

Developed-developing world partnerships for sustainable development (1): an ecosystem services perspective

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Abstract

Developing-developed world partnerships potentially present win-win opportunities for addressing climate-active gas emissions at lower cost whilst propelling developing nations on a lower-carbon trajectory, as carbon emissions, capture and storage are geographically independent. Expanded PES (payment for ecosystem service) principles provides a framework for assessing the transparency and efficacy of partnerships, tested on the model developed by The Converging World (TCW). The TCW partnership model currently links south-west England and Tamil Nadu, raising funds for wind turbines in India to avert emissions from conventional sources and reinvesting operating surpluses into restoration of tropical dry evergreen forest (TDEF). Over assumed 100-year progression to climax community, 123 ha of restored TDEF sequesters a conservatively calculated 270,545,880 tCO₂. This forest area is restored using operating surpluses from a 2.1MW turbine, which generates renewable energy over 20-year operating life conservatively calculated as averting 80,000 tCO₂e compared to a conventional energy mix. Forest restoration funded from turbine generation surpluses represents a substantial 'multiplier effect', providing around 3,000 times greater overall carbon reductions. Climate regulation is one of a linked set of ecosystem services, albeit a driving 'anchor service', that may be optimised to increase overall benefits to stakeholders and contribute to UN Sustainable Development Goals.

Keywords

Developed-developing world partnerships, renewable energy, climate change, eco-restoration, sustainable development, resilience

Research highlights

- Developed-developing world partnerships can address geographically independent services
- An expanded set of PES-related principles provides a framework for assessing such partnerships
- The Converging World model provides mutual benefits for addressing climate regulation targets
- Reinvestment of energy sales into forest restoration acts as a substantial 'multiplier effect'
- Multiple co-beneficial ecosystem services provided by restored forest benefit local people

1. Introduction

Numerous partnerships between the developed and the developing world have been established to promote sustainable development. Some, such as the UN Millennium Development Goals (United Nations, 2015a) reflect the moral responsibility of already-developed states to assist developing nations with poverty alleviation and related development targets. The successor Sustainable Development Goals (SDGs) (United Nations, 2015b) are framed around the goal of achieving 'The Future We Want', including both the developed and developing world. International commitments build upon, and are supported by, state aid programmes such as the UK's DfID (Department for International Development), Sweden's SIDA (Swedish International Development Cooperation Agency) and USAID (the United States Agency for International Development). Redistributive funds from advantaged to less privileged areas also feature across trading blocs such as the EU's Less Favoured Areas scheme (EU, 2013) and SADAC (the Southern African Development Community).

Acknowledgement of obligations upon the developed world, advantaged by historic exploitation of globally common resources, is also evident in market-based initiatives. These include economic incentives under REDD+ (Reducing Emissions from Deforestation and Forest Degradation) for developing nations to retain carbon stored in forests through conservation and sustainable management (UN REDD, 2014). The Clean Development Mechanism (CDM under Article 12 of the Kyoto Protocol) is also market-based, providing an auditable mechanism for states with emission-reduction or emission-limitation commitments to implement relevant projects in developing countries thereby earning saleable certified emission reduction (CER) credits that count towards meeting Kyoto Protocol targets (UNFCCC, undated). The World Bank is also market-based, with an official goal of reducing poverty guided by a commitment to promoting foreign investment and international trade through provision of loans to developing countries for capital programs (World Bank, undated). Market-based schemes with a bi-directional flow of benefits, be they financial or other forms of outcome, are seen in a range of international 'payment for ecosystem services' (PES) schemes (OECD, 2010; UNEP

and UNCN, undated). Organisations such as Forest Trends, an international non-profit organisation seeking to expand the value of forests to society, provide brokerages for businesses and other institutions to partner with representatives of forest interests overseas wishing to undertake sustainable management and restoration (Forest Trends, undated).

Five foundational principles established by Wunder (2005) define PES as: a voluntary transaction where; a well-defined ecosystem service (or land-use likely to secure it); is 'bought' by a (minimum of one) ecosystem service buyer; from a (minimum of one) ecosystem service provider; only if the ecosystem service provider secures ecosystem service provision (conditionality). Smith *et al.* (2013) develop further PES principles including: 'beneficiary pays'; direct payments to ecosystem service providers; additionality (actions over-and-above those resource managers are expected to undertake); ensuring permanence; and avoiding leakage. Everard and McInnes (2013) recognise risks of generating externalities for non-focal services through measures to maximise one or a few favoured services, as seen today in many established markets (food production, water supply, etc.) and potentially therefore in emerging service markets (carbon and biodiversity offsetting, etc.) Everard and McInnes (2013) instead recommend a 'systemic solutions' approach based on "...low-input technologies using natural processes to optimise benefits across the spectrum of ecosystem services and their beneficiaries", explicitly recognising that all ecosystem service outcomes have to be considered systemically within decisions and interventions. The rights of all beneficiaries of ecosystem services are thereby also integrated into decision-making, and net societal value is optimised rather than benefits skewed to a favoured few at potential deficit to overlooked beneficiaries (including future generations). These expanded PES-related principles are described in more detail in Box 1.

Box 1: Expanded PES-related principles

Five foundational PES principles (Wunder, 2005) define PES as:

1. A **voluntary transaction** where;
2. A **well-defined ecosystem service** (or a land-use likely to secure that service);
3. Is 'bought' by a (minimum of one) **ecosystem service buyer**;
4. From a (minimum of one) **ecosystem service provider**; if and only if
5. **Conditionality**: the ecosystem service provider secures ecosystem service provision, or the execution of measures agreed as likely to secure service supply or enhancement, as a basis for payment.

Smith *et al.* (2014) augment these principles with:

- **Beneficiary pays**: payments are made by the beneficiaries of ecosystem services (individuals, communities and businesses or governments acting on behalf of various parties);
- **Direct payment**: payments are made directly to ecosystem service providers (in practice, often via an intermediary or broker);
- **Additionality**: payments are made for actions over-and-above those which land or resource managers would generally be expected to undertake (note that precisely what constitutes additionality will vary from case-to-case but the actions paid for must at the very least go beyond regulatory compliance);

- **Ensuring permanence:** management interventions paid for by beneficiaries should not be readily reversible, providing continued service provision; and
- **Avoiding leakage:** PES schemes should be set up to avoid leakage, whereby securing an ecosystem service in one location leads to the loss or degradation of ecosystem services elsewhere.

Everard and McInnes (2013) emphasise the need to take a systemic approach to assessment seeking 'systemic solutions' comprising "...*low-input technologies using natural processes to optimise benefits across the spectrum of ecosystem services and their beneficiaries*", including three linked principles:

- The **full range of ecosystem service outcomes** have to be considered in all options, decisions and interventions;
- The **rights of all beneficiaries** of ecosystem services are therefore also brought into decision-making; and
- **Net societal value is optimised** rather than benefits to a favoured few achieved at potential detriment to overlooked beneficiaries (including future generations).

These expanded PES-related principles provide a basis for considering the robustness and equity of market-based developed-developing world partnerships, seeking mutually beneficial outcomes rather than simple aid or one-way payments. This is necessary due to the varying distributional characteristics of different ecosystem services. For example, a biodiversity offset to protect or enhance a population or habitat in a recipient region may, in simple terms, result in net gain or stasis in species or habitat protection at a global scale yet is unlikely to make a meaningful contribution to conservation in the donor region. By contrast, the service of global climate regulation is independent of where carbon is emitted, captured or retained. Developed-developing world partnerships for sustainable development have then to be nuanced to take account of the differing characteristics of multiple services.

