# Carbon neutral village/cluster: a conceptual framework for envisioning

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**One of the primary drivers of climate change has been the continuous increase in anthropogenic greenhouse gas emissions. If these emissions continue to increase at the current rate then it would push the carbon cycle out of its dynamic equilibrium which may lead to irreversible changes in the climate system. Thus, it is imperative to initiate systemic changes through various socio-economic and technological interventions to mitigate emissions and enhance sinks. This paper attempts to present a conceptual framework of such interventions and highlights the synergies between mitigation and adaptation.**

**Keywords:** Adaptation, carbon neutral, climate change, mitigation, systems thinking.

## Introduction

GLOBAL carbon dioxide emissions stood at 32.3 billion tonnes in 2014 (ref. 1). In order to keep the temperature change caused by greenhouse gas (GHG) emissions less than 2°C, the atmospheric concentrations of carbon emissions need to be stabilized to 450 ppm (ref. 2). Therefore it is only prudent to act on aggressive mitigation and adaptation measures now rather than wait for catastrophe to strike.

If the top down approaches on policy are failing us, there is a need to focus on the grassroots hopefully to influence policy. There are a few working models of carbon neutral or carbon negative communities or societies but there exists plenty of literature on carbon neutrality and various measures to reduce the sources of emissions and enhance the sinks of GHGs. Carbon neutrality, with all its concepts, needs to be articulated in the form of a conceptual framework which can then be objectively evaluated and implemented.

The present article presents a conceptual framework to move towards carbon neutrality, i.e. a simplification of reality which does not encompass the complexity involved in the nature of natural systems, social systems, economic systems and their interplay. This involves identification of major sources and sinks of GHGs in a cluster of villages and interventions that will facilitate mitigation through various ways of adaptation to climate change. The ideas, assumptions and examples presented here have been evolved from Swiss Agency for Development and Cooperation–National Bank for Agriculture and Rural Development–Watershed Organisation Trust (SDC-NABARD-WOTR) Climate Change Adaptation Project.

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## Background

### *The carbon cycle and global warming*

Carbon is continuously exchanged among oceans, atmosphere, ecosystem and geosphere (Figure 1). This exchange maintains a dynamic equilibrium (a state of balance in a continuous process) which helps preventing excess accumulation of carbon in the atmosphere and regulating the earth's temperature. This fine balance has been altered by anthropogenic activities which have increased the stock of carbon in the atmosphere by burning large amounts of fossil fuel, emissions from agriculture and livestock, land use and land cover change. As a consequence, average global surface temperature rose by 0.6°C to 0.9°C between 1906 and 2005, and the rate of temperature increase has nearly doubled in the last 50 years (ref. 3). Further warming is expected as we continue to increase emissions and more carbon stock gets accumulated in the atmosphere.

### *Thermal inertia: temperature delay*

The increased concentration of carbondioxide and other GHGs in the atmosphere increases radiative forcing and thus warms the earth's surface (land and ocean) temperature. Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010, with only about 1% stored in the atmosphere[4]. It has taken decades to centuries until surface temperature has approached its new equilibrium after a perturbation of the radiative balance[5]. This implies that the current combined increase in ocean and land surface temperatures will be realized a decade or two in the future indicating that we are locked in for further warming independent of changes in future emission scenario.

