that produce on-site, or procure, enough carbon-free renewable energy to meet building operations energy consumption annually.	Hernandez and Kenny, 2010 Architecture 2030, 2016

Sources: Robert Treier (image cropped). Zero-energy test building in Tallinn, Estonia at Tallinn University of Technology

Spotlight on zero energy buildings - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- Health and quality of housing are inextricably linked.

SDG 6 - CLEAN WATER AND SANITATION
- Zero energy buildings generally consider water consumption.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- Zero energy buildings must produce their own energy and zero carbon buildings are highly energy efficient.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Considering industry, innovation and infrastructure associated with zero energy and zero carbon building design, construction and maintenance.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Improving housing.

SDG 13 - CLIMATE ACTION
- Reducing energy consumption associated with the built environment.

Sources: Ravichandran and Krishnan, no date; Baker, 2001; Hernandez and Kenny, 2010; Goodier, 2011; Indira Paryavaran Bhawan, 2011; Perappadan, 2014; International Living Future Institute, 2015; Architecture 2030, 2016

B.3 Passivhaus design

Passivhaus design allows for energy savings related to space heating and cooling of up to 90% compared to typical building stock and over 75% compared to average new builds (Passive House Institute, 2015c).

Passivhaus is a standard of low energy building, designed by Dr Wolfgang Feist in 1991 (Schiano-Phan et al., 2008; Passive House Institute, 2015a). The first Passivhaus was designed in a bid to show that houses can be built to have low energy usage and to provide a comfortable living space whilst also being achievable financially (Schiano-Phan et al., 2008). There are over 30,000 Passivhaus buildings globally (Kingspan, 2015). The standard was originally designed for colder climates but has been adapted for warmer climates by taking into consideration the need to cool the building rather than heat it (Schiano-Phan et al., 2008).

Passivhaus is defined as “a building in which thermal comfort can be achieved solely by post-heating or post-cooling the fresh airflow required for a good indoor air quality, without the need for additional recirculation of air.” (Passivhaus, 2011).

For a building of Passivhaus standard to be achieved, the walls, floor and roof must have U-values that are 0.15W/m²K or less. A U-value is a measure of how effective a material is as an insulator, where the lower the U-value the better the material is as an insulator (NBS, 2017). Important considerations in Passivhaus design include orientation, making use of and limiting solar gains where appropriate, limiting thermal bridges, good airtightness, use of double or ideally triple glazed windows, good U-value of fabric and opaque elements as well, as the use of mechanical ventilation with heat recovery.

New buildings have to contribute to several challenges for environmental protection. While very low energy consumption and hence avoiding CO_2 emission is a fundamental part of sustainable development and climate protection, the use of clean and safe building materials as well as low freshwater consumption and preventing sealing of the surface soil is crucial too. This is important in times of rapidly growing and sprawling cities, settlements and housing demand for the poor that might contribute to reduction of fertile land for food production and biodiversity. (http://www.usgbc.org/education-at-usgbc)

The following case studies can be found in section B.3 of the Case Studies:

- **China - Zhuozhou**
- **Antarctica - Princess Elisabeth Passivhaus research station**

Spotlight on Passivhaus design - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Energy savings related to space heating and cooling of up to 90% compared to typical building stock and over 75% compared to average new builds.	Passive House Institute, 2015c

Sources: Tõnu Mauring (image cropped). Kindergarten in Valga, Estonia, which has been refurbished with Passivhaus components.

Spotlight on Passivhaus design - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING

- Health and quality of housing are inextricably linked.

SDG 7 - AFFORDABLE AND CLEAN ENERGY

- Creating low energy use structures.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with Passivhaus design, construction and maintenance.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Improving housing.

SDG 13 - CLIMATE ACTION

- Reducing energy consumption associated with the built environment.

Sources: Baker, 2001; Schiano-Phan et al., 2008; Kingspan, 2015; Passive House Institute, 2015a

B.4 Green infrastructure and urban water management

Green infrastructure (GI) refers to the location, connection, structure and types of green space that provide goods and services (Forest Research, 2010). GI can be found in both rural and urban settings and includes areas such as coastal habitats, trees in urban streets, woodlands, private and public gardens, agricultural land, churchyards and green roofs (Community Forests Northwest, 2011).

By introducing GI into the landscape, particularly in urban areas, the natural hydrological cycle is enabled. This reduces the speed and amount of surface water run-off and pressures on man-made drainage systems, which reduces the risk of flooding (Mansell et al., 2003; Forest Research, 2010). It also helps to reduce pumping and treatment of surface water runoff, which reduces GHG emissions relating to wastewater treatment (Georges, Thornton and Sadler, 2009).

Blue-Green cities are those that take a natural approach to addressing the water cycle and that link this cycle with GI and its management (Hoyer et al., 2011). This approach is achieved by restoring natural drainage, reducing the amount of impermeable surfaces, increasing surface storage, and mimicking the natural processes that would have occurred before the land was built upon (Novotny, Ahern and Brown, 2010).

An example of a city's approach to water management can be found in section B.4 of the Case Studies in **Copenhagen, Denmark - Cloudburst Management Plan**.

Spotlight on green infrastructure and urban water management - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Andy Hales (image cropped). Vegetated tram lines and swale in Freiburg, Germany.

Spotlight on green infrastructure and urban water management

- Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING

- Benefits for physical and mental health.

SDG 6 - CLEAN WATER AND SANITATION

- Hydrological benefits and more efficient water management.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Considering industry, innovation and infrastructure associated with green infrastructure research, design, construction and maintenance.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Green infrastructure involves the creation of community and green spaces and helps reduce impacts of flooding and drought.

SDG 13 - CLIMATE ACTION

- Required for adaptation to, and mitigation of, flooding and drought.

SDG 15 - LIFE ON LAND

- Helps reduce impacts of flooding.
- Habitat creation.

Sources: De Vries et al., 2003; Mansell et al., 2003; Bell et al., 2008; Whitelaw et al., 2008; Forest Research, 2010; NSW Office of Water, 2010; The City of Copenhagen, 2012; Lawson and et. al, 2014

B.5 Sustainable urban planning

The current level of use of private cars causes congestion, poor air quality and lack of space within cities (UITP, 2016). Private cars are generally parked for around 95% of their lifetime and take up the parking space of at least three bicycles (UITP, 2016).

It has been demonstrated that rail-based transport services are most linked to a reduction in vehicle kilometres travelled per person and consequently investment in high-quality rail transport and building up around stations can aid in reducing car dependence (McIntosh et al., 2014). Cities including San Francisco, Paris and Seoul have been studying how urban rail alongside removal of major freeway infrastructure can help revitalise urban environments (Newman and Kenworthy, 2015). For much of the 20th century the planning process assumed car dependence and now cities are moving beyond this vision of planning (Newman and Kenworthy, 2015).

Public transport generally is the most efficient form of transport in relation to space required for number of people moved (UITP, 2016). The number of daily trips in urban areas has been forecast to rise from around 7.5 billion in 2005 to around 11.5 billion in 2025, with public transport currently accounting for 1.2 billion trips per day (UITP, 2016). High capacity public transport is integral to scenarios that aim to lessen dependence on cars (UITP, 2016).

The following transport and planning dimensions have been highlighted as key for sustainable city development:
- Compact, mixed-use urban form.
- Green space and food production within cities.
- Reducing emphasis on road infrastructure and increasing emphasis on walking and cycling infrastructure, and giving special attention to increasing emphasis on rail infrastructure.
- Considering energy use and environmental impact of water and waste management systems along with renewable energy generation and reducing energy losses.
- Centres and sub-centres being people-orientated and promoting modes of transport other than automobile.
- High-quality community spaces.
- Concentrating the structure of the city on human needs and making them accessible and varied.
- Allowing debate surrounding and public involvement in future planning.
- Considering sustainability in all decision-making. (Kenworthy, 2006)

Public transport specifically has strong links to objectives of social inclusion, accessibility for all and improving quality of life along with reducing energy use and pollution (UITP, 2013). The public transport supply chain is a job-intensive industry, involving a wide range of skills and innovation (UITP, 2013). The design and manufacture of public transport vehicles is highly job-intensive and considering manufacture there is much less automation when compared to car production (UITP, 2013).

An example of sustainable urban planning initiatives can be found in section B.5 of the Case Studies in **Copenhagen, Denmark – urban planning initiatives**.

Spotlight on sustainable urban planning - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Anna Cooke-Yarborough (image cropped). A car-free road in Vauban, Freiburg, Germany.

Spotlight on sustainable urban planning - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- Improving air quality and reducing noise pollution.
- Increasing infrastructure suited to active travel, such as walking and cycling.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH
- An increase in public transport would generate a significant number of jobs in relation to the design of, supply chain to and manufacture of, as well as jobs in operation of vehicles.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Innovation is required for the design of public transport solutions, from vehicle to infrastructure requirements.

SDG 10 - REDUCED INEQUALITIES
- Public transport has strong links with social inclusion and increasing levels of accessibility for all.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Generating space for vegetation and pedestrians.

SDG 13 - CLIMATE ACTION
- Reducing car dependence can lead to a reduction in associated GHG emissions.

SDG 15 - LIFE ON LAND
- Potential to free up space for green infrastructure.

Sources: City of Copenhagen, 2011; UTIP, 2013; UTIP, 2016

SUSTAINABLE BUILDING MATERIALS

Earth, hemp-lime, straw and timber are four sustainable materials covered in the following section. Each material is outlined, and linked to case study examples of where these building materials have been used and a summary of potential positive contribution and negative implications of building with the material on specific SDGs.

The case studies demonstrate that well-placed sustainable materials can make significant contributions to energy and carbon savings, and increase health benefits, earthquake resilience, humidity regulation, community involvement and education. From the global examples considered, a common occurrence is the use of concrete alongside sustainable materials, either for flooring, for damp proofing, to add weight, or to reinforce, or it is added to the material itself. Further research into the implications of this and possible alternatives is needed. It is also evident that further research and building practice in relation to the materials covered are needed to establish and extend their potential.

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B.6 Building with earth

Earth building involves using either unfired bricks or a rammed earth technique, which can be loadbearing and non-loadbearing (Sutton, Black and Walker, 2011). The unfired bricks are made in a similar way to fired bricks – by using compression to form the shape, only without the final process of heating the earth (Sutton, Black and Walker 2011). The rammed earth walls are made by compacting damp earth into layers, traditionally using manual tools but more recently using mechanical compaction, inside a frame. The frame is then removed and the earth dried out (Walker et al., 2005).

Techniques for using unfired earth vary globally depending on climate, materials available and culture (Sutton, Black and Walker, 2011). Working with unfired earth, rather than fired, ensures the embodied energy of the building material is considerably lower (Sutton, Black and Walker, 2011). Often unfired earth is not used for external walls in damper climates, but if it is it must be protected with a render or plaster that is breathable, such as lime or clay, to enable the moisture to move in and out of the earth (Sutton, Black and Walker, 2011).

It is not always possible for earth to be sourced on site, this is due to soil varying in quality and particle size (Walker et al., 2005). To improve reliability, consistency and remove the need for undergoing tests of the soil, builders will use earth from quarries, but this often incurs great transportation distances, adding to the environmental impact of the building (Walker et al., 2005). Both further research and quantification of related GHG reduction potentials need to be undertaken to assess this option further.

The following case studies can be found in section B.5 of the Case Studies:
- **Australia - The Great Wall of WA - 2015**
- **Mali - primary school - 2013**
- **UK - Neil's Yard eco-factory - 2005**

Spotlight on building with earth - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Centre for Alternative Technology (CAT) (image cropped). Inside the Ateic building, CAT, Machynlleth, Wales.

Spotlight on building with earth - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING

- Health and quality of housing are inextricably linked: the material's hygroscopic properties allow it to regulate humidity within the building, creating a healthier internal environment.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Considering industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with building with earth.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Generating housing from a sustainable building material.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION

- Can be easily recycled, safely disposed of or returned to the ground.

SDG 13 - CLIMATE ACTION

- Earth as a material has low embodied carbon.
- When earth is used from quarries it can be transported long distances, adding to the associated impact of the building.

Sources: Walker et al., 2005; Sutton, Black and Walker, 2011

B.7 Building with timber

In recent years the use of timber in construction has decreased, being replaced with non-renewable materials such as concrete, plastic and brick; however, a renewed interest in wood as a material is beginning to emerge due to its carbon storing ability (FAO, 2016a). We have not, however, been able to find specific estimates for the overall GHG reduction potential of this strategy.

The initial decline in timber buildings in Europe is believed to have been due to historical fires in large cities resulting in regulations banning multi-storey wooden framed buildings (FAO, 2016a). The ban was revoked in 1989 however by this time other materials had become more popular and timber was viewed as an inferior material (FAO, 2016a). Now, developed countries are beginning to build with timber again. Japan has even implemented a law that ensures all public buildings below three stories are built from wood (Umeda, 2010; FAO, 2016a).

The use of timber in construction can help mitigate climate change if a large enough supply of sustainable wood can be provided and it is ensured that there are no negative impacts from any associated land use changes (FAO, 2016a). Timber acts as a store of carbon because as trees grow they absorb carbon and when the tree is felled the associated timber continues to act as a store until it starts to break down naturally or is burnt (Davies, 2016). Additionally, an increased use of timber in buildings would hopefully lead to an increase in demand for locally grown timber and related investment in woodland creation and management (Grown in Britain, 2016).