Historically, and often still today, management decisions have tended to be reductive, driven by the narrow disciplinary interests of specific government departments, regulatory bodies, businesses, land managers or other constituencies often blind to or dismissive of externalities. Practical examples of wider negative ramifications arising from a narrow focus on single or few outcomes include the many negative consequences arising from large dam schemes around the world (World Commission on Dams, 2000), degradation of water resources through over-abstraction driven by short-term economic priorities (Everard, 2015a) and the clearance of fringing mangroves from the Mumbai shoreline for real estate development yet increasing the vulnerability of communities to natural hazards (Everard *et al.*, 2014). Recognition of systemic outcomes across all ecosystem services and their associated beneficiaries requires a more integrated basis for decision-making. As a practical example of the scale of wider and often overlooked potential benefits and disbenefits, the overall ecosystem service value of global forests was calculated at over \$16 trillion (Costanza *et al.*, 2014), of which only 6% of temperate forest and 1.6% of tropical forest valuation is from the bundled provisioning service of 'raw materials' (de Groot *et al.*, 2012).

In practice, one or – more rarely – a few linked ecosystem services are the principal driving forces for decision-making about ecosystem use, conversion or management. Historically, these narrow ends may have been pursued in a blinkered way. However, instead of being seen as sole drivers in decision-making, overlooking consequences for linked services, Everard (2014) describes the outcomes required by driving interests as ‘anchor services’ which can constitute a focal driver, or ‘anchor’, around systemic consideration and design can optimise co-delivery of a range of linked ecosystem service benefits. Natural and managed ecosystems do not deliver single services in isolation, but generate suites of linked ‘environmental services’ (*sensu* Schomers and Matzdorf, 2013) of greater potential cumulative societal benefit. These connected sets of services have also been described as ‘bundles’, comprising “...sets of different services that interact synergistically and occur simultaneously across landscapes provided by different land uses” (Balvanera *et al.*, 2016: p.48). Consequently, taking a ‘systemic solutions’ approach to co-delivery of connected services around the driving ‘anchor service’ can secure greater net societal benefit, greater cross-stakeholder equity and enhanced resilience in the productive ecosystem (Everard and McInnes, 2013). This opens up opportunities for collaborative decision-making, pooling of historically fragmented funding streams, more inclusive participatory decision-making, and hence greater understanding of and support for identified management actions.

In the context of developed-developing world partnerships, the expanded PES-related principles can provide a guiding framework for optimisation of ecosystem service outcomes that serve win-win outcomes for donor and recipient regions. To test this assumption, this paper uses the case study of The Converging World (TCW) programme of low-carbon energy development in an established partnership between interests in south-west England and Tamil Nadu state, India. The TCW programme was selected as it is already established. However, the PES model being tested is potentially replicable and out-scalable to other existing and emerging developed-developing world partnerships.

2. Methods

This methods section comprises an overview of The Converging World (TCW) south-west England/Tamil Nadu partnership programme, including key successes to date and future aspirations. The TCW programme is then analysed in terms of outcomes for each partner region of the ‘anchor service’ of global climate regulation, evaluated through carbon fluxes and emissions averted, as well as linked co-benefits assessed through likely outcomes for the full range of ecosystem services.

The Converging World south-west England –Tamil Nadu partnership

The TCW programme partnering south-west England with Tamil Nadu conceives the two regions as constituting a virtual country of two parts, key characteristics of which are noted in Table 1. Conceptually linking these developed and developing world regions is a means to promote an overall lower carbon trajectory at lowest cost, as climate change impacts are geographically independent of where carbon emissions and sequestration occur.

Table 1: Key characteristics of the TCW partner regions of south-west England and Tamil Nadu state, India. (Cumulative annual emissions values derived from United Nations Statistics Division, 2007, with per capital values calculated)

Region	Area extent	Approximate human population	Cumulative annual CO ₂ emissions	Mean per capita annual CO ₂ emissions
South-west England	23,800 km ²	5 million	44.85 million tCO ₂ e	8.97 tCO ₂ e
Tamil Nadu, India	130,058 km ²	72 million	111.86 million tCO ₂ e (nearly three times that of south west England)	1.59 tCO ₂ e (less than 1/5 the south west England average)

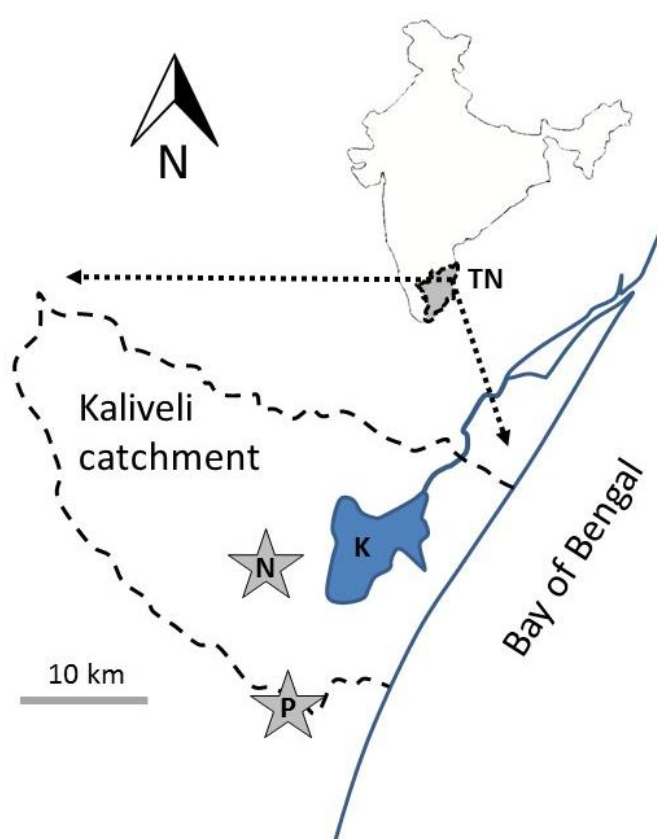
The TCW Group, operating through a range of companies including branches in India, has to date implemented 12.9MW of installed wind turbine capacity in Tamil Nadu to promote low-carbon development. This investment in renewable energy generation averts climate-active emissions growth from the conventional energy mix, much of it fossil fuel-based in India, also 'offsetting' emissions from south west England through UK-based investment products (The Converging World, 2016a).

As part of TCW's wider regional development programme, a proportion of proceeds from energy sales (£100,000 annually from energy sales per 2.1MW turbine: Pers. Comm. Wendy Stephenson: TCW) are reinvested into eco-restoration of tropical dry evergreen forest (TDEF). Selection of TDEF as a priority habitat for restoration reflects the need to address severe deforestation driven by unregulated collection of fire wood, clearance for agriculture and other development across Tamil Nadu over recent decades. 200 years ago, TDEF occupied a belt around 30 km wide stretching for approximately 1,000 km along the south-eastern seaboard of peninsular India (The Converging World, 2015), the area around the Kaliveli catchment remaining heavily forested as recently as 1960. Little remains today of this important habitat, with perhaps 1.5 hectares of climax forest extant, a larger area now constituting disturbed forest and rather more now scrub jungle or degraded thorny thicket. (More details on TDEF characteristics and trends can be found in Champion and Seth, 1968; Meher-Homji, 1974; Venkateswaran and Parthasarathy, 2005; and Parthasarathy *et al.*, 2008.) However, remnant degraded native TDEF, along with other native forest types in Tamil Nadu, still retains culturally important meanings such as sacred groves (Swamy *et al.*, undated).