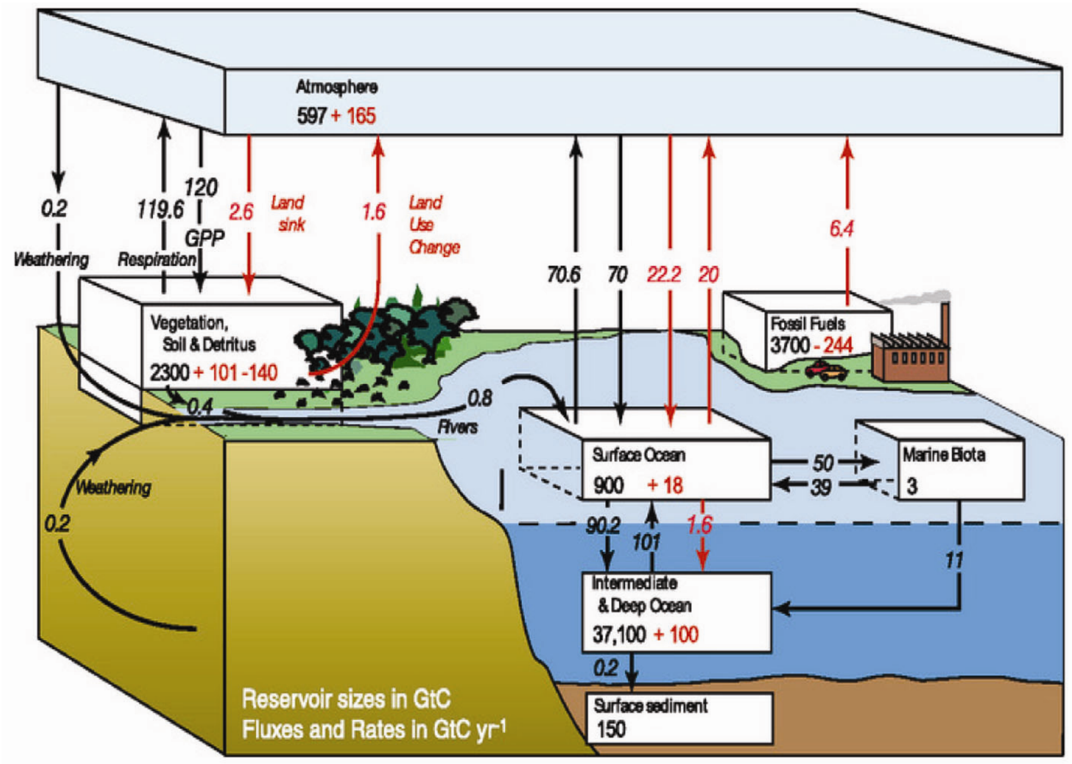


**Figure 1.** The global carbon cycle for the 1990s, showing the main annual fluxes in Gt Cyr-1: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red (source IPCC, 2007).

## *Mitigation and adaptation: synergies and trade-offs*

Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections within and across land use and biodiversity, livelihoods and ecosystem services, water, agriculture and energy. But relevant tools to understand and manage the complexity of these interactions remain limited[4].

Significant co-benefits, synergies, and trade-offs exist between adaptation and mitigation. Activities such as protection and regeneration of ecosystems and ecosystem services for carbon storage, sustainable agriculture and forestry, soil and water conservation, improved energy efficiency and cleaner energy sources, and improved water use efficiency result in reducing emissions and enhancing carbon sequestration.

## *Outlining carbon neutrality*

There exists a stock of carbon in the atmosphere, oceans, soil, forests and there are flows in the form of emissions entering and leaving these stocks. In the absence of any interference from non-natural factors, this cycle of stocks and flows remains in dynamic equilibrium. In order to stabilize earth's atmospheric carbondioxide concentration levels and move towards carbon neutrality or net zero carbon emissions, a dynamic balance between the rate of emissions and the rate of carbon sequestration needs to be maintained with exceptions for temporary emissions over shoots which undergo timely correction. This implies that the rate of anthropogenic emissions needs to be controlled and managed so that it does not exceed the rate of sequestration.

## *Rural trends in carbon dynamics – a snapshot from WOTR's project areas in Ahmednagar*

The stocks of sinks and sources of GHGs have undergone immense changes over the last few decades. This has been elucidated during group discussions with village communities who clearly mentioned that local ecosystems, agriculture, biodiversity, energy usage and livelihoods have undergone significant changes in the area under study. Growth in carbon sources has outpaced the sequestration potential of carbon sinks and in some cases the sinks have also been depleted. This change over time is shown through the causal loop diagram (Figure 2) and narrated in following text. The various sources and sinks of GHGs in the village are presented in Tables 1 and 2.