Use of timber varies globally. For example, houses in tropical regions generally make use of timber for roofing alone whereas in North America wood is used throughout many of the houses constructed (FAO, 2016a). In Sweden and Finland, 90% of detached houses are built from wood (FAO, 2016a). In recent years improvements to timber performance (especially young, weaker timber) have been made by advanced methods of adapting timber such as:
- cross-laminated timber;
- glued laminated timber (glulam);
- structural composite lumber; and
- wood I-joists (Green and Karsh, 2012; FAO, 2016a).

The following case studies can be found in section B.6 of the Case Studies:
- **London, UK - Stadthaus - 2009**
- **Norway - Treet - completion estimated 2017**

Spotlight on building with timber - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A


Source: Hakan Dahlström (image cropped), Timber.

Spotlight on building with timber - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- Health and quality of housing are inextricably linked: timber provides good thermal insulation.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- Wood residues can be used as biofuel.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with building with timber.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Improving housing.
- Related investment in woodland creation and management.

- Potential negative impacts from associated land use changes.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION
- Can generally be easily deconstructed and recycled.
- Easy to make adjustments after construction.

SDG 13 - CLIMATE ACTION
- Carbon stored in timber.

SDG 15 - LIFE ON LAND
- An associated increase in woodland could create habitats and increase biodiversity.

Sources: Roos et al., 2010; Davies, 2016; FAO, 2016a; Grown in Britain, 2016

B.8 Building with hemp-lime

Hemp is a plant that has been used for many purposes, including paper, fabric, rope and oil (Sutton, Black and Walker, 2011). It grows easily and quickly in temperate climates and needs no pesticides or herbicides (Sutton, Black and Walker, 2011a). It is believed to be the oldest cultivated fibre plant in the world (Cripps, 2004). After thousands of years of being used the growing of hemp was made illegal in the 1950s in the US and UK due to the association with the drug cannabis, however the law was revoked in the 1990s (Bevan and Woolley, 2008).

It is the woody core of the plant, known as the shiv, that is shredded and used for construction (Sutton, Black and Walker, 2011a). Lime is mixed with the hemp along with water, and occasionally concrete, to create the combination that can be applied to walls within a framework or sprayed onto a lining board (Sutton, Black and Walker, 2011a). Hemp-lime can also be used for floor insulation and roof insulation (Bevan and Woolley, 2008). The material's hygroscopic properties allow it to regulate humidity within the building, creating a healthier internal environment (Bevan and Woolley, 2008). Once hemp is dry it does not need any additional protection, however it will, like any material, be affected by the elements over time (Sutton, Black and Walker, 2011a). Lime render or timber cladding on external walls can be used as weather protection (Bevan and Woolley, 2008). Hemp-lime can also be made into blocks, which can be used to make walls or as an infill inside a frame; however the blocks do not usually have enough strength to be used as load bearing bricks, and often need to be supported (as with the infill hemp-lime) by a frame (Bevan and Woolley, 2008). Further research is necessary to provide quantitative estimates of the GHG reduction potential of building with hemp-lime.

The following case studies can be found in section B.8 of the Case Studies:
- **UK - Adnams Brewery Warehouse and Distribution Centre - 2006**
- **Machynlleth, Wales - the Wise building at the Centre for Alternative Technology (CAT) - 2009**

Spotlight on building with hemp-lime - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Jnzl's Photos (image cropped). Hempcrete wall at CDL Green Gallery.

Spotlight on building with hemp-lime - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- Health and quality of housing are inextricably linked: the material's hygroscopic properties allow it to regulate humidity within the building and it provides good thermal insulation, creating a healthier internal environment.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Considering industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with building with hemp-lime.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Improving housing.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION
- Low embodied carbon.
- Carbon stored in hemp.

SDG 13 - CLIMATE ACTION
- Hemp grows quickly in temperate climates and needs no pesticides or herbicides.

Sources: Bevan and Woolley, 2008; Sutton, Black and Walker, 2011a

B.9 Building with straw bales

Straw is a material that is usually associated with animal bedding and traditional thatching for roofs. However, it is now more frequently being used in building walls. Straw as a building material can be very stable and reliable, as long as it doesn't get wet before, during or after construction (Sutton, Black and Walker, 2011b).

Straw is produced on agricultural lands as a by-product of crops such as wheat, oilseed rape, barley and oats, and in 2007 in the UK 11.9 million tonnes was produced. Some of this straw is collected for use as animal feed and bedding, in mushroom farming, and biomass power stations (Copeland and Turley, 2008). Even after these considerations, an excess of 5.5 million tonnes of surplus could potentially be available for use, which highlights availability without demand for land (Copeland and Turley, 2008). Further research is necessary to provide quantitative estimates of the GHG reduction potential of building with straw.

The following case study can be found in section B.9 of the Case Studies:
- North-eastern China - straw bale housing project - 1999-2004

Spotlight on building with straw bales - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Centre for Alternative Technology (image cropped). Rendering straw walls with clay plaster.

Spotlight on building with straw bales - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- Health and quality of housing are inextricably linked: straw bales provide good thermal insulation.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with building with straw bales.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Improving housing.
- Construction method well-suited to self-build community projects.

SDG 12 - RESPONSIBLE CONSUMPTION AND PRODUCTION
- Any waste product is biodegradable.

SDG 13 - CLIMATE ACTION
- Low embodied carbon.
- Stores carbon for the life of the building.

Sources: Sutton, Black and Walker (2011b)

ENERGY PROVISION

In 2010, buildings accounted for 32% of total final energy use globally (IPCC, 2014). As well as reducing the energy demand of buildings via design and materials choice, it is also important to consider the networks involved in providing energy. In this section increasing energy access sustainably, smart grids, district heating and urban solar are considered.

B.10 Increasing energy access sustainably

Currently it is estimated that over 2 billion people don't have access to adequate, safe, reliable or affordable energy services. 3 billion cook on open fires, with 4.3 million people dying prematurely each year due to indoor air pollution caused by cooking with wood and coal as their energy source (Practical Action, 2016; WHO, 2016). Universal energy access should be more achievable now than ever before as technologies are continually improving and reducing in cost. Barriers to achieving universal access to energy include:

- decision makers struggling to keep up to date with developments in technology; and
- the lack of clear guidance for the incorporation of new technology (Practical Action, 2016).

When funding to improve energy access is made available to a country it doesn't always reach those who don't have access and the IEA (2011a) suggest investing in more off-grid technologies to reach the poorest communities. Things are made more difficult as many different bodies are responsible for access to electricity resulting in poor coordination (Practical Action, 2016). A positive change has happened in Nepal where there has been a successful decentralised governmental annual planning process, which starts at village committee levels and works its way up to a national level (Practical Action, 2016). This method of planning ensures that small communities are included and their energy access is more likely to be addressed (Practical Action, 2016).

Coal projects are more likely to benefit large industries because the connection costs are often too high for individuals, even those living in close proximity to the grid (Granoff et al., 2016). The coal industry also outcompetes smallholders for fresh water sources (Granoff et al., 2016) and the mining of coal can displace whole communities (Downing, 2002). Burning of coal causes air pollution and associated premature deaths, and contributes to climate change (Granoff et al., 2016).

Renewable energy technologies have the potential to create a much more positive impact in getting to zero emissions, while contributing positively to development (Granoff et al., 2016). In the USA the cost of photovoltaics and wind power technologies have reduced by around 85% and 66% respectively since 2009 (Lazard, 2015) and for the first time they are now cost competitive with non-renewable technologies (Granoff et al., 2016). Other benefits of renewable energy include the abundance of the energy source (IPCC, 2012), job creation, a reduction in air pollution and increasing reliability through greater use and understanding (Granoff et al., 2016).

For an example of a programme designed to increase the dissemination of solar powered products in **Rajasthan, India** see **Rajasthan, India - Frontier Markets** in section B.10 of the Case Studies.

Spotlight on increasing energy access sustainably - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: barefoot college (image cropped). Solar trainees at an Africa- solar workshop.

Spotlight on increasing energy access sustainably - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 1 - NO POVERTY

- Energy access is seen as integral to aiding in alleviating poverty.

SDG 3 - GOOD HEALTH AND WELL BEING

- Improved energy access can allow for improved healthcare facilities, alleviation from the health risks of solid fuel stoves, better working conditions and easier completion of household tasks.

SDG 4 - QUALITY EDUCATION

- Electric lighting can enable longer study hours.

SDG 7 - AFFORDABLE AND CLEAN ENERGY

- Renewable energy technologies are continually improving and reducing in cost.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Job creation.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with renewable energy systems.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES

- Energy access can improve social spaces and improve housing.

SDG 13 - CLIMATE ACTION

- Making use of renewable energy technologies is required for decarbonisation of the energy sector.

Sources: Descotte, 2016; Evans, 2016; Practical Action, 2016

B.11 Smart grids

Smart grids can be described as a two-way communication system in connection with energy generation, transmission and distribution (Di Santo et al., 2015). Within the house, the smart meter is connected to an energy management system (EMS), which allows the occupants to view their real-time consumption (Smart Grid, 2016). In addition to the EMS and smart meter there are also smart appliances that respond to remote signals to adjust usage (Smart Grid, 2016).

Smart grids can drastically change the way energy is generated and used, utilising the customers' needs as a benchmark (DECC, 2014). Further research is needed to provide quantification on a local, national and global basis of the contribution that smart grids can make to climate protection, and to better understand the connection smart grids have to implementing the SDGs.

The following case studies can be found in section B.11 of the Case Studies:
- **UK - proposed smart meter roll out**
- **Perth, Australia - Perth Solar Cities**

Spotlight on smart grids - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: Anna Cooke-Yarborough (image cropped). Smart meter, 2017.

Spotlight on smart grids - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- Creates a more efficient network.
- Better energy security.
- Making energy supply less wasteful and more reliable, with easier integration of renewable energy technologies.
- Reduced cost to customers.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH
- Job creation.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with smart grids.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- More customer and community involvement.

SDG 13 - CLIMATE ACTION
- Easier use of low carbon technologies.
- Reducing energy consumption associated with the built environment.
- Incentivising the reduction of carbon emissions.

Sources: DECC, 2014; Smart Energy GB, 2016

B.12 District heating

A district heating network can be described as two or more separate buildings connected to a single heat source or a building with multiple users and units connected to a single heat source (DECC, 2013, p. 2). The heating or cooling of buildings occurs via the circulation of water or steam in insulated pipes (Dincer and Rosen, 2007 cited in Rezaie and Rosen, 2012, p.3). In general district heating allows for an efficient way to heat urban areas from sources where excess heat would otherwise be waste (Carvalho et al., 2016).

The source of this heat can be waste heat from industrial processes but can also include heat specifically generated for the purpose of heating, including by the burning of fossil fuels, the burning of biomass or by nuclear power (Rezaie and Rosen, 2012). The heat can also be sourced from renewable thermal energy sources (Rezaie and Rosen, 2012). Combined heat and power (CHP) plants are those that integrate the production of usable heat and power, generating electricity whilst also capturing the usable heat that is produced in the process (The ADE, 2017). Due to the higher average efficiency of CHP plants district heating is much less carbon intensive than individual heating – if the same fuel is used. If district heating and cooling can be sustainably managed then it will drastically reduce GHG emissions (Patil, Ajah and Herder, 2009 cited in Rezaie and Rosen, 2012, p.2).

In 2013 district heating only accounted for around 11% of global space heating and water heating energy consumption, however in some countries and regions district heating networks are extensive (IEA, 2016). In 2000 Sweden used district heating to heat half of the country (Gebremedhin, 2003 cited in Rezaie and Rosen, 2012, p.3) and Denmark meets around 46% of heat demand with district heating (Lund et al., 2010). In northern China's urban areas, the district heating network covered more than 90% of floor area in 2013 (IEA, 2016).

The following case study can be found in section B.12 of the Case Studies:
- **Copenhagen, Denmark - district heating**

Spotlight on district heating - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A

Source: U.S. Army Corps of Engineers Europe District (image cropped). Section of a boiler at Camp Ederle in Vicenza, Italy, which includes a cogeneration unit that simultaneously produces heat and power by using the escaping waste heat from electricity production to produce steam that helps heat the installation

Spotlight on district heating - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 3 - GOOD HEALTH AND WELL BEING
- A reduction in pollution and related health improvements.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- Makes use of energy that would otherwise be wasted and can be linked to renewable energy.
- Can reduce cost of heating.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with district heating systems.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- District heating enables the use of excess heat that would otherwise be wasted.

SDG 13 - CLIMATE ACTION
- The use of waste heat from industrial processes can reduce the energy usage for heating.
- If district heating and cooling can be sustainably managed, then it will drastically reduce GHG emissions.

Sources: Sotoudeh, 2003 cited in Rezaie and Rosen, 2012, p.2; Patil, Ajah and Herder, 2009 cited in Rezaie and Rosen, 2012, p.2; Carvalho et al., 2016

B.13 Urban solar

What are photovoltaics?

Photovoltaics (PV) relates to the generation of an electric current at the junction of two substances exposed to light (Oxford University Press, 2017). Solar cells are generally used to convert the sun's energy into a flow of electrons (Bokalders and Block, 2010). Initially solar cells generally came in the form of panels that could be bolted onto a roof to generate electricity (Eco Experts, 2007). There are now different forms that solar cells can take including solar tiles, which are an option for a less intrusive roof covering (Eco Experts, 2007; SolarCity, 2017), and PV glass, where the thin photovoltaic layer is applied on top of the glass, which also reduces solar gain heat (a benefit in warmer climates) (Power Technology, 2016).

What is solar heating?

Solar heating is when sunlight is captured and is used to heat either water or space (Bokalders and Block, 2010). There are three main types of solar collectors: flat-plate solar collectors, vacuum solar collectors and concentrating solar collectors.