Successful TDEF restoration since the 1970s at Pitchandikulam on the Auroville Plateau (Figure 1) demonstrates the feasibility of eco-restoration of severely degraded land, with well-documented recovery of an increasing range of native wildlife as well as associated herbal traditions, forest-based livelihoods, and traditional and religious benefits such as enhancement of sacred groves (Pitchandikulam Forest, undated). Joss Brooks (personal communication) reported that "*TDEF (Tropical Dry Evergreen Forest) contains over 160 woody species of which around 70 are found within the pristine climax forest. The TDEF is predominantly composed of trees and shrubs that have thick dark green foliage throughout the year. Within this forest the number of species approaches 1,000, of*

which over 600 have a recorded use for mankind, either medicinally, culturally or in religious rituals". TCW, in partnership with the Tamil Nadu-based Pitchandikulam Forest and Bio-Resource Centre, has already established an area of a little over 30 acres (0.12 km²) of TDEF reforestation at Nadukuppam in the Kaliveli catchment of Tamil Nadu, with more land available to buy and put into trust as the scheme progresses. The initial phase of TDEF eco-restoration was launched to celebrate Bristol as Green Capital of Europe 2015, with a longer-term aspiration to support forest habitat restoration projects in India as well as south-west England over forthcoming decades through reinvestment of funds generated by expanding renewable energy schemes

Figure 1: The Kaliveli catchment in Tamil Nadu (TN) state, India, showing Kaliveli Lake (K) and the approximate locations of Pitchandikulam Forest (P) and the Naddakuppam restoration area (N)



Outcomes for the 'anchor service' of global climate regulation

The overall carbon averted/sequestered through the TCW partnership between south-west England and Tamil Nadu was assessed by adding carbon dioxide emission savings from low-carbon energy inputs from renewable (wind power) generation to those achieved by sequestration in restored TDEF.

As carbon dynamics in forests differ significantly with forest type and location in India (Chhabra *et al.*, 2003), as indeed globally, it was necessary to conduct a literature search to identify carbon storage in both soil and biomass in an appropriate forest

type in the biogeographic region within Tamil Nadu. This was then compared to carbon storage in the biomass and soil of degraded tropical forest, again using locally appropriate data sourced from the literature. The difference between overall carbon storage, normalised to carbon dioxide to compare with emissions potentially offset, was then annualised over an assumed succession period from forest planting to achievement of climax community. For both soil and biomass carbon, a conservative approach was taken – acknowledging in part the sparsity of data in the literature and hence the tentative nature of conclusions about sequestration rates – including assuming a long (100 year) succession to climax forest and using the condition of carbon storage in degraded forest as a baseline rather than the inevitably far lower carbon in the highly eroded farmland that is being converted to TDEF around the TCW-cosponsored pilot forest restoration at Nadukuppam.

Co-benefits assessed through linked ecosystem services

The concept of social return on investment (SROI) arose in 2012 as a principles-based method for measuring environmental, social and other forms of value not reflected in conventional financial accounts, relative to resources invested (Millar and Hall, 2012). These values can be positive or negative, influencing the overall 'return on investment' of a scheme. To generate evidence of wider SROI beyond the 'anchor service' of global climate regulation in the case study, accounting for both linked benefits and disbenefits, outcomes from both TCW Group wind turbine and TDEF eco-restoration schemes were assessed using the ecosystem services framework. Ecosystem services are identified as the most appropriate framework for making this SROI assessment as: (1) service delivery occurs through linked 'environmental services' or 'bundles'; (2) distributional impacts on people occur through the shared medium of the natural environment; and (3) technology deployment and ecosystem management generate a set of benefits and disbenefits that are inherently interconnected, so it is important to assess them as an integrated set to avoid unintended negative outcomes, as well as recognising all potential co-benefits. The UN Millennium Ecosystem Assessment (2005) classification was used in preference to other subsequent reclassifications of ecosystem services – such as those developed for The Economics of Ecosystems and Biodiversity (TEEB, undated), the Common International Classification of Ecosystem Services (CICES, 2016) and the economic model of the UK National Ecosystem Assessment (UK NEA, undated) – as it spans a broad range of benefits and potential disbenefits (disadvantages or losses) accruing to a diversity of people also explicitly including supporting services. Supporting services, as defined in the Millennium Assessment, have been redefined by TEEB (2010) and Braat and de Groot (2012) as ecosystem functions rather than services. Valuation of supporting services can result in double-counting their contributions to other ecosystem services that are more directly beneficial to people, although Potschin and Haines-Young (2016: p.37) describe how *"The responsibility of avoiding 'double counting' is down to the user of the classification and the purpose to which it is put – not only the designer"* (of the classification). Supporting services are retained in the analysis in this paper as they pertain to the functioning and resilience of productive ecosystems, and therefore constitute important considerations in management decision-making.

This assessment was undertaken using a pragmatic, stakeholder-based assessment of likely outcomes across the range of ecosystem services. Initial assessment was by the core research team, with two subsequent rounds of testing of assumptions and findings with: (1) the wider TCW team; and (2) a workshop in Bristol, south-west England in late 2015. Quantification of ecosystem service implications was not undertaken (other than for the ‘anchor service’) consistent with UK Government guidance (Defra, 2007; Everard and Waters, 2013) on taking a pragmatic ‘likelihood of impact’ approach where the expense and time delays entailed in quantification are either infeasible or unwarranted. Findings of these assessments therefore have to be regarded as indicative rather than definitive, but nevertheless highlight a spectrum of societal values arising from ecosystem interventions.

3. Results

Outcomes for the ‘anchor service’ of global climate regulation

Overall CO₂e sequestration/aversion through the TCW partnership between south-west England and Tamil Nadu was assessed by adding carbon dioxide emission savings from low-carbon energy generation by wind turbines and sequestration in restored TDEF.

For a 2.1MW wind turbine installed by the TCW Group in Tamil Nadu, CO₂e averted annually is approximately 4,000tCO₂e, equating to 80,000tCO₂e over the twenty-year operational life of the turbine (both figures conservatively rounded down: see Box 2).

Box 2: CO₂e averted annually per TCW 2.1MW wind turbine

- Actual sales of renewable energy to the Indian grid from four TCW wind turbines (8.4MW peak capacity in total) were in excess of £650,000 between April-September 2015 (The Converging World, unpublished). Figures reported from TCW operations are used in preference to generic technology cost and return values (for example Schlömer, 2014) as they reflect the ‘real world’ returns in Tamil Nadu under the case study scheme.
- Highly conservative £750,000 sales are assumed for the whole year, taking account of the monitored period spanning the main windy season but only half of the year.
- It is assumed that each 2.1MW turbine will generate approximately 3,750,000 units (kWh⁻¹) annually as:
 - £750,000 ÷ 4 = approximately £187,000
 - £187,000 at an average price of £0.05 per unit = approximately 3,750,000 units
- CO₂ averted annually per turbine ≈ 4,000tCO₂e as:
 - 3,750,000 units @ India’s electricity-specific factor of 1.333174843 kgCO₂e kWh⁻¹ (Brander *et al.*, 2011) = 4,999.41 tCO₂e
 - 3,750,000 units @ onshore wind turbine carbon footprint of 4.64 gCO₂e kWh⁻¹ (Vestas, 2005, cited in POST, 2006) = 17.40 tCO₂e
 - CO₂ displaced from conventional Indian energy mix minus CO₂ footprint of wind turbine = 4,982.01 tCO₂e
 - CO₂ averted annually per turbine, rounded down highly conservatively ≈ 4,000tCO₂e

- Therefore, highly conservative total CO₂ averted per 2.1MW turbine over twenty-year operational life = approximately 80,000tCO₂e

A literature search revealed only one significant publication dealing specifically with a forest type in Tamil Nadu akin to Tropical Dry Evergreen Forest (TDEF). This study by Ramachandran *et al.* (2007) used geospatial technology to assess carbon stocks in natural forested areas of the Kolli Hills, in the southern part of the Eastern Ghats in Namakkal district, including semi-evergreen forest which appears to be the most locally appropriate forest type. The study gathered data on biomass and soil carbon for different forest types and in different stages of degradation.