## *Area description and data collection*

Areas under study are villages located in Ahmednagar district of Maharashtra state. The region falls under dry

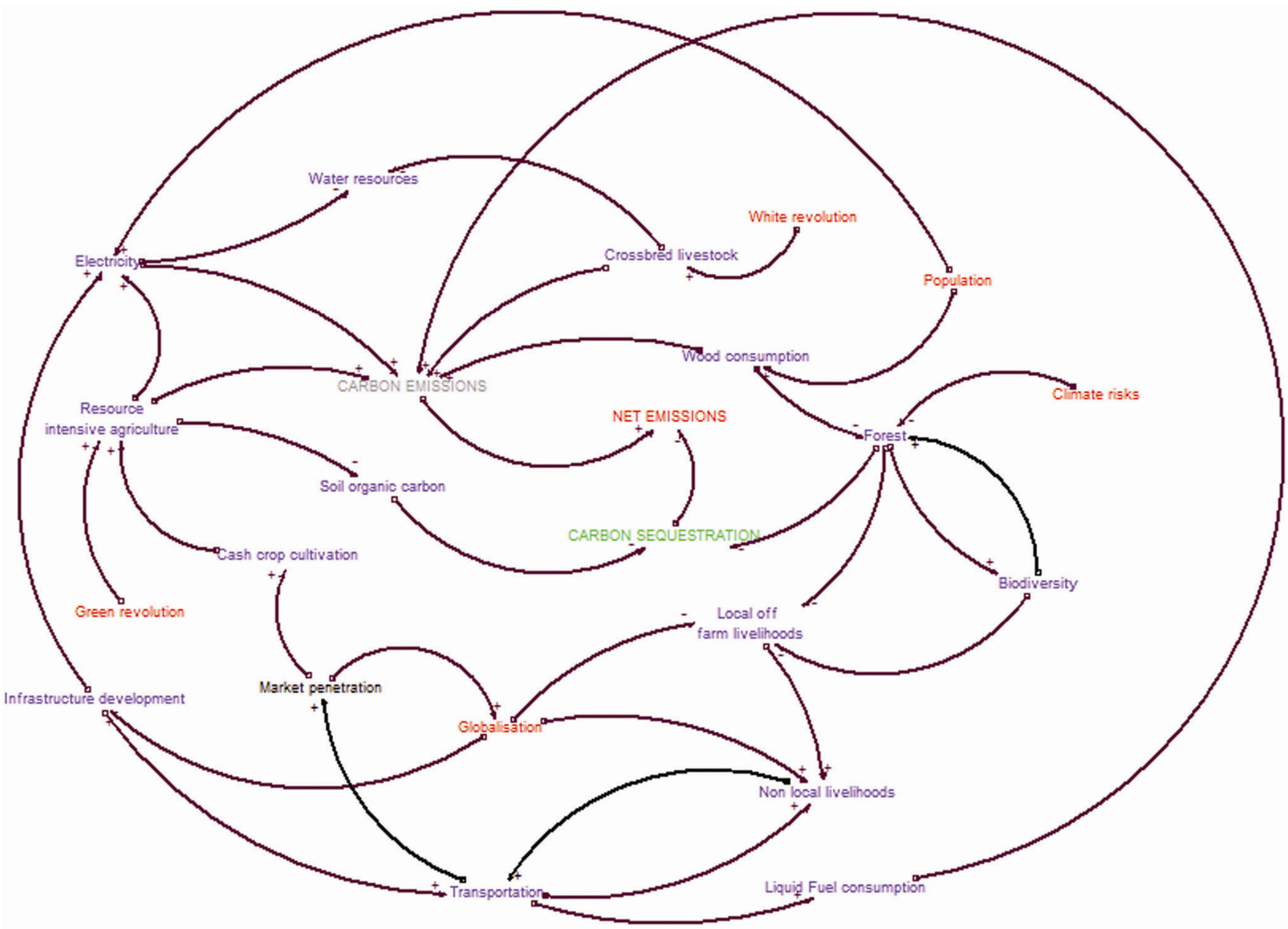


**Figure 2.** Interconnectedness of variables: carbon dynamics in villages.

land where the livelihood of rural communities is mainly agriculture and livestock.

The data has been collected through various participatory methods in the project villages like focused group discussions, interviews with different sections and groups within village communities. Qualitative data in the form of anecdotes have been used in the study.

## *Drivers of change*

The key drivers of local change identified are population growth, globalization, green and white revolutions, and climate variability. These are the major factors contributing to increasing carbon emissions and reducing carbon sinks thereby increasing carbon stocks in the atmosphere. Local culture, aspirations and lifestyles are hurtling towards a new normal – carbon heavy lifestyle. The transformations in the village as a result of driving forces and their contributions to carbon emissions are presented in the loop diagram (Figure 2). The red colour represents the major drivers that trigger transformations and the rests are various sectors or parameters that get affected by the drivers. The (+) sign denotes the increase and the (–) sign denotes decrease. For example, globalization has reduced the opportunities of local off-farm livelihoods in villages and this in turn has led to an increase in non-local, energy intensive livelihoods. This process and its interlinkages have been described in a causal loop diagram in Figure 2.

