gas, both pipeline imports from countries such as Turkmenistan and Russia and LNG imports from Australia, Russia and Qatar. These imports should be at acceptable prices, as global supply options increase and as US exports of LNG impact on traded gas prices in East Asia. This combination of factors provides China with the opportunity to rapidly expand the use of gas — in areas such as power generation, combined heat and power systems, industry, transport and residential use — to meet the targets outlined in Table 1.

Implications for climate change

China's new energy strategy is primarily a response to the air pollution crisis, but will have major implications for greenhouse gas emissions (GHG). There is a large overlap between the sources of $PM_{2.5}$ and GHG emissions[12] (Fig. 4). The primary sources of $PM_{2.5}$ emissions are coal and oil use, while gas and non-fossil fuels generate few $PM_{2.5}$ emissions (Fig. 4a). Coal and oil are the dominant sources of GHG emissions, with gas occupying an intermediate position between these and renewable sources, which have low life-cyle GHG emissions.

If China achieves the 2020 energy scenario in Table 1, CO_2 emissions from energy use should peak by about 2020 and then decline. The transition from coal and oil to gas and renewables will involve many older, highly polluting plants, heating systems and vehicles being replaced by state-of-the-art combined cycle gas power plants, combined heat and power systems and natural gas vehicles as well as by non-fossil energy sources. The gains from eliminating the older coal and oil facilities, in favour of state-of-the-art facilities, should offset the rising emissions from increased natural gas use.

Such an emissions outcome for China would enhance the chances that the world can hold global warming to less than 2°C, and demonstrate an alternative path for countries, such as India, that face rising pollution from development based on coal and oil. China's new energy strategy will also impact on negotiations underway in the United Nations Framework Convention on Climate Change to establish by 2015 a legally binding emissions agreement to apply from 2020.

The main risk to this emissions path would be extensive use of coal-based synthetic natural gas (SNG). With large coal reserves and low coal prices, many see SNG as an important option for China. Many SNG projects have been proposed, some have been approved and a few are operating. But for electricity generation, SNG has lifetime GHG emissions well above coal and, for vehicle use, emissions are well above oil[13,14]. SNG plants are also water intensive, requiring more than six litres of water per cubic metre of gas produced[14]. A big SNG push would undo some of the GHG emissions benefits resulting from the Action Plan[5]. However, the Plan was notably cool on SNG plants, requiring strict enforcement of environmental controls and tight monitoring of water resources. China's severe water shortages might prevent a major expansion of SNG. ❐

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COMMENTARY:

Enabling food security by verifying agricultural carbon

H. Kahiluoto, P. Smith, D. Moran and J. E. Olesen

Rewarding smallholders for sequestering carbon in agricultural land can improve food security while mitigating climate change. Verification of carbon offsets in food-insecure regions is possible and achievable through rigorously controlled monitoring.

Global food demand is projected to double by the middle of this century, but greenhouse gas emissions from food production must be reduced. Mitigation and adaptation are often regarded as separate, though complementary, objectives in climate policy. Possible trade-offs can, in some cases, be reversed for synergy[1–3] with the potential to make smallholder farmers in food-insecure regions the main beneficiaries. Providing incentives for the adoption of carbon-sequestering agricultural practices to increase crop productivity in the developing world could enhance food security and contribute to climate equity while mitigating climate change[4]. Such a productivity increase would also reduce the pressure to expand agricultural land, thus further reducing emissions[3].

The target to reduce global warming below critical limits, while achieving equitable per-capita rights to emit among countries, pushes the required speed of technology shift in industrialized countries beyond reach[5]. However, emissions trading between the industrial and developing worlds could make the mission possible; indeed, this approach may be the only way forward. Exchange schemes — charging for emissions and rewarding emission off-sets — seem likely to be one of the few options for incentivizing the transformation to low-carbon societies worldwide. Such trading could reward the bypassing of high-emission production systems in the transition economies and the developing world. The sink capacity of carbon in agricultural soil has been estimated as having the potential to offset 5–15% of fossil-fuel-based greenhouse gas emissions[6]. To be sufficiently extensive, a reward scheme for farmers to store soil carbon should entail low transaction costs and access by farmers and payers ranging from citizens to enterprises and public actors.