The cost of solar cell and solar heating technologies has decreased over time because of improvements and increased production (Bokalders and Block, 2010).

The following case study can be found in section B.13 of the Case Studies:
- **Edinburgh, Scotland - community solar project**

Spotlight on urban solar - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	None found	N/A	N/A


Source: Andy Hales (image cropped). Solar panels and solar thermal collectors in Freiburg, Germany.

Spotlight on urban solar - Sustainable Development Goals

A summary of the potential positive contribution to implementation of specific Sustainable Development Goals.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- Solar power is a form of decentralised, renewable energy.
- The cost of solar cells and solar heating technologies has reduced over time because of improvements and increased production.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE
- Industry, innovation and infrastructure in relation to research, design, construction and maintenance associated with photovoltaics and solar heating systems.

SDG 11 - SUSTAINABLE CITIES AND COMMUNITIES
- Solar cells and solar heating are suited to community energy projects.

SDG 13 - CLIMATE ACTION
- Solar energy is renewable.

Sources: Bokalders and Block, 2010; ECSC, 2015

C.

CARBON DIOXIDE REMOVAL SOLUTIONS

Carbon dioxide removal (CDR) techniques involve removal of CO_2 from the atmosphere (The Royal Society, 2009). The main policy research effort so far has focused primarily on the role of bioenergy with carbon capture and storage (BECCS), and afforestation and reforestation (Smith et al., 2015). A key question is whether global emissions can be kept in line with the 2ºC/1.5ºC goals set out Paris without recourse to large-scale deployment of BECCS given potential negative implications for the SDGs. Most recent scenarios from integrated assessment models require large-scale deployment of CDR technologies to have a greater than 50% chance of limiting warming below 2ºC (Smith et al., 2015).

The majority of CDR techniques involve the use of land and water, some use fertiliser and some may impact upon albedo (Smith et al., 2015). The land, water and nutrient requirements, GHGs removed or emitted, energy produced or demanded, cost, and side effects of different methods varies greatly and also depends on the nature and scale of their deployment (Smith et al., 2015). In this way, it is important to focus on a CDR portfolio as opposed to concentrating on one specific method (Smith et al., 2015). Many scientific assessments concur that a heavy reliance on removal of carbon dioxide in the future would be extremely risky and a failure for methods to deliver would leave no 'plan B' (Smith et al., 2015). Aggressively reducing GHG emissions at source must remain the main objective in addressing climate change (Smith et al., 2015) and continued policy focus on climate change mitigation and adaptation is required (The Royal Society, 2009). The complex governance issues surrounding both research into and potential implementation of CDR techniques also need to be researched and resolved (The Royal Society, 2009).

There are limits to the CO_2 storage capacity of most CDR methods, which means that they do not represent a substitute to decarbonisation and would need to be phased out as early as possible (Allen et al., 2013). The terminology of "removal' is also imprecise and misleading due to the potential for re-release from various stores, such as gradual decay of biochar in soils and diffuse leakage from geological storage (Lomax et al., 2015).

Many mitigation pathways that aim to keep warming below 2ºC/1.5ºC assume carbon dioxide removal as high as 1,000 GtCO2 and it has been highlighted that carbon dioxide removal techniques cannot safely be relied upon to fill such a large gap (Kartha and Dooley, 2016). The dangers being that large-scale deployment of techniques may involve unacceptable ecological and social impacts, that some techniques may ultimately prove infeasible, and that some techniques may prove less effective than hoped (Kartha and Dooley, 2016). Impacts of climatic change exacerbated by delayed mitigation that could prove partially or wholly irreversible include species extinctions, coral reef death, ocean acidification and loss of sea and land ice (Kartha and Dooley, 2016). The loss of sea and land ice could create additional warming through, for example, albedo effects or methane emissions (Kartha and Dooley, 2016).

In this report the following CDR techniques will be considered in terms of their potential to contribute to the SDGs:

B.1 Afforestation and reforestation
B.2 Bioenergy with carbon capture and storage (BECCS)
B.3 Biochar
B.4 Direct air capture (DAC)
B.5 Enhanced Weathering

Cloud treatment with alkali, ocean fertilisation and ocean treatment with alkali will also be discussed briefly, however these are not deemed viable options in the prevailing literature.

Carbon dioxide removal solutions

C.1 Afforestation and reforestation

It has been estimated that afforestation, reduction in deforestation and forest management could have a mitigation potential of between 1.9 and 5.5 $GtCO_2$-e per year in 2040 (FAO, 2016a). By way of comparison, in 2010 the emissions of the EU-28 were 4.4 $GtCO_2$-e and those of the US were 5.9 $GtCO_2$-e (Boyd, Stern and Ward, 2016).

Both afforestation and reforestation refer to trees being established on land that had been without trees. The difference between the terms is that reforestation refers to land that was cleared of trees in the recent past whereas afforestation refers to land that has not had tree cover for a much longer period, sometimes defined as not being in recorded history (Watson et al., 2000).

There is no agreement on how to optimise forest management for climate change mitigation because it is a complex issue and is still subject to scientific debate with many different values and assumptions that are contested (Creutzig et al., 2014).

It is widely recognised, however, that there is a danger that forests designed specifically for measurable carbon capture will comprise largely of dense monocultures of fast growing tree species, such as eucalyptus and acacia, and that these plantations would be largely in the tropics where growth rates are fastest (Pearce, 2016) yet where there is intense competition for land to secure food and fuel. Many tree planting programmes established as part of carbon offsetting schemes have been dogged by claims of false carbon accounting, and fears over permanence and land grabbing (Pearce, 2016). There is the risk of non-permanence because offsetting schemes could be damaged by droughts, migrating pests, forest fires or poor land management decisions, which would lead to the release of their carbon stores back into the atmosphere (Pearce, 2016). Degradation in relation to the establishment of monoculture plantations would contribute to food insecurity, undermining livelihoods, loss of biodiversity and the depletion of scarce resources (Kartha and Dooley, 2016). Commercial plantations also require high inputs of nutrients and water without commensurate benefits for local communities (Kartha and Dooley, 2016).

Some of these negative implications could be addressed by better project design. A recent study has shown that afforestation and reforestation programmes are improved if native vegetation is taken into consideration, especially in relation to water requirement of vegetation highlighting the importance of observing the local ecosystem before planting large-scale woody vegetation (Zheng et al., 2016).

A study in Sicily demonstrated that carbon sequestration in the soil under artificially afforested sites using pine was not suitable when compared to the carbon sequestration achieved in soils under naturally afforested locations through spontaneous secondary succession processes (Rühl et al., 2016). Chazdon et al. (2016) highlight the need to establish a better set of forest definitions where the quality and type of tree cover, along with placement in a dynamic landscape, have all been considered. A study in Europe established that it is very important to consider forest management practices carefully because otherwise increased afforestation can fail to result in net CO_2 removal from the atmosphere and have a warming impact (Naudts et al., 2015). This is because wood extraction releases carbon otherwise stored in the biomass, dead wood, leaf litter and soil (Naudts et al., 2015). In particular, the conversion of deciduous forest into coniferous forest can lead to changes in albedo, canopy roughness and evapotranspiration from the land, which can contribute to warming (Naudts et al., 2015).

These case studies contain important lessons for reorienting afforestation schemes to achieve greater compatibility between the SDGs and climate protection. Many monoculture tree plantations are funded by international climate finance mechanisms. These mechanisms need to recognise the negative impacts of these plantations on communities and biodiversity if the SDGs and the Paris Agreement are to be successfully aligned (Global Forest Coalition, 2016) through afforestation and reforestation programmes.

If properly designed, forests can also have significant positive impacts on local hydrologic and thermodynamic cycles in relation to climate change adaptation and mitigation, and in tropical and temperate regions, forests have a cooling effect (Ellison et al., 2017). It is in high latitudes where there is the potential for forests to reduce albedo and cause local warming (Ellison et al., 2017). The complex relationship between tree type, location and management needs to be recognised (Ellison et al., 2017). Not all forest management practices contribute to climate change adaptation and mitigation, and it is important to research and establish effective ways of establishing and managing forests, so they contribute to climate change adaptation and mitigation, and also enable wood production and the continuation of other ecosystem services (Naudts et al., 2015).

In all cases, however, the permanence of the carbon sequestered and stored in trees needs to be considered. This carbon can be released following natural mortality or through disturbances such as forest fires and pest outbreak. Once trees are harvested, the carbon is stored in the wood throughout the lifetime of the product becomes, but in the long run this will be released again in decay. In this way, mitigation projects require the related trees to be in place for the long-term which in turn requires effective systems of governance (FAO, 2016).

Opportunities offered by native trees over increasing cases of monoculture plantations, using China's Grain-for-Green programme as an example, can be found in section C.1 of the Case Studies in **China - Grain-for-Green Programme**, highlighting the opportunities for native forest to align climate protection, biodiversity and other ecological goals.

Spotlight on afforestation and reforestation - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Estimated removal of between 1.1 (mean) and 3.3 (maximum) GtC-eq per year in 2100. It has been estimated that afforestation, reduction in deforestation and forest management could have a mitigation potential of between 1.9 and 5.5 $GtCO_2$-eq per year in 2040.	Smith et al. 2015 FAO, 2016a

Spotlight on afforestation and reforestation - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- Forests are important for ensuring food security.

- Monoculture plantations do not provide the food source benefits that diverse forest ecosystems do.

SDG 6 - CLEAN WATER AND SANITATION

- Forests are important for ecosystem services, including clean water and storm-water control.

- Commercial plantations require high land and water inputs.

SDG 8 - DECENT WORK AND ECONOMIC GROWTH

- Forests and forest products make a significant contribution to the lives of rural communities.

- Land degradation in relation to monoculture plantations can undermine livelihoods.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Industry, innovation and infrastructure associated with afforestation and reforestation practices.
- Research into effective sustainable forest management.

SDG 13 - CLIMATE ACTION

- The place of forests within the carbon cycle mean that actions affecting forests have a large impact on GHG emissions, which makes forest conservation and restoration important aspects of climate change mitigation.

- Monoculture plantations are less resilient, which risks re-release of carbon stores.
- Monoculture plantations do not provide carbon storage comparable to natural afforestation.

SDG 15 - LIFE ON LAND

- Forests are important for conservation of biodiversity.
- Forests have an important role in the regulation of temperature and fresh water flows.

- Monoculture plantations would have a detrimental effect on biodiversity.

Sources: Angelsen, 2011, cited in Suzuki, R., 2012, p. 6; Stevens et al., 2014; UN-REDD, 2015; FAO, 2015; FAO, 2016; Hua et al., 2016; Pearce, 2016; Kartha and Dooley, 2016; Rühl et al. 2016; Ellison et al., 2017

C.2 Bioenergy with carbon capture and storage

Bioenergy with carbon capture and storage (BECCS) is currently the most widely discussed option for removal of CO_2 from the atmosphere. BECCS refers to the process of capturing CO_2 originating from the use of biomass in energy production (Selosse and Ricci, 2014). It is the combination of bioenergy, and carbon capture and storage (CCS) (Price, Littleton and Le Quéré, 2016). Out of the IPCC Fifth Assessment Report Working Group III scenarios about half include more than 5% of their energy mix from BECCS by 2100 (IPCC, 2014; Price, Littleton and Le Quéré, 2016, Rockstrom, 2017).

BECCS is based on the idea that growing biomass absorbs CO_2 from the atmosphere through photosynthesis and releases it during transformation or combustion. If the released CO_2 is captured and stored in geological storage sites, this would theoretically result in negative CO_2 emissions (Gough and Vaughan, 2015).

One estimate for carbon storage potential has been 3.3 GtC-eq per year in 2100 (Smith et al. 2016). The climate change mitigation value of technologies involving bioenergy systems is difficult to quantify because it depends on a range of site and case specific factors (Creutzig et al., 2014).

A rapid growth in the use of bioenergy is anticipated even without considering climate policies to achieve the Paris temperature limits because of continued development of options, technologies and infrastructure (Schleussner et al., 2016b). When considering scenarios that include a temperature increase limits of 2°C/1.5°C bioenergy is assumed to be combined with CCS. In both cases, it is important to consider the potential problems associated with large-scale biomass use, which include potential negative impacts in relation to food security, water availability, nutrient availability, biodiversity and societal dimensions surrounding land use (Schleussner et al., 2016b). How much biomass is available for energy in the future will depend on the progression of a range of social, political, technological and economic factors (Creutzig et al., 2014).

What is the potential for BECCS implementation on a large scale?

Experts have highlighted the reliance of many integrated assessment models on BECCS specifically, with concerns surrounding unrealistic assumptions about future availability and performance of the technology, which could risk overshooting critical warming limits (Fuss et al., 2014; Lomax et al., 2015; Smith et al., 2016; Vaughan and Gough, 2016). BECCS technology is still in its infancy and most discussion about its assumed future implementation is largely speculative, with numerous limitations to the widespread adoption of the technology (Keith and Rhodes, 2002; AVOID2, 2015a; Muratori et al, 2016; Price, Littleton and Le Quéré, 2016).

It has been argued that the use of woody biomass specifically for energy cannot be automatically considered as a carbon-neutral process (Brack, 2017). Carbon dioxide is produced when biomass is burnt in the presence of oxygen, methane emissions are produced in relation to the storage of wood pellets and wood chips, and nitrous oxide emissions are increased due to greater use of fertiliser (Brack, 2017). It is also important to consider GHG emissions in relation to harvesting, collecting, processing and transporting throughout the supply chain of woody biomass (Brack, 2017). There is also the risk that intensification of forestry to supply wood pellets may lead to the replacement of naturally regenerating forests with planted monocultures (Pearce, 2016).