Forests act as one of the major carbon sinks. However, a sharp decline in forest cover in and around villages has been observed. Therefore, the sequestration rate of the emissions has reduced. Various reasons for loss of forest cover as shared by the communities are:

- The drought of 1972 brought about a severe water scarcity. People resorted to cutting trees and converting them to charcoal. This was then sold in the market and the income generated was used to buy food and water. This has been cited as one of the major drivers for the decline of forest cover.
- Local people need fuel wood for cooking, timber for farm equipment, house construction, furniture, etc. With increasing population, the demand for the same

**Table 1.** Sources of greenhouse gas emissions in rural areas

| Sector | GHG | GHG sources |
|---|---|---|
| Agriculture | Methane ($CH_4$) | Rice cultivation |
| | Methane ($CH_4$), carbon monoxide (CO), nitrogen oxide ($NO_x$) | Burning of crop residues |
| Agricultural soils | Nitrous oxide ($N_2O$) | Application of synthetic fertilizers on soil |
| Livestock | Methane ($CH_4$) | Enteric fermentation due to ruminant digestive system |
| | Nitrous oxide ($N_2O$) and methane ($CH_4$) | Manure management |
| Energy | Carbon dioxide ($CO_2$) | Combustion from cow dung, fuel wood, liquefied petroleum gas, coal, kerosene, petrol, diesel, etc. |
| Waste | Methane ($CH_4$) | Anaerobic decomposition of solid waste |

**Table 2.** Major sinks of greenhouse gas in rural areas

| Sink | Benefits |
|---|---|
| Forest | Remove carbon dioxide from atmosphere and store as carbon biomass |
| Soils | Agricultural soils act as sink for atmospheric carbon through crop residues and storage of fixed carbon as soil organic carbon which contributes to soil fertility |

has increased exponentially. This has led to a drastic reduction in canopy cover, even though it may not result in complete felling of the tree.

The depletion in forest cover has greatly reduced the potential for local carbon sequestration, loss of biodiversity, increased soil run off, and non-timber forest produce (NTFP) for livelihoods.

### *Forests and livelihoods*

Most rural livelihoods are dependent on NTFP for their livelihoods. A decline in forest and trees results in shrinking resource base for NTFP-based livelihoods. This in turn increases the pressure on local people to search and find alternate livelihoods. A majority of alternate livelihoods are energy intense in nature as they all have high transport and electricity demands. A rise in such forms of livelihoods increases emissions.

### *Energy*

Fossil fuel consumption has also been on the rise in rural areas. Non local goods and services entering the economy and movement of people for diverse occupations have led to an increase in vehicle density and liquid fuel consumption. Alternate forms of livelihood like pick up/jeep service have come up which act as quasi–public transport.

Emissions from electricity have been considered only at the consumption source or at the end use (household and irrigation) and not at the generation source (thermal power plants, etc). The GHG emissions from electricity production can be attributed to the sectors that use electricity. The emissions from generation and transmission have not been considered in this study.

### *Agriculture and livestock*

The green revolution brought about an enormous change in agriculture with the introduction of hybrid varieties of seed, increased use of chemical fertilizers and irrigation. This has rendered agriculture resource intensive leading to over-exploitation of water resources, higher electricity consumption to pump water, resulting in more emissions. Excessive use of chemical fertilizers has negative impact on the soil health and affects the soil organic carbon, therefore reducing the potential capacity of the soil as carbon sink. A large area has been brought under irrigation which has led to an increase in the consumption of electricity (for electric pumps) and fuel (diesel pumps) to pump water, this attributes to the increased carbon emissions[6].