Based on the most conservative limits of these and other relevant published data, and equally conservative assumptions about a 100-year succession to climax community, estimates of annual carbon dioxide sequestration rates by biomass in regenerating TDEF are described in Box 3.

Box 3: Estimation of biomass carbon storage from TDEF restoration

Biomass carbon (above and below ground) for semi-evergreen forest was estimated by Ramachandran *et al.* (2007) as contributing 22% of the total 2.74 Tg of carbon stored by five forest types (tropical broadleaved hill forest [semi-evergreen], southern dry mixed deciduous forest, secondary deciduous forest, southern thorn forest, and *Euphorbia* scrub forest) in the Kolli Hills.

Biomass carbon density for semi-evergreen forests, the locally most appropriate forest type for TDEF, is approximately 0.60 TgC ha⁻¹ (600,000 tonnes C ha⁻¹).

Obtaining comparative figures for carbon storage in the biomass of degraded tropical forests is more elusive, generic studies of tropical forests estimating average biomass carbon density of 63.33-156 tC ha⁻¹ (Bolin *et al.*, 1986) and 70 tC ha⁻¹ (German Bundestag, 1990).

Taking a conservative approach, it is therefore assumed that TDEF restoration can enhance biomass carbon storage from 156 tC ha⁻¹ (the highest figure suggested for degraded tropical forest) to 600,000 tC ha⁻¹, a difference of 599,844 tC ha⁻¹.

We recognise that these forest-type specific figures are substantial in comparison to other published generic forest carbon storage values (for example those derived from above-ground biomass values published by Condit, 2008, and Garzuglia and Saket, 2003). However, we have used literature directly relevant to carbon storage by the specific forest type being restored, acknowledging uncertainties generated by the sparseness of supporting literature.

Assuming a simplistic linear increase over a 100 year recovery period to climax community, this equates to an annual sequestration rate in the biomass of TDEF of 5,998.4 tC ha⁻¹ year⁻¹ (599,844 tC ha⁻¹ divided by 100).

Converting this to CO₂ equivalent (x44/12 for molecular weights of CO₂/atomic weight of C) yields a sequestration rate of 21,994.28 tCO₂ ha⁻¹ year⁻¹.

This figure must be regarded with caution as the published data behind it are sparse. More research is recommended to verify or modify this value as more published or unpublished data become available. However, the assumption is highly conservative as:

- Evidence from regenerated Pitchandikulam forest is that climax TDEF has been achieved in a shorter timeframe (approximately 50 years), which would imply a higher sequestration rate, albeit a shorter lifetime.
- In practice, restoration of the Naddakuppum forest (both the area already planted and surrounding land identified for further planting) occurs on highly eroded farmland rather than degraded forest, so the baseline of soil carbon is likely to be far lower and the resultant sequestration rate therefore far higher.

Soil organic carbon (SOC) is primarily concentrated in the upper 12 inches of the soil where it is readily depleted by anthropogenic (human-induced) disturbances such as land-use changes and cultivation (Post *et al.*, 1982; Tian *et al.*, 2002). The potential of the pedosphere (the soil layer) to sequester carbon can play an important role in the overall management of carbon, and there is significant potential for increasing SOC through restoration of degraded soils and widespread adoption of soil conservation practices (Lal and Bruce, 1999; Albrecht and Kandji, 2003). Reforestation, and conversely deforestation, are particularly significant land use changes affecting soil organic carbon storage and CO₂ flux into the atmosphere (Moghiseh *et al.*, 2013). The range of mean soil organic carbon densities (tC ha⁻¹) calculated by Ramachandran *et al.* (2007) in the top 90cm of evergreen forest soils in the Kolli Hills is reproduced in Table 2.

Table 2: Mean soil organic carbon densities calculated by Ramachandran et al. (2007) in the top 90cm of evergreen forest soils in the Kolli Hills

Forest type	Soil organic carbon density (tC/ha) (0 to 90 cm)		Confidence interval (tC/ha) ($\alpha = 0.05$)	
	Mean	SD	From	To
Very dense evergreen	274.06	175.57	159.35	388.76
Dense evergreen	233.65	193.92	89.99	377.31
Medium evergreen	143.02	54.85	105.01	181.03
Degraded evergreen	193.49	80.62	122.83	264.15
Total evergreen	184.00	123.13	139.19	228.82

As for biomass carbon storage, the most conservative limits of these and other relevant published data, and equally conservative assumptions about a 100-year succession to climax community, are used to estimate of annual carbon dioxide sequestration rates in the soil of regenerating TDEF in Box 4.

Box 4: Estimation of soil carbon storage from TDEF restoration

There is a logical disconnection in the data provided by Ramachandran *et al.* (2007) as 'Medium evergreen' has a lower recorded mean SOC concentration (143.02 tC ha⁻¹ with SD of 54.85) than 'Degraded evergreen' (mean SOC of 193.49 tC ha⁻¹). However, the calculations in this study take a conservative approach, assuming that TDEF eco-restoration will elevate SOC condition from:

- 193.49 tC ha⁻¹ (mean degraded evergreen) to 233.65 tC ha⁻¹ (mean dense evergreen), a difference of 40.16 tC ha⁻¹.

Assuming a linear increase over a 100 year recovery period to climax community and maximum SOC, this equates to an annual sequestration rate of 0.4016 tC ha⁻¹ year⁻¹ (40.16 tC ha⁻¹ divide by 100).

Converting this to CO₂ equivalent (multiplying by 44/12), this equals 1.47 tCO₂ ha⁻¹ year⁻¹.

Conservative assumptions as well as considerations about treating derived values with caution, and the need for further research to verify or modify these values, are the same as those for calculated biomass carbon storage (Box 3).

TCW plans include investment of £100,000 per annum from the operating surplus of each turbine. The total cost of TDEF eco-restoration is £16,255 per hectare, including the purchase price of land and costs entailed in restoring TDEF (planting, maintenance, etc.) (full details in Everard, 2015b). Annual reinvestment of £100,000 from renewable energy sales therefore supports eco-restoration of 6.15 hectares of TDEF, cumulatively creating 123 hectares of regenerated TDEF in phased blocks over the 20-year operating life of a 2.1MW wind turbine. This represents a lifetime CO₂ sequestration of 270,547,756 tCO₂ through TDEF restoration, with incremental annual forest blocks maturing in a phased pattern.

Total CO₂ sequestered ultimately achieved as the twenty blocks of restored TDEF achieve climax community (270,545,880 tCO₂) dwarfs by approximately 3,000 times the CO₂ averted directly from the wind turbine over its operational life (a highly conservative 80,000 tCO₂e). A powerful 'multiplier effect' therefore arises for the ecosystem service of global climate regulation from the TCW model of year-on-year reinvestment of renewable energy generation surpluses into TDEF restoration.