Some forms of woody biomass feedstock can be genuinely carbon neutral. For example, sawmill residues are a waste product from other forest operations and require no additional harvesting. They would otherwise be burnt or left to rot, which would release carbon into the atmosphere. Black liquor is another waste product from the kraft process, which is the process of conversion of wood into wood pulp. Black liquor is generally burnt on site in recovery boilers to generate energy for the mill and often for export to the local electricity grid as well. This process also allows some chemicals used in the kraft process to be recovered. Unless black liquor is used in this way it has to be carefully disposed of as it is highly polluting substance. (Brack, 2017)

The use of forest and agricultural residues is generally beneficial for climate protection and for the SDGs, however it is important to consider and mitigate potential adverse side effects. These can include impact on biodiversity, loss of soil carbon and associated loss of fertility. These impacts can be difficult to assess because they depend on case specific conditions in relation to the residues. Alternative use of the residues also needs to be considered, such as for bedding or as fertiliser. (Creutzig et al., 2014)

Bioenergy production can be integrated with existing CCS technologies relatively simply and there are no technical implications of capturing a CO2 stream from biomass (Gough and Upham, 2010; Muratori et al., 2016). BECCS could complement the current expansion of the use of biomass as fuel (Rhodes and Keith, 2008). However, the success of BECCS is dependent on upcoming developments in CCS, where there are significant uncertainties surrounding CO2 transport networks, storage capacities, legality, social acceptability and technology incentives (McGlashen, Shah and Workman, 2010).

Current uncertainties surrounding future deployment of BECCS underlines the need to enhance understanding through more research and development (Schaeffer et al., 2015), including from the various pilots and BECCS trials discussed below. It also highlights the importance of not relying on future large-scale implementation of BECCS and to instead focus on emissions reductions today from the rapid phase out of fossil fuel related emissions (Anderson and Peters, 2016).

There are around 15 pilot scale BECCS plants globally that are active or soon to come online (Gough and Vaugan, 2015; Global CCS Institute, 2010; Shwartz, 2013). For more detail one of these, the Archer Daniels Midland plant in Illinois, see **Illinois, US - Archer Daniels Midland plant** in section C.2 of the Case Studies.

Spotlight on bioenergy with carbon capture and storage - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Estimated removal of 3.3 GtC-eq per year in 2100.	Smith et al. 2015

Spotlight on bioenergy with carbon capture and storage - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER

- Conversion to biomass cropping could increase pressure on food security.

SDG 6 - CLEAN WATER AND SANITATION

- Biomass production is fundamentally subject to water availability.
- The implementation of BECCS to remove 3.3 Gt Ceq yr-1 by 2100 would require an increase in freshwater demand, on top of that already appropriated for human use, of around 3%.

SDG 7 - AFFORDABLE AND CLEAN ENERGY

- As biomass energy plants are typically smaller than conventional fossil power plants, which could help provide energy where more decentralised provision is required.
- Biomass is a low-emission energy product.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Research into and development of BECCS.

SDG 10 - REDUCED INEQUALITIES

- Vulnerable communities may be put at risk of land-grabs and other rights abuses.

SDG 13 - CLIMATE ACTION

- Growing biomass absorbs CO_2 from the atmosphere through photosynthesis and releases it during transformation or combustion, if the CO_2 released is captured and stored it theoretically results in negative CO_2 emissions.

SDG 15 - LIFE ON LAND

- Conversion to biomass cropping could lead to deforestation, bring biodiversity losses and cause soil degradation

Sources: Rhodes and Keith, 2008; Smolker and Ernsting, 2012; Selosse and Richi, 2013; Andersen, 2015; Gough and Vaughan, 2015; Pearce, 2016; Smith et al., 2016

C.3 Biochar

Biochar is the high-carbon residue from the pyrolysis of biomass. Pyrolysis is the thermal decomposition of biomass in the absence of oxygen, which does not allow full combustion to occur (Windeatt et al., 2014). The returning of biochar to soil rather than burning it and producing CO_2 sequesters the atmospheric carbon removed by the plants during growth, creating a potentially carbon-negative cycle (Matthews, 2008; Mattila et al., 2012).

Using biochar to improve soil fertility has been estimated to provide the potential carbon storage of between 0.7 and 1.8 GtC-eq per year (Woolf et al 2010; Smith 2016). The use of biochar is increasingly discussed as a potential technology for CO_2 removal from the atmosphere, alongside improving soil quality, food security and water management (Windeatt et al., 2014). Some research has highlighted the conversion of biomass to biochar as the most promising method for sequestering carbon (McHenry, 2009). However, it is important to bear in mind that the potential carbon storage relating to and impacts of intensive, industrial-scale biochar carbon storage is not currently known (Hansen et al., 2016).

Research in the area is still new and best practices are not yet fully developed (Windeatt et al., 2014). Communities in the Amazon region have a lengthy history of biochar use for crop productivity (Lean, 2008). Commercial expansion of a biochar production sector has only just begun and it is expected that this will grow rapidly (An and Huang, 2015). As with BECCS, research and data need to be gathered in more detail before the role of biochar in securing the Paris Agreement and SDGs can be fully understood.

The following case studies shed some light on the use of biochar and can be found in section C.3 of the Case Studies:
- **Haiti - biochar production**
- **Liberia and Ghana, Africa - biochar use**

Spotlight on biochar - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Using biochar to improve soil fertility has been estimated to provide the potential carbon storage of between 0.7 and 1.8 GtC-eq per year.	Woolf et al. 2010 Hansen et al., 2016 Smith 2016


Source: Oregon Department of Forestry (image cropped)

Spotlight on increasing biochar - Sustainable Development Goals

A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 2 - ZERO HUNGER
- Higher crop yields.
- Minimal effect on land use.

SDG 6 - CLEAN WATER AND SANITATION
- Greater water retention improves water management.
- Water is not used directly in biochar production.

- There would be irrigation requirements of any biochar feedstock growth.

SDG 7 - AFFORDABLE AND CLEAN ENERGY
- The biochar production process can yield oil and gaseous products as forms of renewable energy.

SDG 9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE
- Research into and development of biochar production and use.

SDG 13 - CLIMATE ACTION
- Biochar sequesters the atmospheric carbon removed by the plants during growth, creating a potentially carbon-negative cycle.

SDG 15 - LIFE ON LAND
- Improved soil chemistry and reduced nutrient losses can lead to a rise in soil biota.

- Biochar can become a sink for anthropogenic soil pollutant chemicals.

Sources: Matthews, 2008; Lehmann, 2010; Mattila et al., 2012; Smetanová et al., 2013; Windeatt et al., 2014; An and Huang, 2015; Smith, 2016; Vochozka et al., 2016

C.4 Direct air capture

Direct air capture (DAC) is the term used for the attempt at selective removal of CO_2 directly from atmospheric ambient air flows over chemical sorbents, resulting in a concentrated stream of CO_2 for storage or reuse. This principle can be deployed throughout a range of different engineering formats (Pritchard et al., 2015; Chen and Tavoni, 2013, Socolow et al., 2011).

CCS from concentrated point source emissions has received a much greater research focus than DAC. However, because roughly half of CO_2 emission sources come from small, decentralised fossil fuel burning units (like car engines) universal point source collection is not practical or economical (Geoppert, et al., 2012). Even if direct air capture becomes significantly cheaper it is likely that it could only meaningfully contribute to global mitigation once all point-sources of emissions are accounted for (Pritchard et al., 2015, Socolow et al., 2011). Initial estimates suggest that investment requirements required by DAC are currently significantly higher than those considered necessary for BECCS (Smith et al., 2015).

Preliminary findings on the role of DAC can be found in the following case study in section C.4 of the Case Studies:
- **British Columbia, US - Carbon Engineering DAC pilot plant**

Spotlight on direct air capture - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Estimated removal of 3.3 GtC-eq per year in 2100.	Smith et al. 2015

Spotlight on direct air capture - Sustainable Development Goals
A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 6 - CLEAN WATER AND SANITATION

- If an aqueous solvent is used in the CO_2 capture processes the technology could consume large amounts of water.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Potential research into and development of direct air capture.

SDG 13 - CLIMATE ACTION

- Attempts selective removal of CO_2 directly from atmospheric ambient air flows over chemical sorbents for storage or reuse.

- Requires significant energy inputs.

Sources: Simon et al., 2011; Socolow et al., 2011; Chen and Tavoni, 2013; Pritchard et al., 2015; Smith et al. 2015

C.5 Enhanced weathering

Enhanced weathering is the sequestration of CO_2 from the atmosphere via the dissolution of silicate minerals (Renforth, 2012). Silicate minerals are naturally occurring in igneous rocks and to speed up the natural weathering process, these igneous rocks are crushed into a fine powder (Renforth, 2012). These crushed rocks are then spread either onto soil or the ocean (Carbon Brief, 2016) and when these silicate minerals are dissolved, calcium and magnesium are released and are able to react with CO_2 (Renforth, 2012). The resulting bicarbonate eventually washes into the oceans where it is then stored on the sea floor (Carbon Brief, 2016). Increasing bicarbonate in the oceans would not only sequester CO2 but it might also partially counterbalance ocean acidification by increasing alkalinity (Hartmann et al., 2016). Again, as with DAC, initial estimates suggest that the costs of implementing enhanced weathering would be higher than those considered necessary for BECCS (Smith et al., 2015).

To date, there has been no experimental data published on the findings of enhanced weathering (Berge et al., 2012, cited in Hartmann et al., 2013, p.121) and therefore all suggested positives and negatives of this solution in terms of climate protection and contribution to the SDGs are largely theoretical.

Spotlight on enhanced weathering - GHG reduction potential

	Yes/No	Detail of estimates	Source/s
Are there estimates available for GHG reduction potential?	Yes	Estimated removal of between 0.2 (mean) and 1.0 (maximum) GtC-eq per year in 2100.	Smith et al. 2015

Spotlight on enhanced weathering - Sustainable Development Goals
A summary of the potential positive contribution to and negative implications for implementation of specific Sustainable Development Goals.

SDG 9 - INDUSTRY INNOVATION AND INFRASTRUCTURE

- Potential research into and development of enhanced weathering.

- The movement of large quantities of rock required for large scale enhanced weathering would demand extensive infrastructure and distribution networks, which may not coincide with the locations that are most suited to the process.

SDG 13 - CLIMATE ACTION

- Could reduce CO_2 levels in the atmosphere.

- The consequences and effects of enhanced weathering are not fully understood.
- Requires significant energy inputs.

SDG 14 - LIFE BELOW LAND

- Potential to reduce the acidity of water could reduce stress on coral reefs in tropical locations.

- Tracking and monitoring would be difficult but would be required to highlight any possible contamination, such as heavy metals, and changing pH levels in water.

SDG 15 - LIFE ON LAND

- Enhanced silicon levels in the soil could improve plant health.

- Tracking and monitoring would be difficult but would be required to highlight any possible contamination, such as heavy metals, and changing pH levels in water.

Sources: Van Straaten, 2002; Hernandez and Torero, 2011, cited in Hartmann et al., 2013, p.130; Hangx and Spiers, 2009, cited in Hartmann et al., 2013, p.130; Hartmann et al., 2013; Smith et al. 2015; Taylor et al., 2016

A brief look at other carbon dioxide removal methods

Cloud treatment with alkali, ocean fertilisation and ocean treatment with alkali are three further concepts that have recently been presented in literature surrounding carbon dioxide removal. They are not deemed viable options by the bulk of scientific opinion due to their potential large scale negative implications and the fact that they raise genuine moral hazard concerns. Consequently are only briefly outlined in this section.

Cloud treatment with alkali

The concept was initially created by Langmuir and Schaefer (1937, cited in Amirova and Tulaikova, 2015, p.1) in 1937 and involves spraying alkaline compounds into clouds to cause the precipitation to increase in alkalinity, which in turn will increase CO_2 solubility in water (Amirova et al., 2015; Amirova and Tulaikova, 2015). The precipitation transports the CO_2 to the ground, then to plants and groundwater (Amirova and Tulaikova, 2015).

Despite being initially developed in 1937 this process does not appear to be viable, as all study appears to remain theoretical.

Ocean fertilisation

The concept of ocean fertilisation is to remove CO_2 from the atmosphere by increasing the supply of one or more nutrients to surface ocean waters. The intention is to artificially assist the growth of phytoplankton (free-living microscopic marine plants), which use CO_2 in photosynthesis and ultimately sink to the deep ocean. Nutrients, particularly iron, are often limiting factors to phytoplankton growth (Robinson et al., 2014; Williamson et al., 2012; Lampitt et al., 2008).

Trial studies to thoroughly assess the effectiveness of ocean fertilisation on a large-scale would require analysis of thousands of square kilometres of ocean over many months or years along with a combination of observation and modelling, which presents major logistical and financial hurdles (Watson et al., 2008). So far studies have largely been limited to demonstrating the impact of iron fertilisation on phytoplankton growth, and not CO_2 removal (Williamson et al. 2012). There is a range of potential negative side-effects associated with ocean fertilisation including an increase in the production of gases such as CH_4 by marine microorganisms, unforeseen consequences in areas of ocean large distances away, an increase in acidification rates deeper in the ocean and the stimulation of growth of harmful toxin-producing marine microscopic plants (Wingenter et al., 2004; Denman, 2008; Gnanadeskian and Marinov, 2008; Lampitt et al., 2008; Cao and Caldeira, 2010; Williamson et al., 2012; Robinson et al., 2014). At present, the better legal view is that ocean fertilisation would appear to contravene customary and treaty based international law obligations (Freestone and Rayfuse, 2008; Wilson, 2013).