The introduction of crossbred exotic varieties of cows also influenced carbon emissions. The poorly-fed livestock, i.e. fed on inadequate rations or less digestible crop by-products or grazing on poor quality rangelands, results in the release of high levels of methane via enteric fermentation[7]. Due to high productivity, the number of crossbred cattle in the villages has increased while that of small ruminants and indigenous cattle has gone down. The feeding requirements of crossbred cattle are different from that of the indigenous ones, while indigenous cattle have better capacity to digest low-quality feeds; the farmers of these regions are unable to feed crossbred cattle adequately, causing the cattle to produce high levels of methane. Therefore, one may conclude that methane emissions in high yielding crossbreds, considered in totality, will be much higher when compared to indigenous cattle[8]. Emission scenario for the study area is presented in Table 3.

## Systemic interventions to move towards carbon neutrality

To bring down the net emissions to zero, emission sources are to be reduced and sinks are to be enhanced. Various interventions like watershed development

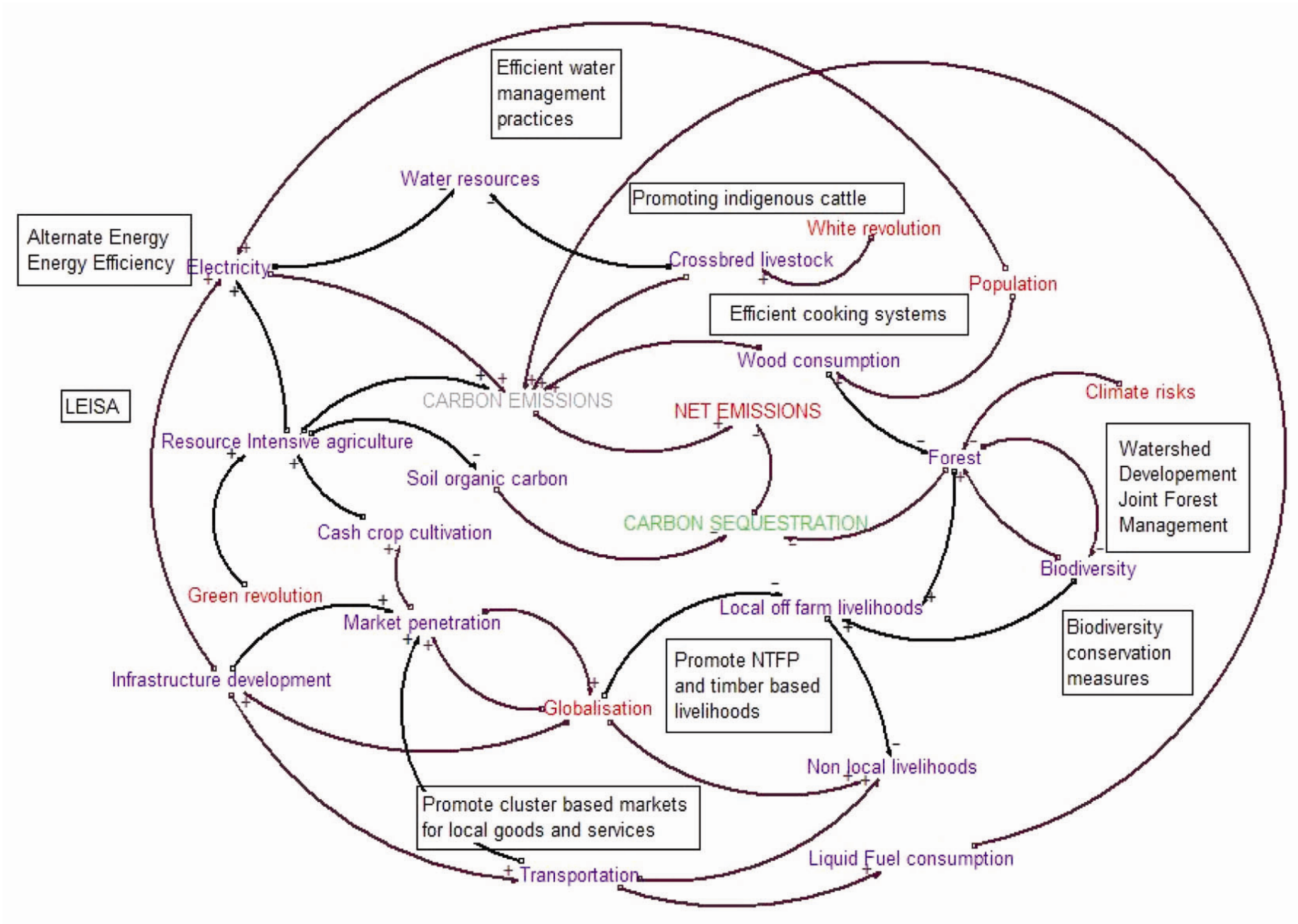


**Figure 3.** Moving towards carbon neutrality through systemic interventions.

programme, sustainable agricultural practices etc. have direct carbon benefits by enhancing the biomass and soil carbon while deployment of renewable energy sources to meet the energy demands helps in reducing the emissions. Features of various carbon enhancement and reduction measures and their benefits are described below. In the causal loop diagram (Figure 3), the leverage points from the transformations triggered by the drivers mentioned are identified and appropriate interventions that contribute to mitigation and sequestration are presented (text in boxes).

## *Ecosystems management through watershed development programme*

WSD projects are the package of activities aimed at soil and water conservation measures, catchment area treatment, afforestation, grassland management, improved cropping systems etc. These practices help increase biomass cover and therefore enhance the soil carbon stocks.

Afforestation on degraded forests and waste land help increase the biomass and therefore increase the rate of carbon sequestration. Practices like contour bunding, gully plugging, check dams, cover cropping, multiple cropping and other soil and water conservation measures help reduce soil erosion, conserve the soil moisture for crops that lead to an increase in biomass which in turn add to increased soil organic carbon. Afforestation on degraded land has the potential to enhance the carbon stock by 4.2–4.6 tonnes per hectare per year. Similarly, agroforestry can enhance the soil organic carbon (SOC) by 30% per year or 7.3 g SOC per 1 kg of soil[9].