The loss of carbon and associated nutrients from soils has been the main cause of declining crop productivity in sub-Saharan Africa (SSA)[6], which is projected to remain the most food-insecure region in the future. The reversal of carbon stock losses, or prevention of their decline, could induce greater and more resilient yields[7] through improved water and nutrient supplies[8]. Carbon stocking in soil organic matter does not require only carbon but also presumes increased stocks of nitrogen, phosphorus and sulphur[9], a fact that is critical to the effectiveness of sequestration measures. Agroforestry can integrate above- and below-ground carbon sequestration with biological nitrogen fixation and efficient nutrient uptake through mycorrhizae, while also providing food and fodder security, and fuel wood. Replacing the practice of burning manure for fuel with anaerobic digestion, other sources of bioenergy, or solar stoves would allow nutrients and carbon to be recycled to the soil. However, efficient uptake and recycling do not help to improve carbon storage if key nutrients are deficient in the system[9]; placing small amounts of fertilizer close to roots, or incorporating it in feed to avoid sorption in unavailable forms in soil, can prevent carbon-rich but nutrient-poor organic residues being lost from the soil[9]. Carbon in soil and vegetation can also be restored through

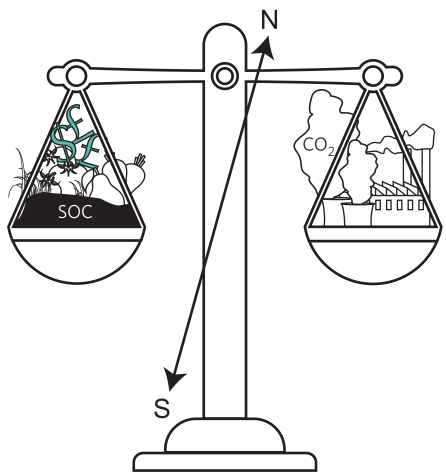

Figure 1 | Measuring soil carbon stocks enables payments from emitters in the north to food producers in the south for balancing the global carbon budget and food security. SOC, soil organic carbon. Figure includes images from Sjhaytov/Istock and Mariya Stankova/Istock.

exclusion of free-grazing livestock in areas where only selective harvesting is allowed. Furthermore, residue-based biochar carbon has a very long persistence in soil, while also contributing to yield-enhancing soil functions[10].

Increased food productivity resulting from increased soil carbon stocks would be a primary gain for African smallholder communities[2] and carbon payments could act as a trigger to overcome the reluctance of farmers to change practices[2,11]. A core requirement for the carbon market to function is verification of carbon sequestration; so far, this has been a barrier for smallholder farmers because the transaction costs of the present vehicles such as the Clean Development Mechanism and National Appropriate Mitigation Actions are high, and the time lag in payments undermines any incentive[2]. To involve smallholders, the verification of carbon offsets cannot be carried out on a case-by-case basis but rather must be 'practice-based', that is, based on knowledge of the impact of specific agricultural management practices under various agro-ecological conditions[2,12]. At present, empirical knowledge of the carbon effects of agricultural practices in food-insecure regions is scarce. For SSA, the few empirical estimates are based primarily on descriptive data with no controls or replication. Model-based simulations raise expectations, but have substantial uncertainty[13]. Thus, measurements are necessary to estimate the carbon budget of agricultural land even in temperate conditions[14], where many process-based models were developed. In developing countries the soil carbon dynamics and land uses may differ and there are limited data even for model parameterization[15], which may potentially bias estimates of carbon stock changes[16].