Ocean treatment with alkali

The direct liming of oceans was initially designed by Chishti (1995, cited in Rentforth, Jenkins and Kruger, 2013, p.2) who believed that the change in pH would draw CO_2 from the atmosphere into the ocean to form a natural equilibrium between the two locations (Renforth et al., 2013). This concept involves adding soluble minerals on top of the ocean (Kheshgi, 1995, cited in Paquay and Zeebe, 2013, p.184) either in the form of calcium or magnesium oxide (Renforth et al., 2013). This would theoretically neutralise the carbonic acid in the ocean and to create the natural equilibrium the ocean would potentially draw down CO_2 from the atmosphere (Renforth et al., 2013). Whilst being theoretical, the process would also have a series of side effects including water pollution where the lime is added, disturbance of ecosystems where the lime is extracted and further potential environmental implications that would be difficult to predict (Ilyina et al., 2013; Renforth et al., 2013). As with ocean fertilisation, this process would also likely fall foul of international law given the significant, irreversible risks and unknown negative effects for oceans and marine life.

CONCLUSIONS

The abundance of solutions set out in this Report shows the world already has the technologies at its finger tips to turn away from fossil fuels and towards a vision of social and economic development that is aligned with the SDGs and based on climate protection.

Some of these solutions could begin to deliver very significant SDG benefits whilst also reducing large amounts of GHG reductions in relatively short timeframes if the right policy and financial incentives were put in place and the distorting subsidies to fossil fuels removed.

Rapid deployment of these solutions should be an urgent political priority given the critical need to raise global levels of mitigation ambition before 2020.

Dietary changes, for example, could lead to dramatic reductions of between 4.3 and 7.8 $GtCO_2$-eq per year whilst promoting forest conservation and restoration could deliver a mitigation potential of between around 2.3 and 5.8 $GtCO_2$-eq per year. To put these figures in perspective, it is important to note that Decision 1/CP.21 adopting the Paris Agreement stated that least-cost 2ºC scenarios would require global emissions to be around 40 gigatonnes in 2020 whereas the aggregate emissions resulting from the intended Nationally Determined Contributions countries have committed to at Paris lead to a projected level of 55 gigatonnes by 2030 (UNFCCC, 2015).

The 1.5ºC pathway would require more stringent and earlier emissions reductions to close the gap in emissions between the Paris and SDG goals but this still remains technically feasible.

The good news is that change is happening must faster on the ground than models and research papers are able to capture. For example, China’s coal use has shrunk dramatically in just two years going from growth of 3.7% per year in 2013 to now contracting at a rate of 3.7% by 2015 (BP, 2016). At the November 2016 Marrakech meeting of the UNFCCC Parties, fifty of the world’s most vulnerable countries committed to going carbon neutral (net-zero) by 2050 in spite of the election of a climate denying Administration in the USA.

We hope this Report will help countries and stakeholders take up solutions that weave together achievement of the SDGs and climate protection policies that have the effect of keeping the below 2ºC/1.5ºC pathway open. But we are conscious that much more research needs to be undertaken to fill knowledge gaps and to provide comprehensive, costed roadmaps for each country that integrate the SDGs and climate action on their own terms and priorities.

ABBREVIATIONS

AFOLU	Agriculture, forestry and other land use
BECCS	Bioenergy with carbon capture and storage
BREEAM	BRE Environmental Assessment Method
CAT	The Centre for Alternative Technology
CCS	Carbon capture and storage
CHP	Combined heat and power
CDR	Carbon dioxide removal
CMP	The Cloudburst Management Plan (Copenhagen, Denmark)
CWR	Crop wild relatives
DAC	Direct air capture
ECSC	The Edinburgh Community Solar Co-operative (Edinburgh, Scotland)
EMS	Energy management system
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GI	Green infastructure
glulam	Glued laminated timber
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
PV	Photovoltaics
SDG	Sustainable Development Goal
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
ZEBs	Zero energy buildings

UNITS AND CHEMICAL FORMULAS

ºC	Degrees Celsius
C	Carbon
C-eq	Carbon equivalent
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
gC	Grams of carbon
Gt	Gigatonnes - a gigatonne is a unit of mass equal to 10^9 (one billion) tonnes
ha	Hectare - 100 metres by 100 metres
Kwh	Kilowatt-hour
m^2	Square metre
Mg	Milligrams - a milligram is a unit of mass equal to 0.001 grams
Mt	Megatonne - a megatonne is a unit of mass equal to 10^6 (one million) tonnes
N_2O	Nitrous oxide
Pg	Petagram - a petagram is a unit of mass equal to 10^{15} (one quadrillion) grams
pH	Potential of hydrogen is a numeric scale used to specify the acidity or basicity of an aqueos solution - solutions with pH less than 7 are acidic and solutions with pH greater than 7 are basic
t	Tonne
Tg	Teragrams - a teragram is a unit of mass equal to 10^{12} (one trillion) grams
tonnes	Unit of mass equal to 103 (one thousand) kilograms or 10^6 (one million) grams
W/m^2K	Thermal transmittance or U-value - the rate of transfer of heat (in watts) through one square metre of a structure, divided by the difference in temperature across the structure (expressed in watts per square metre kelvin, or W/m^2K)

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A.

AGRICULTURE, FORESTRY AND OTHER LAND USE SOLUTIONS

CASE STUDIES

Agriculture, forestry and other land use solutions - case studies

A.1 Improving soil health

Australia - potential for increasing soil carbon levels

In Australia, it has been estimated that in a lot of areas there has been a decrease in soil organic carbon levels of up to 50% when compared to pre-agricultural periods (Chan, 2008). The majority of this reduction in soil organic carbon occurs in the surface soil layer, around 0-10cm (Chan, 2008). There is a limit to the amount of organic carbon that can be stored in soils but because there have been large losses caused by agricultural practices in Australia there is the potential for large increases in soil organic carbon (NSW Government, 2008). Some of the practices encouraged to increase soil organic carbon include:

- Reducing or eliminating tillage and retaining stubble from previous crops, which is often known as conservation farming
- Improving crop management, e.g. through better rotation of crops
- Maintaining trees, increasing the number of trees and improving tree management
- Improving management of grazing
- Adding organic materials to the soil, e.g. composts and manures (Future Farmers, 2017)

Agriculture, forestry and other land use solutions - case studies

A.2 Dietary changes

Germany - German environment minister banning meat at official functions

In January 2017 Germany's environment minister, Barbara Hendricks, announced that Germany's environment ministry would no longer serve meat, fish or meat derived products at official functions. The reason for this ban was because animal agriculture is a leading cause of climate change and environmental degradation and Hendriks wanted the environment ministry to act as role model on environmental and sustainability issues. The mandate also stated that meals served should be organically sourced, transported short distances, with preference towards seasonal, local and fair-trade products.

(Mosbergen, 2017)

Agriculture, forestry and other land use solutions - case studies

A.3 Reducing food loss and waste

France - food waste law

Following a grassroots anti-food waste campaign in France a law was passed in 2015, which requires supermarkets to first aim to re-distribute food destined to become waste and to deal with any waste more responsibly (Schiller, 2015; Chrisafis, 2016). The law also makes it simpler for excess products from factories to go direct to food banks (Chrisafis, 2016). Supermarkets could face fines of up to €75,000 if they don't sign contracts with charities involved in redistribution (Schiller, 2015) and can claim a tax break when they do redistribute food (Varney, 2016). France now redistributes around 100,000 tonnes of food to charities in a year (Sheffield, 2016).

Italy - food waste law

In 2016 Italy adopted a new law with the aim to cut its estimated annual food waste of five million tonnes by one million (BBC News, 2016). Health and safety laws and complex procedures surrounding donating food had made it difficult for businesses to try and reduce food waste and the new law hopes to make it easier to donate food (BBC News, 2016). Now businesses will only be required to record donations in an uncomplicated, monthly form, they will also not risk penalty for giving away food that is passed its sell-by date and they will pay less waste tax by re-directing food away from waste streams (BBC News, 2016). In contrast to the French law, supermarkets don't face fines for failing to sign contracts with food waste charities and reducing waste is instead incentivized (BBC News, 2016). Italy now redistributes around 86,000 tonnes of food to charities in a year (Sheffield, 2016).

UK - food waste inquiry

More than 8 million people in the UK struggle to get and provide enough food to eat, however it is currently a lot cheaper to convert edible food to animal feed or send it for anaerobic digestion than redistribute it (Varney, 2016). An inquiry was launched into food waste in England in July 2016, which includes looking into redistribution, how voluntary initiatives contribute and if there is a need for legislation (UK Parliament, 2016). The inquiry will also look into the food waste from homes, which makes up 85% of food waste post-manufacture each year, an estimated 7 million tonnes (UK Parliament, 2016). It is estimated that the elimination of just household food waste in the UK could reduce GHG emissions by around 17 million tonnes CO_2-eq per year (UK Parliament, 2016).

International - the Real Junk Food Project

Adam Smith, a professional chef, set up the Real Junk Food Project in the UK in 2013. The project now intercepts between two and ten tonnes of food a day with 125 Real Junk Food cafés worldwide, creating pay as you eat meals from food that would otherwise be wasted. Examples of this set up can now be found across the UK and in Israel, Australia, France, and Germany, and is soon to launch in the United States (The Real Junk Food Project, 2016; Cadwalladr, 2016). Another initiative set up by the Real Junk Food Project is called Fuel for School, providing food after assemblies and at breakfast time in primary schools in deprived areas of Leeds. This managed to feed 10,000 children across the city entirely with waste food one day last autumn (Cadwalladr, 2016). As the project was intercepting food at such a high level they have now set up their first supermarket in Leeds, which is called 'the warehouse', where customers pay what they can afford for food that would otherwise be disposed of (Moss, 2016).

Denmark - selling and using food waste

In Denmark, the world's first food waste supermarket was opened in Copenhagen in February 2016 by the charity Folkekirkens Nødhjælp, with a second planned for Copenhagen and a third for Denmark's second biggest city, Arhus (Sheffield, 2016). In the city of Horsens, a social housing project called Bo Welfare runs a food waste pop-up shop, selling to 100-150 locals each week, there is also Horsens' Visionary Kitchen, which prepares meals from food that has reached its sell-by date donated by shops, (Russell, 2016). In the Danish Seaport, Kolding, a volunteer run food bank called Koding Madhjælp sells food from wrongly marked pallets that might otherwise be destroyed and food wasted from a nearby hotel (Russell, 2016). All these initiatives are volunteer run and they have helped cut food waste in Denmark by a quarter since 2010, these and other measures were largely prompted by a lobby group called Stop Spild Af Mad (Stop Wasting Food) set up by graphic designer Selina Juul (Russell, 2016).

International - food waste app, Too Good To Go

The food waste app Too Good To Go was launched by Chris Wilson and Jamie Crummie in the UK and is available in cities in Austria, Denmark, France, Germany, Norway, Switzerland and the UK. Participating restaurants and bakeries list their leftovers, which customers can browse and reserve to purchase for a low price. Those participating can choose how they provide the food, some will give goodie bags and others will provide a box to fill with a selection of leftovers. Currently it is largely independent stores or small chains that have signed up to be featured on the app. (Sorrel, 2016)

Spain - community fridges

In May 2015 in Galdakao, Spain a solidarity fridge was placed on a pavement. Residents and businesses are now able to drop off leftover or unused food that would otherwise become waste. A network of shared fridges in Berlin was what inspired the organiser, Álvaro Saiz. It took around a month to work through the paperwork necessary in order for the fridge to launch. Volunteers keep an eye on the fridge to discard anything that is past it's use-by date or to throw away anything homemade that is more than four days old but generally food is taken quickly. In June 2015 Murcia became the second city in Spain to host a solidarity fridge. (Kassam, 2015).

In Frome, UK a community fridge was set up and is run by the organisation edventure Frome, which costs about £250 a month to run including rent, electricity and volunteer coordination, and it is reliant on donations for maintenance and expansion (edventure Frome, 2016).

In Germany new rules threaten the community fridges of Berlin because they mean that one person would have to be made responsible for the fridge, documenting everything that is put in and everything that is taken out, which isn't feasible given the frequency of use (Osborne, 2016).

Ghana - mud silos

In Ghana an approach introduced by organisations involved the extension of the use of mud silos for communities in areas where people were dependent on less reliable storage structures, such as baskets woven from grass matting or sorghum stalks (Bediako, Nkegbe and Iddrisu, 2004). The technique of building mud silos from locally available materials was already known in some parts of northern Ghana having been first introduced around 300 years ago by traders from Burkina Faso (Busch, 2014). The basket structures used by some communities are not as durable and allow easier access to stores by rodents and insects, they also make use of materials including wooden poles and grass, which are a diminishing resource in Northern Ghana (Bediako, Nkegbe and Iddrisu, 2004).

The mud silos were strongly recommended by those that had them installed, with report of lower losses compared to other structures. Other benefits included saving money that would otherwise be spent on jute sacks, saving time that would be spent constructing and weaving other storage containers, saving of wood and stalks that would be used that are then made available to use elsewhere. Most of the problems associated with the new mud silos were technical and relating to construction defects, which could be improved with training, greater practice and experience. (Bediako, Nkegbe and Iddrisu, 2004)

Afghanistan and Kenya - metal silos in, Food and Agriculture Organization of the United Nations (FAO) projects

Afghanistan - 2009

An FAO project, which was largely funded by the German government, coordinated the production of metal silos for 18,000 households and local tinsmiths made the silos. Very soon after installation recipients were able to report higher net incomes from increased sales and lower food losses. The loss of food fell from around 15-20% to 1-2% per year. Following the project, farmers that hadn't been a part of the scheme hired local tinsmiths to build an additional 4,500 silos because they had seen the benefits.