## *Efficient water management practices*

Better water management practices for agriculture such as switching from flood irrigation to micro-irrigation practices is one way to mitigate emissions by reducing the electricity or fuel consumption and fertilizer consumption. In micro-irrigation practices such as drip irrigation, water is supplied at regular intervals using piped networks, unlike flood irrigation where water needs to be pumped for a longer time for equal distribution of water on a farm, thus requiring more energy. Drip systems and

**Table 3.** Emission scenario of a project village

| | At present | Proposed reduction (%) | Revised | Mitigation activity |
|---|---|---|---|---|
| Emissions from agriculture | | | | |
| Area under agriculture (hectare) | 400.0 | 0 | 400.0 | NA |
| Quantity of fertilizers applied (tonnes) | 665.1 | 40 | 399.1 | Use of organic compost and fertilizer |
| Emissions ($N_2O$) tonnes | 11.5 | 40 | 6.9 | |
| Emissions ($CO_2$ equivalent) tonnes | 3427.0 | 40 | 2056.2 | |
| Emissions per hectare (tonnes) | 8.6 | 40 | 5.2 | |
| Emissions – electric water pumping ($CO_2$ equivalent) (tonnes) | 10.0 | 20 | 8.0 | Deployment of solar/wind/treadle pumps for lifting water for agriculture purpose |
| Diesel water pumps (tonnes) ($CO_2$ equivalent) | 0.6 | 50 | 0.3 | Deployment of solar/wind/treadle pumps for lifting water for agriculture purpose |
| Emissions – diesel water pumps (tonnes) ($CO_2$ equivalent) | 1.6 | 50 | 0.8 | |
| Emissions from agriculture (tonnes) ($CO_2$ equivalent) | 3438.6 | 40 | 2065.0 | |
| Emissions from energy consumption | | | | |
| Fuel wood (tonnes) | 311.0 | 10 | 279.9 | Deployment of hot water Chullahs at 50% households, improving fuel wood efficiency by 20% |
| Cowdung (tonnes fuel wood equivalent) | 7.0 | 10 | 6.3 | Deployment of Hot Water Chullahs at 50% households improving fuel wood efficiency by 20% |
| Kerosene (tonnes) fuel wood equivalent) | 8.2 | 0 | 8.2 | |
| LPG in ((tonnes) fuel wood equivalent) | 0.3 | 10 | 0.3 | Deployment of hot water Chullahs at 50% households using LPG thereby improving fuel wood efficiency by 20% |
| Agro waste (tonnes fuel wood equivalent) | 0.3 | 0 | 0.3 | |
| Total fuel wood consumption (tonnes) | 326.8 | | 295.0 | |
| Emissions from cooking fuels (tonnes) ($CO_2$ equivalent) | 424.8 | 10 | 383.5 | |
| Household lighting and electricity | | | | |
| Kerosene (tonnes of litre) | 10.4 | 20 | 8.3 | Deployment of portable solar home lighting systems and/or solar study lamps at 50% households |
| Kerosene emissions (in $CO_2$ equivalent tonnes) | 13.6 | 20 | 10.9 | |
| Electricity (kW) | 7929.6 | 20 | 6343.7 | Improving energy efficiency by replacing point of use lights by efficient lights (LEDs) |
| Electricity emissions (tonnes) ($CO_2$ equivalent) | 8.7 | 20 | 7.0 | |
| Household electricity emissions | 22.3 | 20 | 17.8 | |
| Personal transportation | | | | |
| Liquid fuel for personal transportation (litre) | 2.8 | 10 | 2.5 | |
| Emissions from personal transportation ($CO_2$ equivalent) (tonnes) | 7.5 | 10 | 6.7 | Promote use of local goods and services produced within the village or group of villages and sold in local markets |
| Total emissions ($CO_2$ equivalent) (tonnes) | 3893.2 | 36 | 2473.0 | |
| Other Sources ($CO_2$ equivalent) (tonnes) | 973.3 | | 973.3 | |
| Grand total emissions ($CO_2$ equivalent) (tonnes) | 4866.5 | 29 | 3446.3 | |