Co-benefits assessed through linked ecosystem services

Consequences for ecosystem services arising from both renewable energy generation from TCW Group wind turbines and eco-restoration of TDEF were analysed in detail by Everard (2015b), primarily as 'likelihood of impact' evaluations rather than with quantification (other than for global climate regulation). It was necessary to make this assessment on a systemic basis as all ecosystem services are produced as a connected set; only when an initial screening has been undertaken on a systemic basis is it possible to determine the most significant outcomes (Everard and Water, 2013).

The breakdown of direct and indirect ecosystem service benefits and potential disbenefits is not replicated here in full, but some of the more significant outcomes identified are highlighted respectively for wind generation and TDEF eco-restoration in Tables 3 and 4. Ecosystem service benefits at the TDEF eco-restoration site at Nadukuppam forest are evident in TCW-promoted initiatives at the adjacent 'Nadukuppam field' and Nadukuppam school. Nadukuppam field is a women's collective set of businesses including herbal medicinal products and crafts linked to forest products, local employment of women in germinating and nurturing indigenous forest plants, as well as *Spirulina* growth for sale as a healthy dietary supplement. Nadukuppam school has an environmental programme permeating its learning programme, and is used as a model for many schools across Tamil Nadu state. The wider Nadukuppam forest eco-restoration therefore very deliberately links with associated economic, women's empowerment and educational development.

Table 3: Significant ecosystem service benefits and potential disbenefits arising from TCW Group wind generation

<p>Provisioning Services:</p> <ul style="list-style-type: none"> • Access to fresh water and its use in production of food and fuel and fibre through: <ul style="list-style-type: none"> ○ Energisation of groundwater pumping; ○ Averting water demand from alternative thermal energy or hydropower generation; ○ Enhanced trading of commodities through enabling electronic communication; and ○ Empowering women freed from historic drudgery of gathering water, fuel wood or fodder. • Potential avoidance of harm to genetic resources, species of biochemical, medicinal and pharmaceutical value, or ornamental resources due to displacement of traditional, non-renewable energy production technologies. • Associated risk of aquifer depletion through energised over-pumping (Jha and Sinha, 2009; Wani <i>et al.</i>, 2009).
<p>Regulatory Services:</p> <ul style="list-style-type: none"> • Air quality as well as microclimate: <ul style="list-style-type: none"> ○ Directly, through averting emissions from coal, biomass and other combusted fuels; and ○ Indirectly through avoidance of indoor fumes from biomass fuel burning. • Global climate regulation through averting: <ul style="list-style-type: none"> ○ Carbon-intensive emissions from coal, biomass and other combusted fuels; and ○ Methane generation from large hydropower dams, a significant global contributor to global warming (Lima <i>et al.</i>, 2008; International Rivers. 2007; South Asian Network, 2007). • Potential benefit to water regulation through wind farm contribution to catchment porosity (Pisinarasa <i>et al.</i>, 2014). • Indirect benefits to regulation of pests, diseases and pollination: <ul style="list-style-type: none"> ○ Where habitat beneath turbines hosts to natural predators, breakdown processes and pollinators, or averts habitat loss for alternative energy generation methods; and

<ul style="list-style-type: none"> ○ Averted need for river impoundments for hydropower, which can be a major cause of the spread of a range of diseases (Malaria, Dengue, West Nile Virus, etc.) with aquatic vectors. ● Associated potential risks associated with noise and visual intrusion.
<p>Cultural Services:</p> <ul style="list-style-type: none"> ● Indirect benefits for aesthetics, recreation and tourism, spiritual and inspiration of arts where damage from traditional energy generation technologies is averted by renewable generation. ● Education and learning enhancement through access to lighting and digital communication. ● Potential risks for some cultural benefits associated with insensitive siting of turbines.
<p>Supporting Services:</p> <ul style="list-style-type: none"> ● Indirect potential benefits for soil formation, primary production, cycling of nutrients and water, photosynthetic oxygen production and provision of habitat where wind generation displaces traditional technologies more damaging to habitats and their ecosystem functions. ● Potential threat to wildlife, requiring further research and careful siting.

Table 4: Significant benefits and potential disbenefits arising from TDEF eco-restoration

<p>Provisioning Services:</p> <ul style="list-style-type: none"> ● Fresh water availability to local people is enhanced by habitat regulation of the quality, quantity and local recycling of water. ● A direct benefit of enhanced aquifer recharge is helping avert distress migration, witnessed during droughts across India (Kumar and Kandpal, 2003; Sinha <i>et al.</i>, 2013). ● Food security and food availability supported by enhanced direct cropping or shade-tolerant polyculture. ● Fuel and fibre resources available for use or trade. ● Genetic resources, such as rare breeds of stock or crops or promotion of regeneration of natural diversity of inherent genetic value. ● Species with medicinal properties, particularly related to traditional medicine, from which biochemicals can be exploited in other ways.
<p>Regulating Services:</p> <ul style="list-style-type: none"> ● Enhancement of air quality through metabolism of pollutant gases, settling fine particulate matter and dust, and avoidance of aeolian erosion from formerly bare soil surfaces. ● Microclimate regulation within and adjacent to the forest. ● Global climate regulation, primarily by sequestering carbon (assessed elsewhere in detail). ● Catchment hydrology enhanced by tree cover (Krishnaswamy <i>et al.</i>, 2012). ● Buffering natural hazards such as storm energy, potentially protecting buildings, other infrastructure and crops from damage. ● Regulation of pests and diseases of both humans and stock, by providing habitat for natural predators (of both pest organisms such as aphids and the vectors of disease) and microbial breakdown processes.

- **Erosion regulation** through binding the soil surface, particularly in formerly degraded landscapes. (Sheet and gully erosion are significant regional problems on degraded lands in this part of Tamil Nadu: Ramasamy *et al.*, 2005).
- **Water purification**, largely through the role of forests in slowing water flows and providing habitat for natural purification processes.
- **Pollination**, by playing host to pollinating organisms.
- **Regulation of soil salinisation** by restoration of more natural landscape hydrology.
- **Visual and noise buffering.**

Cultural Services:

- **Cultural heritage**, if restoration of forest is appropriately planned and managed.
- **Recreational and tourism**, if forest restoration is appropriately planned.
- **Aesthetic importance**, an increasing number of studies relating physical and psychological health to exposure to nature (Pretty *et al.*, 2011; World Health Organisation, undated).
- **Spiritual importance**, including for example regenerating valued habitats (such as sacred groves) or species (e.g. Peepal and Banyan trees).
- Inspiration of locally important **artistic, mythological, folklore** and other **cultural expressions**.
- **Income, employment and training opportunities**, particularly where marginalised communities (including female empowerment) are involved in restoration and maintenance.
- **Educational and research opportunities**, both formal and informal.

Supporting Services:

- Enhancement of linked **soil formation, primary production, nutrient cycling, water recycling, photosynthetic oxygen production**, and **provision of habitat** rebuilding ecosystem integrity, functioning and capacity to produce other beneficial services, particularly where it replaces degraded habitats.

Not all benefits are realised without risk of associated disbenefits although, by significant majority, potential disbenefits (mainly relating to cultural perceptions and potential implications for wildlife) are a matter for further study as well as dialogue with local communities to ensure sensitive siting of TCW wind turbines and also eco-restoration sites such that they do not displace culturally important locations.