Kenya - 2012

Another FAO project was launched to promote metal silo technology. Funding from Swedish and Spanish governments went towards training of sixteen metal artisans in eastern Kenya and around 300 metal silos were distributed to famer groups. FAO facilitated access to credit through community banks, which allowed for farmers without savings to purchase silos.

(Lipinski et al., 2013)

Agriculture, forestry and other land use solutions - case studies
A.4 Crop wild relatives and local plant breeding programmes

Washington State University, US - The Bread Lab

The Bread Lab develops diversity in locally grown organic grains. They highlight that as plant breeding becomes more corporate there are less crop varieties available and there is less genetic diversity within crops, which creates a system more reliant on pesticides. They emphasise the need to decentralise plant-breeding programmes, making them relevant to local environments. Historically, the goals of plant breeders have been driven by conventional farming practices and large milling and baking industries, whereas the focus of The Bread Lab is on how the grains work for farmers including functionality, flavours and nutritional value. The plant-breeding programme creates a hub of activity and development local to the growth of the related crops. Diversifying crop development is beneficial to the famer, soil and community.

(Patagonia, 2016)

Agriculture, forestry and other land use solutions - case studies
A.5 Urban agriculture

Cuba - urban agriculture

After the collapse of the Soviet Bloc in 1989, a US embargo meant that Cuba lost its food imports (Clouse, 2014). The oil scarcity was so extensive that it restricted pesticide and fertiliser production and limited the use of agricultural equipment as well as of the transport and refrigeration network (Clouse, 2014). This led to a series of major food shortages across Cuba, which particularly impacted on the capital Havana (Danish Architecture Centre, 2014).

Food production became decentralised from large, mechanised state farms and urban cultivation systems developed (Danish Architecture Centre, 2014). Agricultural initiatives were intertwined into the urban environment and continue to demonstrate that food growing and raising animals can be achieved on scale within the urban environment (Clouse, 2014). Now over 50% of Havana's fresh produce originates from within the city limits and the crops are grown using organic compost and simple irrigation systems (Danish Architecture Centre, 2014). The interventions range in size from small pockets of agriculture to farming in empty city lots (Danish Architecture Centre, 2014). Accompanying this transition was widespread community engagement, improvement to local environments, greater care for local environments and much greater self-sufficiency (Clouse, 2014).

The urban agriculture movement in Cuba presents a useful demonstration of the development of self-sufficiency and food security in an oil-scarce environment, which has now operated for 26 years (Clouse, 2014). The Cuban government supported the developments with training and support and subsidising of agricultural stores, compost production sites, artisanal pesticide labs and urban veterinary clinics (Novo, Quintero and Masalías, 2008, cited in Clouse, 2014). The Cuban Ministry of Agriculture and Havana's city government formed the Urban Agriculture Department in 1994, which initially focused on securing land use rights for urban gardeners and today provides education around organic agriculture, plays a role in the start-up of popular gardens and community-based horticulture clubs, and operates centres selling agricultural supplies (Danish Architecture Centre, 2014).

Some thought that when Cuba's food crisis eased the urban agriculture would fade away but Havana's farms and gardens have continued to increase steadily, not only in size and number but in quality too. They have made, and continue to make, a clear impact on both food security and diet and also provide environmental and aesthetic benefits (Danish Architecture Centre, 2014).

Agriculture, forestry and other land use solutions - case studies
A.6 Agroforestry

Montpelier, southern France - agroforestry

The agriculture sector in Montpelier is largely based on monocultures, which are very vulnerable to a changing climate, including expected higher temperatures and more frequent droughts. Agroforestry was adopted in Montpelier as part of the Silvoarable Agroforestry for Europe (SAFE) project, which provided models and databases surrounding profitability and suggested policy guidelines surrounding implementation of agroforestry.

In Montpelier, walnut trees were grown in combination with wheat cultivation. It is an example of agroforestry that has been developed to work within the constraints imposed by mechanisation. Researchers showed that the production from one hectare of walnut and wheat mix was the same as for 1.4 hectares where trees and crops are separated. The trees provide shelter for crops, which helps reduce damage caused by high temperatures. There is greater biodiversity, as the habitats created are more diverse than in monocultures, which aids in controlling pests and enhances pollination. Agroforestry also helps reduce soil erosion and improve soil and water quality.

Over time agroforestry farms can become less dependent on crop subsidies and susceptible to crop price variations, as the timber can generate a significant part of their income. Agroforestry schemes are a long-term investment, as it takes time for the trees to mature and so provide the associated functions and benefits. It has now been practiced in Montpelier for over 20 years.

(European Climate Adaptation Platform, 2014)

San Martin, northern Peru - agroforestry

Soluciones Prácticas (Practical Action in Latin America) implemented an agroforestry project in the tropical rainforest of northern Peru between 2006 and 2007, with the aim of reducing the vulnerability of small-scale coffee and cocoa producers and increasing their ability to adapt to climate change.

San Martin is one of the largest coffee and cocoa producing areas in Peru. The agricultural techniques generally adopted involved slash-and-burn practices, which cause significant GHG emissions. Productivity levels were low because of poor soil quality. The project was implemented in the Sisa river basin, where gradual deforestation had been taking place for decades, with the clearance of large areas of forest for corn and cotton production. Soils quickly lost their nutrient levels under this farming practice and this led to demand for new agricultural land. The related logging increased risk of flooding and mudslides, and led to greater soil erosion and biodiversity losses.

Soluciones Prácticas began a two-year agroforestry project in 2006, working in partnership with 300 small-scale coffee and cocoa producers, local NGO Capirona and the Oro Verde Cooperative.

The three key components were:
- Implementation of sustainable agricultural practice to reduce desertification and avoid the need for migration;
- Strengthening social organization; and
- Improving commercialisation of the coffee and cocoa to enable small-scale producers to sell on international markets.

The project taught famers how they could benefit from planting multi-strata native tree varieties, through highlighting the direct links between biodiversity, soil conservation and higher quality produce. Complementary practices, such as the use of organic fertilisers, were also encouraged. Local knowledge was fundamental to the success of the project and farmers provided essential knowledge surrounding local biodiversity, including the range, uses and production methods of native forest species. This knowledge meant that management plans could be implemented at low cost and with locally available materials.

The project established area committees and promoted membership of the Oro Verde Cooperative, which works with committees to enable access to national and international markets, improving the technical capacity and commercial viability of small-scale production. The integration of agroforestry and cooperative production models meant that producers could be certified as meeting the required standards for organic and fair trade markets.

Some of the main results were:
- increased biodiversity;
- improved technical capacity using sustainable methods, with increased and diversified yields;
- strengthened social organization; and
- increased household income levels.

(Evidence and Lessons from Latin America, 2012)

Agriculture, forestry and other land use solutions - case studies
A.7 Forest conservation and restoration

Lulanda Village, Southern Tanzania - participatory forest management

Lulanda forest is located in the southern Udzungwa Mountains in Mufindi District and covers 315.9 ha (Painemilla et al., 2010). The forest was once a Local Authority Forest Reserve, and so under the authority of the District Government, however the District Forest Officer did not make visits to the forest and the Ward forest attendant was found to be involved in the selling of illegal logging licenses (Woodcock, 2002). It is now managed by Lulanda Village through a joint forest management agreement with the Mufindi District (Painemilla et al., 2010). The conservation project was initiated by the Tanzania Forest Conservation Group and described as participatory forest management (Painemilla et al., 2010).

Since 2005 access to the forest has only been permitted for specific purposes, such as the collection of medicinal plants, beekeeping, and the collection of a limited amount of firewood, sand and stones (Painemilla et al., 2010). Since the participatory forest management began villagers have noticed that the water level of ground springs and the flow of the Ilondo River have both increased, and that regeneration of the forest has led to an increase in growth of medicinal plants (Painemilla et al., 2010).

The transition to participatory forest management hasn't come without difficulties. Reduced access to firewood and polewood has created difficulties for poorer households, as it hasn't been possible to secure alternatives, which was addressed by permitting access to firewood once a month on a trial basis (Painemilla et al., 2010). Traditional collection of wild honey was prohibited because it relies on fire and honey collectors were generally alienated from those practicing modern beekeeping (Painemilla et al., 2010). There was also a loss of access to fields adjacent to the forest, which had been used for agriculture, and a noticeable increase in wildlife damaging cropland (Painemilla et al., 2010).

A significant requirement of related schemes going forward would be to facilitate transitions in relations to livelihoods. Where access to the forest and agricultural land is reduced for forest regeneration purposes it is important to establish alternative forms of income. Finding ways of financing maintenance of forest boundaries, patrols, clearing of fire breaks, record keeping and the holding of meetings, and involving the local community in this could go some way to helping such a transition. Accepting that the vision and desire of local communities may be different to that of those initiating projects would be necessary to ensure understanding alongside interventions. However, villagers evidently felt strongly about protecting the forest and were able to observe positive changes for the forest. Enabling deeper participation in the project and creating opportunities for villagers to develop new skills and income in relation to similar projects would help reduce potential losses in relation to the livelihoods of those living alongside the forest. (Painemilla et al., 2010)

Agriculture, forestry and other land use solutions - case studies
A.8 Grassland conservation and restoration

South Dakota, US - regenerative grazing

The Cheyenne River Ranch in South Dakota is a 28,000 acre ranch that raises indigenous buffalo for their meat. Whilst cattle would eat grass to the ground the buffalo allow for regenerative grazing, which eliminates overgrazing and so maintains pastureland. This method of farming allows for the buffalo to spend their entire lives on the prairie, it also removes the need for feeding areas and associated waste and contamination. There are many sources of contamination and GHGs along the supply chain to feed farmed animals and this method eliminates these.

The farmers at Cheyenne River see the land as their priority and in particular the health of the soil and grasses, they also appreciate that the buffalo aid land management. They highlight that grass is better food for the animals than anything humans have created as it sequesters carbon, builds organic matter and improves soil health. They aim to preserve the natural ecosystem of the Great Plains by farming native buffalo, offering an alternative to the prevalent industrialised food system.

(Patagonia, 2016)

A.9 Wetland conservation and restoration

Ruoergai Plateau, China - peatland restoration

The Ruoergai Plateau includes 4,733 ha of peatlands and is in the upper catchment of the Yellow River. The peatlands are vital for the conservation of alpine biodiversity and provide habitat for a number of endangered wildlife species including black-necked cranes and a range of rare bird, fish, amphibian and plant species. The area includes two national nature reserves, two Ramsar Sites, a wetland site designated as having international importance under the Ramsar Convention and two provincial nature reserves.

The main threat to the peatlands of the Ruoergai Plateau is from overgrazing. Increasing temperatures due to climate change also affect the area. The degradation of the peatlands not only impacts the environment but also has negative impacts for local communities including a reduction in water supply, feed for livestock and tourism potential.

Wetland International China has been working with local and international partners and supporting local government sectors to raise awareness of the value of the peatlands. Peatland restoration activities have been tested and demonstrated in some drainage canals, where gullies have been eroded and where part or all of the original peat had been removed through turf cutting. This restoration has taken place with support from the UNEP/Global Environmental Facility and EU-China Biodiversity Conservation.

The restoration techniques used include:
Blocking of canals using wooden planks, peat-filled bags, sand and/or boulders
Installation of plastic pipes to help guide water flow to the canals
Fencing off some of the blocked canals to prevent yaks from walking on them
Re-vegetation of areas to stabilise the soil surface
Blocking of gullies using peat-filled bags
Construction of a concrete dam to hold the water in an area of peatland that had been cut 2m deep

Around 1,568 ha of peatland have been restored and there has been evidence of successful re-vegetation. The demonstration sites created have helped convince people that restoration is necessary for both the environment and the livelihoods of communities. Local authorities have since provided funding for large-scale restoration and local government has prioritised ecological conservation as a long-term goal.

Grazing is a traditional practice and as more of the area has been reserved or designated as protected land the pressure on remaining pastures has increased. For restoration to continue it is important to establish alternative options for local communities to support themselves as a reduction in the dependency on livestock is required.

(Cris et al., 2014)

Mekong River Delta, Vietnam - mangroves

The Mekong River Delta (MRD) is one of the most vulnerable places in the world due to sea level rise (Dasgupta et al., 2009). 45% of the MRD is less than 2m above sea level and 81% is less than 4m below sea level (Woodroffe et al., 2006) and the population is around 17.5 million (GSO Vietnam, 2013, cited in Warner et al., 2016, p. 666).

An estimated 400,000 ha of mangrove forest in 1940 (Phan and Hoang, 1993) had reduced to around 269,000 ha in 1980 and 158,000 ha in 2000 (Gebhardt, Nguyen and Kuenzer, 2012; Vo et al., 2013). Part of the reason for the loss of mangrove forest was in relation to chemicals used during the Vietnam War to reduce leaf cover of plants in order to reduce hiding places. Other reasons for mangrove loss include forest fire, anthropogenic activities such as land conversion and collecting of wood for fuel (Thu and Populus, 2007). There has been a sea-ward expansion of mangroves in one area of the MRD, Ca Mau, due to the deposition of sediment associated with longshore drift (Walsh and Nittrouer, 2009) but this is situated alongside an inland reduction of mangroves replaced with shrimp farming (Binh et al., 2005).

Successful restoration requires community engagement and an acknowledgement of the dependence of communities on the mangroves, in relation to both culture and livelihood (My, 2014, cited in Warner et al., 2016 p.666). In Ca Mau it was found that by involving shrimp farmers in the replanting and restoration of mangroves their income wasn't reduced and they were able to diversify their source of income through selling wood (Ha et al., 2012).