Securing financial support for agricultural carbon enhancement requires empirical verification for each type of management practice, agro-ecological zone and soil (Fig. 1). As long-term experiments would not satisfy the immediate demands for documented effects of management practices, other approaches must be applied. We propose that programmes for monitoring land managed by farmers with rigorous controls and replication should be employed to acquire this urgently needed knowledge. A useful approach would be to employ replicated matched pairs of geo-referenced field plots, including the potentially carbon-sequestering management and, because of the notable spatial variation in carbon stocks, an adjacent field plot in which the previous traditional management continues, to serve as the control. Such approaches have been used, without replication, in comparisons of cropping systems[17]. The soil-forming properties must be equal on the matched plots and sufficient replication reduces the significance of potential differences; the plots with the 'improved' management may even form a chronosequence. The fact that traditional long-term management in, for example, SSA is relatively homogeneous per region, agro-ecological zone and management system ensures availability of valid controls.

Empirical monitoring of changes in soil organic carbon stocks directly serves as verification and contributes to the improved reliability of future process-based models. Some long-term traditions of carbon-sequestration potential, such as Ethiopian terracing and agroforestry around homesteads, represent an immediate opportunity for assessment and the ongoing extension of soil conservation and climate-smart practices offers increasing options for monitoring. An evolving database enabled by modern information and communication technology, with transparent quality control and common access, would provide a solid foundation for estimating the impact on carbon stocks and thus for a practice-based verification in support of adaptive management to increase carbon sequestration. Among the parameters to be documented for below- and above-ground carbon stocks are: the management history before the change in practice; the nature of the new management practice and its duration; altitude and slope; and soil depth and characteristics depending on the approach adopted[18]. As well as the ecological determinants of carbon sequestration, the barriers to transitions in management must be identified to develop effective incentives and governance, based on understanding of the local cultures and practice[19]. The monitoring programme could be financed by the Green Climate Fund of the United Nations Framework Convention on Climate Change, which is just taking its first steps, and managed by the Food and Agriculture Organization of the United Nations.

Realization of the full potential for synergy between adaptation and mitigation requires social innovation on the global scale to reconcile conflicting views through joint learning[20], not least between the north and the south. What is needed is a beyond-nation-state cross-scale, multi-actor and inter-knowledge institutional architecture for carbon exchange, inclusive in its decision-making through new constituency models[21]. To be effective, the exchange scheme must be inclusive also in action, a priori rewarding any verified practice by citizens and private and public actors — on a voluntary, market-driven or regulatory basis. Extensive carbon rewards from industrial countries to African smallholder communities through as small a number of intermediaries as possible, giving the land and carbon rights to local communities, and a voice also to the poorest, could foster physical, human and social capacities, and ensure food security improvements[4,11]. Even small carbon rewards could act as a trigger for low-income communities to transition to carbon-sequestering agriculture when low-cost, reliable verification enables upfront payments[2,4].

The Green Climate Fund can be designed as a role model for social learning[20] on governance to underpin a just and resilient global community. Carbon rewards to African smallholder communities represents an excellent case, as it also offers opportunities to trigger food security. Quantification of carbon sequestration in smallholder agriculture represents the primary knowledge gap to be bridged and the use of farmers' fields for obtaining this information is a powerful solution that seems to be readily at hand. ❐

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COMMENTARY:

Water stewardship in the twenty-first century

Peter Simpson

The impacts of extreme weather are being felt by us all and scientific research points to a likely worsening of weather patterns in the next decades. Therefore, it is imperative to think carefully about how we build the infrastructure of the future to increase the resilience of our societies.

Over the past three years the UK has experienced some of the most varied and extreme weather events and seasonal trends ever recorded. We may not be able to link these directly to climate change, but since 2011 we have seen examples of precisely the type of extreme conditions that climate projections suggest are likely to be the norm in the future. Are we preparing well to cope with these changes? Will our water infrastructure meet the changing pressures and demands? Will our landscape be resilient and able to buffer extreme weather? As communities, are we willing to adapt our behaviour to a changing climate? These are questions that we all need to urgently consider.

As a water company, we at Anglian Water need to understand what role we play in the water cycle and, more widely, in a society tackling these challenges. In the UK, water companies are privately owned and provide either only water services to their customers or, in addition, treat used water before returning it to the environment. Water companies prioritize improving