4. Discussion

India has a legitimate right to develop with associated growth and eventual contraction related to global per capita convergence of climate-active gas emissions under the Kyoto Protocol (the 'convergence and contraction' principle). However, India's national policy priorities currently rank coal for development above the importance of addressing climate change (Scientific American, 2015). On the back of this development agenda, India's total CO_{2e} emissions are forecast to exceed Europe's output in 2019, albeit that this total emission is distributed over a larger population (McGrath, 2014). India's aggressive pace of coal exploitation, with the goal of doubling or tripling production, may potentially make it the world's second

largest carbon emitter, adding to a historic contribution of around 7% of the warming the world has already experienced as part of a misplaced national and international 'development-out-of-poverty versus environment' agenda (Rose, 2015). Simultaneously, India also has aspirations to become a 'renewables superpower' (Carrington, 2014) against a backdrop of burgeoning energy demand by a fast-growing population and industrial base. The need to promote renewable energy growth in India is pressing and, seemingly, the opportunity is open, which makes TCW's investments to date and plans for the future timely and necessary. In south-west England, the developed world partner in the TCW programme, there are firm international, national and voluntary commitments to reduce per capita emissions of climate-active gases. If a transparent and practical developed-developing world partnership can be established to address overall global emissions reductions, as part of a package of linked cost-effective climate change management measures, this could constitute an attractive proposition with win-win lower-carbon development outcomes for both nations.

The TCW programme represents a sophisticated developed-developing world partnership between a developed world region (south-west England) and a developing region (Tamil Nadu state) conceived as a notional single geographic entity. Within this partnership, the developed world partner may potentially find a cost-effective means to constrain overall emissions, whilst the developing region benefits by installation of renewable energy capacity to serve societal needs on a lower-carbon basis whilst also benefitting from carbon sequestration and a wide suite of ecosystem service benefits arising from reversal of historic degradation of regionally characteristic forest habitat.

The robustness with which mutual benefits may be achieved is tested using the set of expanded PES-related principles outlined in Box 1.

- The partnership does represent a **voluntary transaction** driven initially by charitable interests but seeking progressively stronger business and philanthropic engagement;
- The primary basis of the partnership is a **well-defined ecosystem service** (global climate regulation), though this 'anchor service' may form the basis for building in a linked set of co-beneficial services;
- The 'anchor service' is 'bought' by an **ecosystem service buyer** (TCW) that transparently routes investment from a wider spectrum of buyers into renewable energy and eco-restoration schemes;
- The **ecosystem service providers** include partners in wind turbine installation and management as well as in TDEF eco-restoration;
- **Conditionality** applies in that payments are routed to clear wind turbine and TDEF eco-restoration projects believed by all parties, with evidence reinforced by this study, to secure service supply or enhancement as a basis for payment;
- The '**Beneficiary Pays**' principle is observed in investment from the developing world partner targeting the desired 'anchor service' of global climate regulation, though also supporting non-paying developing world beneficiaries of the wider suite of ecosystem services produced by forest regeneration;
- **Direct payment** occurs to providers of wind turbine installation and management as well as TDEF land purchase, planting and maintenance;

- **Additionality** is achieved as there is no statutory expectation that these measures would be put in place, with higher-carbon development likely to continue in their absence;
- **Ensuring permanence** is achieved by long-term contracts for wind turbine operation, management and energy sales and also the purchase of land and its vesting in local companies and trustees in Tamil Nadu;
- The **avoidance of leakage** is ensured as low-carbon energy input to the power supply grid does not promote – in fact actively averts – the need for investment in fossil fuel-based generation, and regeneration of degraded habitat does not promote exploitation of other extant habitat in Tamil Nadu;
- This study explores the **full range of ecosystem service outcomes**, concluding that the linkage of reinvestment from renewable energy sales into TDEF eco-restoration generates a wide range of ecosystem services of benefit to a diversity of beneficiary groups;
- This then promotes the **rights of all beneficiaries** of ecosystem services in decision-making; and thereby
- **Net societal value is optimised** rather than benefits to a favoured few being achieved at potential deficit to overlooked beneficiaries (including future generations through regeneration of supportive ecosystem capacity).

Maximisation of carbon sequestration through reinvestment of a proportion of surpluses from low-carbon energy generation into TDEF eco-restoration (over a 100-year CO₂e-sequestering lifetime) evidently has a substantial 'multiplier effect', increasing the carbon efficiency of the initial investment in turbines (over a 20-year CO₂e-averting lifetime) by three orders of magnitude. The substantial efficiency of carbon sequestration in regenerating TDEF endorses observations that allowing or encouraging the reversion of cropland or unproductive, degraded landscapes to forest (Stern, 20016) or other land cover similar to native vegetation (Smith *et al.*, 2006) is one of the most effective and economically efficient means to tackle climate change.

However, global climate regulation benefits constitute just one of a broad linked set of ecosystem services, the benefits of which are diverse if by majority non-market. Though perceived as cumulatively significant, it was not possible to quantify these other services in this study. The bulk of the direct benefits appear to arise from TDEF eco-restoration activities, with major implications for poorer stakeholders adjacent to and potentially enhancing their livelihoods from restored forest. These systemic benefits thereby support sustainable development aspirations and commitments at Tamil Nadu state level as well as internationally, including:

- Tamil Nadu State Forest Department aspirations toward reforestation. The Pitchandikulam Forest and Bio-Resource Centre has established good relationships with the State Forest Board and Agriculture Department, which has aspirations to achieve reforestation as well as regenerate the linked tank (traditional water storage) systems. An important aspect of the ongoing reforestation programme is the creation of sustainable jobs for the economically marginalised, as well as education in local schools about the critical importance of the forest to local people (also known as 'social fencing');

- UK and Indian aspirations for a low-carbon development trajectory, including Indian government intentions to become a 'renewables superpower';
- Helping towards Kyoto Protocol and subsequent international climate emissions targets;
- Aspirations of the international community to cut natural forest loss in half by 2020 and strive to end it by 2030, cutting between 4.5 and 8.8 billion tonnes of carbon remobilisation annually (approximating that currently emitted by the United States) under the New York Declaration on Forests (United Nations, 2014). This Declaration is a non-binding global pledge endorsed by more than 130 governments, companies (including thirty of the world's largest) and more than fifty influential civil society and indigenous organisations to restore 350 million hectares of deforested and degraded landscapes by 2030;
- UN Millennium Development Goals (MDGs), including poverty alleviation goals; and
- Contributions to addressing all seventeen of the UN Sustainable Development Goals (SDGs) (see Table 5 for a summary of more detailed considerations in Everard, 2015b) including:
 - No contribution of wind turbines to SDG 14 (marine resources); but
 - Direct contributions to SDGs 7 (turbines and forest contributing to energy systems), 9 (turbines providing valuable infrastructure), 12 (turbines contributing to sustainable sources of energy), 13 (turbines and forest restoration helping tackle climate change) and 15 (restored forest rebuilding terrestrial systems); and
 - Indirect contributions to all other SDGs.