The MRD is the world's third largest delta, with an area of around 40,000 km2 (The DELTAS project, 2017). Due it's large size the MRD presents significant opportunities for climate change mitigation as well as providing coastal protection, the cycling of nutrients and a diverse habitat for aquatic organisms (Warner et al., 2016).

San Francisco Bay, US - salt marshes

A study in San Francisco Bay found that salt marshes there have grown in height as sea levels have risen, caused by the continuous deposition of sediment and accumulation of dead organic matter, suggesting that this natural habitat may be able to adapt to climate change induced water level rises (Whittlesey et al., 2013). The study found that the salt marshes present in the area have the potential to sequester a significant amount of carbon (Whittlesey et al., 2013). There is a concern that if salt marshes become damaged or degraded via human intervention or rapid climate change then large quantities of carbon may be released into the atmosphere (Macreadie et al., 2013), to avoid this careful land management is necessary.

A.10 Seagrass meadow conservation and restoration

East Coast Virginia, US - seagrass meadows

On the east coast of Virginia, US, seagrass meadows used to thrive (Orth et al., 2006b). However, the combination of disease and a hurricane destroyed all of the seagrass meadows by 1993 (Cottam, 1934; Rasmussen, 1977 cited in Orth et al., 2006a p.989; Orth et al., 2006b). This caused the soil sediments to destabilise and the local scallop fishing industry to fail (Orth et al., 2006a; Orth et al., 2006b). Starting in 2001, over a period of 10 years, seagrass species were planted and have successfully spread (McGlathery et al., 2012; Orth et al., 2012). Studies conducted over this period found that the density of shoots increased with time (McGlathery et al., 2012). This in turn affected the water flow, decreasing erosion and increasing sediment deposition (Gacia and Duarte, 2001). After 10 years of restoration the carbon accumulation rates determined were 36.68 gC per m^2 per year and were expected to increase to a rate comparable with natural seagrass meadows within 12 years of seeding (Greiner et al., 2013), which is estimated at between 41 and 66 gC per m^2 per year (Kennedy et al., 2010).

B.
BUILT ENVIRONMENT SOLUTIONS
CASE STUDIES

B.1 Retrofitting and refurbishment

Lebanon - Casa Batroun

This project involved the refurbishment and extension of a small sandstone house with the aim to double its 100m² size and reduce energy use. Materials used in the project were natural, recycled and handmade.

The elements of the refurbishment included:
- Solar water heating panels
- Natural, breathable materials
- Thermal insulation
- Cross ventilation means that no mechanical cooling is needed
- Minimising solar gain
- LED lighting
- 2 wood pellet stoves
- Low energy and low water appliances
- A green roof
- Photovoltaic panels
- Rainwater harvesting

Reclaimed timber was used for some floor tiles and a frame to support the existing stone wall. The windows, shutters and staircase, and much of the interior furniture were salvaged.

A range of natural materials was used. Any virgin timber used was forest stewardship council approved or from sustainable forests, with a cradle-to-cradle certification. Sheep wool was used to insulate the roof and a wood fibre mix to insulate the walls. Earth plaster was made using a mix of local clay, straw, lime and sand, and finishing was done using lime plaster made from Italian natural lime, which helps make the building breathable.

Modelling has enabled estimations of the change to the building's performance, which are outlined below along with the accreditation that it has been awarded:
- 38% reduction in number of hours the house is overheating
- 79% reduction in coldest hours
- 55% decrease in total energy consumption of house
- 41% reduction in CO_2 emissions
- Annual consumption of 20 kWh/m²
- BRE Environmental Assessment Method (BREEAM) certified with an 'excellent' rating

(EcoConsulting, 2014; BREEAM, 2016)

Bulgaria - The National Programme for Energy Efficiency in Residential Buildings

In Bulgaria 55% of the population can't afford to heat their homes and in 2013 100,000 people protested against high energy costs. In response, the government created The National Programme for Energy Efficiency in Residential Buildings, committing €500 million to retrofit over 2,000 apartment blocks, each with 100 apartments, that are poorly insulated and difficult to heat. The project will reduce energy use in buildings by 40-60%, save occupants money, benefit health and wellbeing and create an estimated 50,000 jobs.

The work will take place in a step-by-step process, gradually improving the energy rating of the buildings. The programme will first focus upon fully funding retrofitting of the roof, walls and foundations of the apartments because it is the most difficult stage and most in need of financial support. This step often improves the aesthetics of the building too, benefiting the wider community. Additional steps will occur afterwards, including window and ventilation replacement. Research shows that it is more beneficial long-term to have deep retrofitting to a high standard rather than shallow renovation.

The programme is aware that it needs to build trust with the public to ensure success, which is done by clear and comprehensive communication. Knowledge is also transferred to a new generation by working with children to educate them about energy use and the retrofit process.

Ultimately energy savings will only occur if the occupants themselves maintain the low energy use and are happy with their thermal comfort.

(Georgiev, 2015; BPIE, 2016; FOE, 2016)

B.2 Zero energy and zero carbon buildings

International - Living Building Challenge (LBC)

The LBC is a voluntary international programme that was launched in 2006 by the International Living Future Institute based in Seattle and Portland, US. It seeks to promote building that is restorative and has a positive impact for future generations. There are twenty steps that must be taken to do so, providing a holistic approach. This programme has been designed so that it can be applied to any building project in any climate. To become LBC certified there are two rules:

1. Follow all 20 steps
2. Wait 12 months before the assessment can be evaluated to allow for full data to be gathered.

The LBC has 7 performance categories known, which consist of place, water, energy, health and happiness, materials, equity and beauty. The twenty steps that lie within these performance categories cover a similar breadth of targets as the seventeen SDGs.

The 20 LBC steps are:
1: Limits to Growth
2: Urban Agriculture
3: Habitat Exchange
4: Human Powered Living
5: Net Positive Water
6: Net Positive Energy
7: Civilized Environment
8: Healthy Interior Environment
9: Biophilic Environment
10: Red List
11: Embodied Carbon Footprint
12: Responsible Industry
13: Living Economy Sourcing
14: Net Positive Waste
15: Human Scale + Humane Places
16: Universal Access to Nature and Place
17: Equitable Investment
18: Just Organizations
19: Beauty + Spirit
20: Inspiration + Education

(International Living Future Institute, 2015)

New Delhi, India - Indira Paryavaran Bhawan

The first net ZEB in India has been built for the Ministry of Environment and Forests with the aim to reinforce the need for more ZEBs throughout the country. The construction used a combination of local, recyclable and sustainable materials. The building design allows 75% of natural light to be utilised, which minimises artificial lighting needs, and it boasts the largest rooftop solar system of any multi-storey building in the country. Recycling water, rainwater harvesting and low-flow fixtures have reduced water consumption. The lift systems supply the energy generated when a lift travels to the ground floor into the network. The building was orientated east-west to allow for better natural ventilation and chilled beam air conditioning is installed, which makes use of convection currents.

(Ravichandran and Krishnan, no date; Indira Paryavaran Bhawan, 2011; Perappadan, 2014)

B.3 Passivhaus design

China - Zhuozhou

The Passivhaus building in Zhuozhou is the first that met the standard in China. The office building has been designed for a company called Hebei Xinhua Curtain Wall Co. Ltd., which produces Passivhaus windows. This building marks a milestone for the Passivhaus industry as it shows how the European concept has been developed and adapted to include local materials in China. The government is using the building as a pilot scheme and monitoring will take place to assess the success of the project.

(Passive House Institute, 2015b)

Antarctica - Princess Elisabeth Passivhaus research station

In 2007-2008 the Princess Elisabeth was constructed by the International Polar Foundation in Antarctica as the world's first zero-emission, Passivhaus research station. In the extreme conditions of the South Pole the station utilises solar gain and heat from appliances and occupant body heat. There is a heat exchange and ventilation system, which replaces air in the station with fresh air whilst moving heat around the station. The station walls have nine layers, which each have properties that help contribute to its efficiency including thermal insulation, water vapour barriers and airtightness.

In addition to the Passivhaus structure the research station utilises the natural resources available through nine wind turbines, photovoltaic solar panels and thermal solar panels around the site. These are linked to a room of batteries, which store any excess energy for when demand is higher than production.

The energy solutions used at the research station are being commercialised for use in mainstream applications including homes, offices and schools across the globe.

(International Polar Foundation, 2015; International Polar Foundation, 2016)

B.4 Green infrastructure and urban water management

Copenhagen, Denmark - Cloudburst Management Plan

Copenhagen had two consecutive years of extreme rainfall events in 2010 and 2011, which caused a lot of damage economically and socially. The city of Copenhagen decided that in order to make the city a safe place to live and visit it would be necessary to mitigate against these extreme rainfall events and not only by improving the sewerage system. They acknowledged that they needed to coordinate and consolidate action across the city, adapting to each area's needs.

The Copenhagen Climate Adaption Plan (CCAP) was established by the city council in 2011 and out of this plan came the Cloudburst Management Plan (CMP) in a bid to help the city better adapt to these extreme rainfall events. The CMP has been coordinated with the city Frederiksberg as currently all of the Frederiksberg's water goes to either a water treatment plant or via Copenhagen to the sea. It is estimated that these rainfall events will only increase in their volume as time goes on.

The CMP includes the following proposed plans in a bid to redirect storm water away from the sewerage system and back into the natural water cycle:
- Draining rainwater out to sea, rather than to the sewerage system, via the construction of canals and urban waterways.
- Storing rainwater in buffer areas such as parks
- Use of natural watercourses as flood ways

These measures have to be applied to high-risk areas first, and all areas will eventually have mitigation strategies in place by the end of the twenty-year timeframe.

(The City of Copenhagen, 2012)

B.5 Sustainable urban planning

Copenhagen, Denmark

In Copenhagen cycling was made central to urban planning and design. Designated cycle lanes were introduced along already existing roads so as to separate cyclists from other road users and by 2010 there were 369 km of cycle lanes as well as two cycle bridges. Bicycles were also integrated into public transport networks, such as space for bicycles on trains. 42km of 'Greenways' were introduced in suburban areas to provide more direct cycle routes away from main roads and through parks and recreational spaces where possible.

An increased emphasis on cycling has reduced noise pollution, air pollution and CO_2 emissions by an estimated 90,000 tonnes annually. Health care costs are reduced at an estimated rate of US$1 per km cycled. Cycling also provides a low cost form of transport.

Copenhagen has also invested in improvements to its public transport network. Integrated ticketing was introduced so that tickets were valid on buses, trains and the metro. SMS ticketing was also introduced to speed up journey times and an online Journey Planner was developed.

The City of Copenhagen Municipal Plan 2015 outlined that 95% of new homes would be built within 1,000 metres of a station. Office buildings over 1,500 square metres and more visitor-intensive functions are meant to be built within 1,000 metres from a station, which is estimated to have the potential of reducing carbon emissions by a total of 95,000 tonnes between 2015 and 2027.

The overall goal of traffic composition was a maximum of 1/3 cars, minimum of 1/3 bicycles and minimum of 1/3 public transport. It also included the aim of increasing the number of bicycle parking spaces to 4 spaces per 100 square metres of floor area by residential buildings and workplaces. Goals for pedestrians are to be incorporated into the 2019 Municipal Plan. The Metro City Circle Line is also due to open in 2018, which will cover 15.5 km and add 17 stations. Trials with electric buses are also planned for 2018 and in 2016 around 300 buses had filters installed to reduce nitrous oxide and particulate emissions by 90-95%.

(City of Copenhagen, 2015; Lauristen, 2016; Danish Architecture Centre, 2017)

B.6 Building with earth

Australia - The Great Wall of WA - 2015

A cattle ranch in Western Australia has built rammed earth accommodation for its seasonal workers. The accommodation comprises of twelve rooms set behind a 230m long rammed earth wall, and beneath a bank of sand and plants. The rammed earth wall is believed to be the longest in Australia and the materials for the wall have been locally sourced and give it a similar colouring to the surrounding land. The earth wall keeps the interior rooms cool and its zig-zag shape gives the occupants privacy.

(Mairs, 2015)

Mali - primary school - 2013

A primary school in Mali was made using unfired bricks, with earth from local mines, made on site. The building fits in with the local building and cultural traditions but mechanical means have been used to compress the bricks to give them more strength. The school structure is single storey and comprises of three large classrooms, joined together in a line with a sheltered veranda on two sides of the building, which provide shade for students in between classes. In addition to the shuttered windows ceramic pipes have been inserted into the roof for dual purpose of ventilation and sunlight, which can be blocked during the rainy season. The roof has been covered in a 20-30mm mixture of earth and cement to stop any leaks. The local community and students from a nearby university were involved in the building of the school.

(Frearson, 2014)

UK - Neil's Yard eco-factory - 2005

Neil's Yard Remedies manufacturing and headquarters used a combination of materials to build with. Glulam and untreated larch was used for the frame of the building. Unfired bricks were used for an internal wall, with a lime mortar and a clay plaster. One of the reasons unfired bricks were decided upon is because they require significantly less energy than fired bricks for manufacture. They also provide thermal mass, which helps control daily and annual temperature peaks, and the clay plaster finish absorbs moisture in humid conditions and releases moisture in dry conditions. In combination with the polished concrete floor and design of the windows the wall helps create comfortable conditions without air conditioning.