Table 5: Direct and indirect contribution of TCW partnership projects to the seventeen UN SDGs

Sustainable Development Goals (SDG)	Potential contribution of TCW renewable energy generation	Potential contribution of TCW reinvestment in restored TDEF
1. _End poverty in all its forms everywhere	Indirect: Energy access helps lift people out of poverty	Indirect: Restored forest provides subsistence and economic resources, training and employment
2. _End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Indirect: Energy access contributes to food security and nutrition, for example by mechanised pumping of water	Indirect: Restored forest promotes food security and nutrition by direct harvesting, agroforestry and income generation
3. _Ensure healthy lives and promote well-being for all at all ages	Indirect: Energy access contributes to health and wellbeing through poverty alleviation, food security and enhanced opportunities for education and trade	Indirect: Restored forest enhances healthy lifestyles and wellbeing from traditionally valued and exploited forest services (material and non-material)

4._Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Indirect: Energy access enables study into hours of darkness and more reliable access to electronic learning media	Indirect: Restored forest supports training and recovery of traditional practices and values (herbal medicine, forest food traditions, etc.)
5._Achieve gender equality and empower all women and girls	Indirect: Energy access increases security for women and girls using sanitation during hours of darkness (public safety is an underappreciated problem for young women leaving rural homes after dark – The Economist, 2014), extends their capacity to access education, and frees them from the drudgery of traditional roles gathering water and fuelwood	Indirect: Restored forest contributes to gender equality through relieving limitations on resources such as fuelwood, and the burden of its collection, as well as supporting women-centred business activities and cooperatives as seen in the 'Nadukuppam field'
6._Ensure availability and sustainable management of water and sanitation for all	Indirect: Energy access promotes access to pumping for fresh water extraction and wastewater treatment, and may also relieve demand for impoundment of rivers for hydropower generation	Indirect: Restored forest positively influences the water cycle, enhancing the availability of water for healthy and other beneficial uses
7._Ensure access to affordable, reliable, sustainable and modern energy for all	Direct: Energy access from renewable sources is enhanced by installation of wind generators	Direct: Restored forest provides fuelwood, and also natural cooling averting some energy demand
8._Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Indirect: Provision of energy, particularly to those formerly without access, opens up a wide range of employment and wealth-generating opportunities	Indirect: Restored forest provides a range of economic opportunities ranging from forestry to cropping, traditional medicine and other skills
9._Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Direct: Renewable energy generation systems and associated infrastructure represent long-lived assets supporting sustainable industrialisation and innovation	Indirect: Restored forest builds natural infrastructure, providing a range of economic resources
10._Reduce inequality within and among countries	Indirect: Energy provision to those formerly without access potentially increases energy parity between societal sectors, though supporting governance and tariffs are required to secure this benefit	Indirect: Restored forest enhance availability of resources and services, potentially supporting development in regions lagging behind after asymmetric international development patterns, but requires inclusive

		governance to secure this benefit
11._Make cities and human settlements inclusive, safe, resilient and sustainable	Indirect: Energy access can enhance security through lighting in vulnerable areas (as noted above access to sanitation) and the rebuilding of equity of access to renewable resources	Indirect: Restored forest contributes to resilience through the supply of a diversity of (particularly) regulatory and supporting services, benefitting downstream urban centres and transport and energy infrastructure
12._Ensure sustainable consumption and production patterns	Direct: Provision of energy to those formerly without access can be set on a sustainable basis with appropriate governance of energy resource use	Indirect: Restored forest enhances resource availability, through inclusive governance is required to ensure equitable and sustainable use
13._Take urgent action to combat climate change and its impacts	Direct: Provision of energy from renewable sources contributes to low-carbon development	Direct: Restored forest provides significant mitigation and also adaptation (via regulatory services) combatting climate change
14._Conserve and sustainably use the oceans, seas and marine resources for sustainable development	No contribution: Provision of renewable energy to those formerly without access does not make a direct contribution to this SDG	Indirect: Restored forest enhances land-ocean interactions, particularly through water-vectored ecosystem services (freshwater flows to the coastal zone, reducing saline intrusion into groundwater, reducing inputs of eroded matter in run-off, and relieving pressure on exploitation of coastal and estuarine mangroves)
15._Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Indirect: Energy access from renewable sources relieves pressure on mining, damming and other destructive energy conversion technologies that degrade terrestrial habitats	Direct: Restored forest rehabilitates terrestrial ecosystems and their diversity of services to people and wildlife, including reversing desertification
16._Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Indirect: Energy availability may not automatically promote greater inclusivity in resource access, but can contribute to it if accompanied by a more Inclusive approach to governance systems	Indirect: Restored forest promotes resource access, though inclusive governance systems are required to ensure their sustainable and equitable exploitation

17. Strengthen the means of implementation and revitalize the global partnership for sustainable development	Indirect: Energy access empowers local people and institutions, supporting international partnerships for sustainable development	Indirect: Restored forest increases resilience and scope for ecological recovery and, with it, connected social and economic opportunity, including in international partnerships such as the TCW programme
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The 'anchor service' of global climate regulation may be the principal economic and policy driver of the TCW partnership. However, a wide range of co-beneficial ecosystem service outcomes arise from TCW schemes, and particularly from TDEF eco-restoration. Within the constraints of this study, it was possible only to provide illustrative implications of TCW partnership activities for the linked set of ecosystem services beyond the 'anchor service'. It would be helpful and is a future goal of the research team to quantify further ecosystem service outcomes – for example for local water resources, biodiversity and female empowerment – to substantiate the broader outcomes of TCW partnership activities.

Further eco-restoration in Tamil Nadu remains a strategic TCW partnership goal, with opportunities to address regionally representative functional habitat types including other areas of former or degraded TDEF as well as different locally characteristic forest types, mangroves, wetlands, tanks, hill tops and slopes. The water system is of particular importance not merely due to its close interaction with forestry but as it is a major contributor to the vitality of ecosystems of inherent worth crucial for supporting diverse human needs including poverty alleviation. Of particular interest is the Kaliveli system in which Nadukuppam and part of Pitchandikulam is located (Figure 1). The Kaliveli system is a triangular catchment stretching from Gingee to Marakkanam to the Auroville plateau, spanning an area of 740 km² (25,000 ha). Restoration of the Kaliveli catchment is a significant target at state level. The Kaliveli water body is the second largest in South India, located 18 km north of Pondicherry and extending for 28 km parallel to the coast covering a total area of 13,200 ha comprising: (1) the Kaliveli floodplain; (2) Uppukalli creek connecting the floodplain to the estuary; and (3) Yedayanthittu estuary comprising intertidal mudflats and salt pans. The water system of the Kaliveli is characterised by an intricate, ancient network of 225 tanks (mainly seasonal but some perennial) which, together with associated channels, have been pivotal to human settlements over hundreds of years. A management plan has been developed for the Kaliveli wetland complex (Bhalla, 2011). The tank systems of Tamil Nadu are also a priority, having suffered the same kinds of declines in quality, extent and loss of traditional collaborative management as witnessed across much of the rest of India and indeed the tropical world (Everard, 2015a). Privatisation and proliferation of tube wells may enable access to groundwater resources and their supportive services, but can cumulatively contribute to poverty and inequities as people with more resources can access groundwater preferentially through mechanised pumping technologies, depressing groundwater levels and suppressing incentives for community-based management of common water capture technologies that have persisted for centuries as an adaptation to local conditions (Bardhan, 2000; Kajisa *et al.*, 2004). Rehabilitation of traditional groundwater recharge and other water harvesting

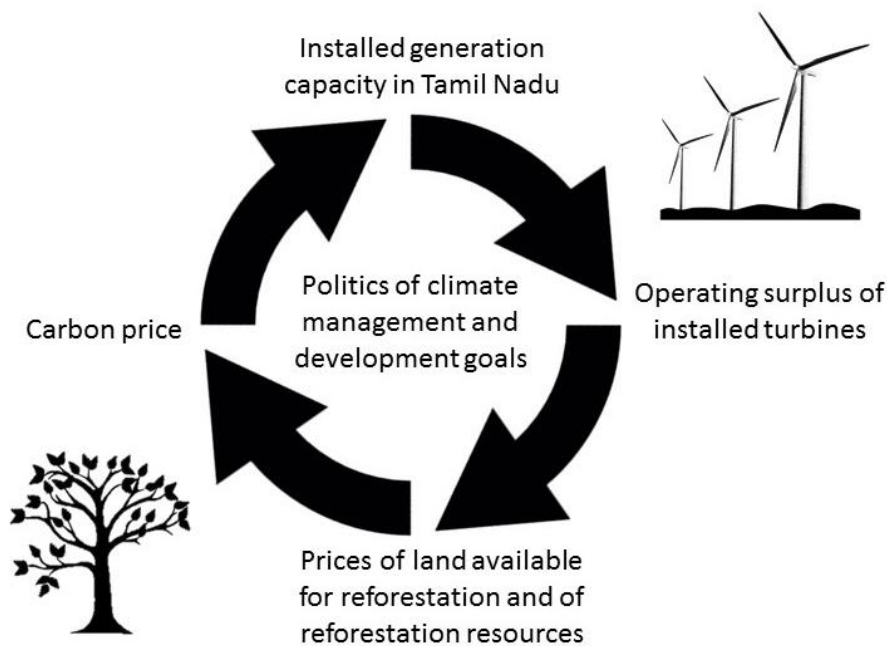
techniques and the social infrastructure that supports them, including effective community-level agreements to avert asymmetric access to groundwater resources, is a necessary condition for the recovery of ecosystems and intimately linked socio-economic security and progress (Palanisami, 2000; Everard, 2013). Given the critical role of water in arid and semi-arid environments, water management will have many additional co-benefits. Threats to poverty and equity arising from the decline in collective tank irrigation management have been identified as a particular threat in Tamil Nadu (Kajisa *et al.*, 2007).

Ecosystem service benefits resulting from restoration of these additional habitat types warrants further research. Extension of the characterisation, ideally with quantification of ecosystem service outcomes arising from targeted forest restoration addressed above also warrants further detailed study. All can make a significant contribution to the sustainability of the energy-water-food nexus of interconnected issues within which TCW is operating.

There is a need for further economic analysis of the 'anchor service', particularly including more monitoring of sequestration and storage above- and below-ground of carbon in degraded, climax and regenerating forests. Quantification of linked co-beneficial ecosystem services generated by TCW-promoted wind turbine and TDEF eco-restoration activities is also a future priority progressively to assess overall SROI. A partner paper (Everard *et al.*, in preparation) explores economic aspects of carbon sequestered and averted, building a case for investment by interests in the donor region, benefit realisation in the recipient region, and the up-scaling and out-scaling of lessons to promote wider uptake and new, robustly and transparently-founded developed-developing world partnership schemes for sustainable development through enhancement of ecosystem services.

This case study makes a number of pragmatic assumptions to facilitate calculations including, for example, about stationarity of population, carbon emissions and the prices of land, reforestation and carbon. This was necessary to derive an illustrative quantum of benefits arising from TCW activities. We recognise sensitivities arising from a linked set of interacting elements (see Figure 2), and the desirability in the longer term to develop an interactive model that can take account of them. However, the purpose of this study was to provide an illustration of the magnitude of potential benefits for the 'anchor service' and linked ecosystem service co-benefits supporting sustainable human wellbeing.

Figure 2: Interacting elements potentially affecting the viability and net returns of the TCW partnership model



Moral implications also arise in terms of the rights of the developed country partner to continue emitting high levels of carbon, offset in a developing nation. The case study in this paper has to be seen within the wider programme of work in Tamil Nadu, elsewhere in India as well as in south west England being undertaken by The Converging World, which includes a range of development activities and including working towards a 'convergence and contraction' outcome overall for climate-active emissions. Behavioural and policy change in both the 'buyer' and 'seller' regions was not part of this study, but will clearly be important in the future development and practical outcome of this and other developed-developing world partnership programmes. To audit and steer future progress, it will be necessary to develop and implement robust and transparent evaluation criteria. This monitoring programme includes assessing continuing systemic contributions across the range of PES principles (for example ensuring continuing conditionality, additionality, permanence, and net societal value), as well as driving the 'joining up' of the policy environment to take an increasingly integrated approach to sustainable development in Tamil Nadu and south west England, for example averting perverse outcomes such as greater availability of energy increasing the unsustainable pumping of groundwater.

This illustrative study, illustrating the potential quantum of climate regulation benefits and making a preliminary assessment of wider ramifications of other linked ecosystem service co-benefits, provides initial evidence supporting monitoring and evaluation of outcomes to steer future scheme development and roll-out to other regions.

Conclusions

- The expanded PES-related principles constitute a useful framework for assessing the transparency and efficacy of developed-developing world partnerships for sustainable development.

- The TCW developed-developing world partnership linking south-west England and Tamil Nadu, founded on wind turbine installation and operation with reinvestment in multi-beneficial TDEF eco-restoration, meets the criteria of this framework, representing a robust and seemingly cost-effective means for addressing climate change challenges.
- The 'anchor service' (the primary driving policy and business rationale for a project) of global climate change makes a compelling case, though requires further economic analysis to demonstrate the extent of benefit persuasively to potential investors.
- The TCW approach already provides evidence that a low-carbon, locally beneficial approach to development is more sustainable and equitable than the current Indian government 'development-out-of-poverty versus environment' trajectory, including its substantial increase in coal production with associated climatic, forest loss and air quality threats. It also provides a potential vehicle or model for the promotion of Indian aspirations to becoming a 'renewables superpower'.
- A wide range of additional direct and indirect ecosystem service co-benefits, as well as some potential disbenefits requiring management, arise from TCW-sponsored renewable energy generation and TDEF eco-restoration schemes. These wider co-benefits add to the economic case for action. However, it is important that management actions are planned with optimisation of the full range of ecosystem service benefits in mind if externalities are to be avoided, and to achieve optimal and equitable societal benefit. A future research aspiration is to quantify a wider range of these linked ecosystem service outcomes substantiating conclusions about SROI.
- Beneficial outcomes arising from TCW Group renewable energy and eco-restoration schemes address many of the sustainability goals reflected in national and international commitments, significantly including the internationally agreed UN Sustainable Development Goals.
- The TCW developed-developing world partnership approach, particularly the substantial 'multiplier effect' of reinvestment of renewable energy surpluses into ecosystem restoration, serves as a model for robust and transparent up-scaling and out-scaling of effective developed-developing world partnership schemes for sustainable development.
- There is a compelling case for continued investment in eco-restoration of TDEF, in terms not merely of its contribution to carbon sequestration and microclimate regulation but also a far broader set of societally beneficial ecosystem service outcomes, many relating to restoring landscape hydrology, soil stability and fertility, and cultural values.
- Significantly beneficial parallel climate regulation and wider ecosystem service outcomes are likely to accrue from restoration of other degraded habitats (mangroves, tank and wetland systems, hill slopes, etc.) within the bioregion and more broadly across Tamil Nadu, India and beyond.

- Further research taking account of economic factors of this scheme will build the case for investment by interests in the donor region, benefit realisation in the recipient region, and the up-scaling and out-scaling of lessons to other developed-developing world partnership schemes.
- To audit and steer future progress of the TCW partnership scheme, including the linked turbine and habitat restoration initiative as well as the wider TCW programme, it will be necessary to develop and implement robust and transparent evaluation criteria that also take account of the distribution of benefits and disbenefits. This illustrative study provides initial strands of evidence serving that need.

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