(Morris, A., 2014)

Built environment solutions - case studies

B.7 Building with timber

London, UK - Stadthaus - 2009

The Stadthaus can be found in London and is an 8-storey block comprised of 29 apartments, with half belonging to the housing trust and half being independently owned. The building is made using strips of timber that are glued together at right-angled layers (of 3, 5, 7 or more) to form panels – this process creates cross-laminated timber (CLT). CLT is beneficial because when compared to conventional construction materials it demands less energy in construction, provides better thermal insulation, reduces heat loss and can be easily deconstructed and recycled at the end of the building life. The façade of the building is made of timber, 70% of which was waste material. The ground floor walls are made of concrete, which was used to reinforce the structure and act as good damp proofing. Had the building been made of conventional materials it would have used an extra 124 tonnes of carbon during the construction phase. Adding this to the 188 tonnes of carbon sequestered by the timber in its growth means the building effectively offsets 310 tonnes of carbon. Time was also saved with the structure taking 49 weeks to build where a fully concrete structure would have taken 72 weeks, this not only reduced costs of labour but also minimised disruption to the surrounding inhabitants.

(TRADA, 2009)

Norway - Treet - completion estimated 2017

The timber building in Norway is the largest timber framed building in the world. The aim of the structure is to focus upon energy consumption, sustainable development and communal outdoor spaces. The building has been built using glulam and cross laminated timber with a concrete base and is built to Passivhaus standard. The structure comprises of a glulam, load-bearing frame with prefabricated sections stacked on top of one another. Elements like the staircases and lift shaft are also made from timber. The external timber is protected by glass on two of the building faces and an insulated lining on the other two. To reduce swaying of the building in windy conditions glulam cross braces have been added as well as concrete at various points in the structure. As most elements were prefabricated on site construction only took three days. It is estimated that if the whole structure had been built with more conventional materials it would have led to around 18,000 tonnes more CO_2 emissions. There is also the carbon storing ability of the timber to consider which equates to the building having avoided around 21,000 tonnes of CO_2 emissions overall.

(reThinkWood, 2014; Timber design and technology, 2015)

Built environment solutions - case studies

B.8 Building with hemp-lime

UK - Adnams Brewery Warehouse and Distribution Centre - 2006

Adnams Brewery has created a building to store their stock, with glulam beams, a green roof and 100,000 hemp-lime blocks. The large area (4,400m^2) has a cool, stable temperature due to the materials used in construction. There is a brick plinth, which was a requirement to protect the structure against any vehicles that might back into it. By using hemp-lime the walls cost £40,000 more than the standard walls would have cost but the hemp-lime meant that no cooling system was needed, saving £400,000. Using hemp-lime instead of conventional aluminium or steel walls saved more than 500 tonnes of CO_2 emissions.

(Bevan and Woolley, 2008)

Machynlleth, Wales - the Wise building at the Centre for Alternative Technology (CAT) - 2009

The Wise building at CAT is made using a number of sustainable materials including rammed earth for the lecture theatre, glulam and timber for the frame of the building and a hemp-lime composite for the walls. Hemp-lime was chosen due to its thermal insulation and thermal mass properties and although 15% cement was used the walls are still hygroscopic, which helps to regulate the internal humidity. The hemp-lime mix was sprayed to the frame of the building using shuttering and an adapted concrete spraying machine.

(CAT, 2016)

Built environment solutions - case studies

B.9 Building with straw bales

North-eastern China - straw bale housing project - 1999-2004

A housing project in China utilised waste rice straw to build over 600 houses, in a bid to reduce fossil fuel consumption for heating, improve health, improve resistance to earthquakes and reduce the use of top soil in brick production. The project began in an area where those fleeing from desertification had set up home. Their housing was substandard offering very little protection from the cold (-40°C winters) and from earthquakes. The project involved the community in the design of the houses and gathering of materials, and during the 5 years the programme ran 464 people were trained. Due to cultural acceptance of using brick, it was impossible to fully remove bricks from the building process, although they were reduced by two thirds. The houses built in the project withstood earthquakes as the lightweight straw bales were able to absorb the related energy. The straw bale homes were also 68% more energy efficient that conventional houses in the area and occupants used 5kg less of coal on cold days. Post occupancy surveys found that there were high levels of satisfaction with the building technique and the houses produced. Straw bale construction is now occurring independently outside of the project and some local building codes have been modified to include straw as a material.

(BSHF, 2016)

Built environment solutions - case studies

B.10 Increasing energy access sustainably

Rajasthan, India - Frontier Markets

In the Indian state of Rajasthan around 10 million households, or half of all homes, only have access to unreliable grid power or don't have access to electricity at all, which accounts for around half the homes in the area. Frontier Markets was founded in 2011 with the aim of helping to bring solar power access to rural Rajasthan and with the intention of focusing particularly on the needs of women. The solar devices are sold through existing rural shops and an after-sales service is provided for the products.

Frontier Markets partnered with NGOs and government agencies to help identify local women who could act as sales agents and solar energy service providers, finding them in already established Self-Help Groups where local women were given the opportunity to develop their skills and capacities. The women working for Frontier Markets in this way are known as Solar Sahelis or solar friends. Solar Sahelis are paid monthly for their services marketing products, educating potential users about the benefits of solar power, signing up customers, collecting data and providing a first point of contact for follow up and repairs. They are trained in marketing, finance and record keeping and go on to market products within a range of about 5km from their homes.

By May 2016 Frontier Markets had sold around 70,000 solar torches, 45,000 solar lamps and 12,000 solar home lighting systems, which brought their benefits to around 630,000 people. About 30% of sales were through an active network of over 250 Solar Sahelis. The cost of one light product can often be recovered between 3-6 months through savings of around US$3 per month that would have otherwise been spent on kerosene and dry cell batteries.

(Ashden, 2016)

Built environment solutions - case studies

B.11 Smart grids

UK - proposed smart meter roll out

The UK government wants all energy providers to install smart meters in every home in the UK by 2020. This scheme was initially started by the European Union and rolled out in all member countries in a bid to reduce energy usage and in turn carbon emissions. The installation of smart meters will give occupants more awareness and control over their energy usage. The scheme is not compulsory but it is estimated that 53 million smart meters will be installed by 2020. This initial step of installing smart meters in the UK will pave the way for a smart grid. This smart grid will make it easier for suppliers to match energy demand, making energy supply less wasteful and more reliable with easier integration of renewable energy technologies.

(Smart Energy GB, 2016)

Perth, Australia - Perth Solar Cities

The solar cities programme ran in Perth between 2009 and 2012 and in that time 9,269 smart meters were installed, 6,300 homes were provided with 12 months of eco-coaching, 700 homes were fitted with a SunPower photovoltaic system and 1,000 homes bought a Solahart hot water system. 16,000 homes took part in the solar cities scheme in Perth and they collectively saved over 1million Australian dollars from their electricity bills during the final year of the scheme.

(Perth Solar City, 2013)

Built environment solutions - case studies

B.12 District heating

Copenhagen, Denmark - district heating

98% of Copenhagen is heated via its district heating system. It was set up in 1984 in a bid to provide residents of the city with affordable and clean heating. In total 30% of the city's heating annually comes directly from the waste heat from combined heat and power (CHP) plants and waste incineration, with the rest coming from a combination of geothermal energy and the burning of wood pellets, straw, natural gas, oil and coal. Between 1995 and 2000 the CHP plants changed from coal to natural gas and bio fuels, making the energy supply more sustainable. Copenhagen's CO_2 emissions reduced from 3,460,000 tonnes in 1995 to 2,522,000 in 2000 and sulphur dioxide emissions reduced by one third in the same timeframe because of the district heating system.

(C40, 2011)

Built environment solutions - case studies

B.13 Urban solar

Edinburgh, Scotland - community solar project

In Edinburgh, the Edinburgh Community Solar Co-operative (ECSC) was set up in 2013 to provide renewable solar energy for the community. As a city, Edinburgh has seen a limited uptake of solar energy because many inner city homes are apartments with few homeowners having access to a roof. This cooperative is aiming to be able to offer joint ownership of solar panels. To date panels have been installed on 24 buildings including public buildings such as schools and community centres. Members of ECSC are able to buy shares (each costing a minimum of £250) and the funds need to be raised before the panels can be bought and installed. After installation, once annual administration costs have been paid, each shareholder will be paid share interest (with any additional funds allocated to the community benefit fund) and after 21 years all shareholders will be paid back and the panels will belong to the council.

(ECSC, 2015)

C.

CARBON DIOXIDE REMOVAL SOLUTIONS

CASE STUDIES

Climate intervention strategies as solutions - case studies

C.1 Afforestation and reforestation

China - Grain-for-Green Programme, highlighting the need for native forest

In a study of China's Grain-for-Green Program (using 202 reported locations) it was found that monocultures were planted at 82.2% of locations, monocultures with one or two shrub or grass species were planted at 35.6% of locations, mixed forests were planted at 38.6% of locations and only three locations reported planting of native forest (Hua et al., 2016). The study found that reforestation using monocultures generally resulted in a net loss of bird diversity whilst using mixed forest generally resulted in net gains (Hua et al., 2016). The current modes of reforestation used by the Grain-for-Green Program all fall well short of restoring biodiversity to those levels approximated as existing in the native forests that preceded croplands (Hua et al., 2016). Incentivising conservation and restoration of native over structurally and compositionally basic forests would enable much greater biodiversity enhancement (Hua et al., 2016). Gamfeldt et al. (2013) demonstrated that tree biomass is 41% more likely to be higher on plots with five species compared to those with just one. In their study soil carbon storage was also 11% greater and understory plant species richness was 31% greater in plots with five species compared to those with just one.

Climate intervention strategies as solutions - case studies

C.2 Bioenergy with carbon capture and storage

Illinois, US - Archer Daniels Midland plant

The Archer Daniels Midland plant in Illinois is the most developed BECCS project in the world however it has yet to be proven carbon negative (Global CCS Institute, 2015; Yeo, S. and Pearce, R., 2016). CO_2 is captured from the plant's fermenters, which convert corn to ethanol, and the gas is dehydrated and compressed before injection underground (Yeo and Pearce, 2016). The gas is dried and compressed before injection underground, the fermentation process produces high-purity CO_2, which makes the processes cheaper and easier (Moreira, et al., 2016). The plant aims to capture and store 2.26m tonnes of CO_2 (MtCO2) in local porous sandstone over a period of 2.5 years, at a rate of around 0.9 MtCO2 a year (Yeo and Pearce, 2016). The sandstone in the region is suitable for storage due to its porosity, and layers of shale above it acting as a lid preventing leakages (Yeo and Pearce, 2016).

As corn absorbs CO_2 during its growth the overall process captures CO_2 from the atmosphere, however data concerning the amount of CO_2 absorbed by corn as it grows and that emitted by the plant in relation to its conversion, capturing and burying is not currently available and would be needed to establish whether the process is carbon negative (Yeo and Pearce, 2016). The other processes at the plant are also not fitted with carbon capture and storage technology (Yeo and Pearce, 2016).

Climate intervention strategies as solutions - case studies

C.3 Biochar

Haiti - biochar production

In Haiti, the leftover residues from the country's sugar cane pressing industry, known as bagasse, often gets burned as a means of disposal. It cannot be used for compost or feedstock, which means the related carbon is emitted back into the atmosphere.

The non-profit organisation Carbon Roots International started an enterprise of converting bagasse to biochar, and also to charcoal briquettes in order to satisfy the high demand for cooking charcoal. Because the demand for briquettes was so high, the focus is now on charcoal for cooking (i.e. not carbon-negative), however profits from this are being put towards biochar tests. At the organisation's facilities, biochar is mixed with local organic nutrients to make a blend of compost and biochar. This is then cycled back to farmers and used in their soils with the aim of increasing crop yields. Tests are being carried out with tomatoes, peppers, millet, cassava and peanuts.

The initiative benefits local communities by helping create jobs, providing training on biochar production and utilisation through workshops, helping limit the extensive deforestation in Haiti caused by the demand for biomass to burn for cooking.

This case study demonstrates that the technology is still in its infancy and that it has the potential to benefit local communities in a number of ways.

(International Biochar Initiative, 2013; Carbon Roots International, 2016)

Liberia and Ghana, Africa - biochar use

Soils where isolated communities have used biochar were compared to soils where the technology has not been used. It was found that these 'dark earth' samples store 200-300% more organic carbon and 2-26 times more pyrogenic carbon (originating in pyrolysis) than soils from elsewhere. The soils also have acidity more suited to plant growth.

These soils can support far more intensive agriculture and the communities have achieved improvements in soil fertility comparable to 'modern' agricultural techniques, demonstrating how indigenous knowledge can provide a model for sustainable and socially appropriate methods of agriculture.

(Solomon *et al.* 2016; Suzuki, 2016)

Climate intervention strategies as solutions - case studies

C.4 Direct air capture

British Columbia, US - Carbon Engineering DAC pilot plant

In recent years, some pioneering companies such as Carbon Engineering and Global Thermostat have been developing DAC pilot plants, and have benefitted from significant venture capital investment. In 2016, Carbon Engineering got a full end-to-end air capture demonstration plant up and running. The operating plant removes around 1 tonne of CO_2 from the atmosphere per day, which gets processed through the plant's infrastructure as it would on a full scale commercially running plant.

The pilot plant, in British Colombia, uses fans to push air through towers that contain hydroxide solution. The atmospheric CO_2 chemically reacts with this to form stable potassium carbonate, with the remaining air being reemitted. The captured CO_2 can be further separated with additional treatment, meaning the hydroxide solution can be used again. The plant process is powered by hydroelectric power. As the company scales-up further they hope for costs of $100-200 per tonne CO_2.

The company's mission is to develop and bring to the market commercial and cost effective large-scale DAC technologies.

(Climate Engineering, 2016; Gale, 2015; McLaren, 2014)

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