Existing sequestration

| Sinks | Tonne per year C | Conversion factor | Tonne per year $CO_2$ |
|---|---|---|---|
| Total increment in carbon stocks in forest land remaining forest land[11] | 373.5 | 3.67 | 1369.5 |
| Total increment in carbon stock in trees in village[11] | 9.8 | 3.67 | 35.9 |
| Agriculture, soil organic carbon[12] | 547.2 | 3.67 | 2006.3 |
| Other Sources (unrecorded taken as 15% of the total emissions, e.g. Grassland, humus, water bodies, etc.) | 82.1 | | 300.9 |
| Total | 1012.5 | | 3712.6 |

| Scenario | Equation | Net impact (tonne per year) | Result |
|---|---|---|---|
| Net impact | | | |
| At present (business as usual) | Sources *minus* sinks (tonnes of $CO_2$) | 1153.9 | Carbon positive |
| Carbon neutral interventions | Sources *minus* sinks (tonnes of $CO_2$) | –266.3 | Carbon neutral/negative |

sprinklers can act as mitigation measures to reduce emissions generated while pumping water. Also, these measures reduce the surface run off and help enhance the efficiency of fertilizer application which is one of the major sources of nitrous oxide ($N_2O$) emissions. In these methods, nutrients are applied to the soil at low concentration frequently according to plant requirements and the roots in the wetted area increase the efficiency of water and nutrient uptake. For instance, one study observed a 44% reduction in electricity consumption to run pumps under sugarcane cultivation (1059 kWh per ha)[10].

### *Adaptive sustainable agriculture*

The objective of sustainable agricultural practices is to promote low external input agricultural practices and can also be termed as low external input sustainable agriculture (LEISA). It constitutes a set of practices which include: indigenous seeds, organic manuring, composting, mulching, soil and manure preparation, reduced or no tillage operations which are also combined with water budgeting and water management practices. Low external input refers to reduction in the usage of synthetic fertilizers which helps in reducing GHG emissions and improves soil fertility. Incorporation of organic manure increases the soil moisture availability and therefore leads to an increased stock of soil organic matter through increased crop and root biomass production. Mulching helps in addition of organic components like crop residues, litter, leaf, etc. that enhances the soil organic carbon. Application of 50% organic manure (rest from fertilizers) helps in increasing the SOC by 0.26% and incorporating 5 tonnes of mulch per hectare adds 29.6 g of SOC per kg of soil[11]. Conventional farming practices that involve tillage remove carbon from the soil by removing the crop residues, it expose the top soil to heat leading to increased oxidation of soil organic matter. In zero tillage farming, the crop residues are left to decompose in the field and carbon loss is slowed down.

### *Action plan for low carbon energy*

India has a large percentage of impoverished population in rural areas whose energy demands are well below global average, yet their energy needs (for cooking, drinking water and irrigation) are still largely unmet. Besides this, rural women spend a significant amount of their time and energy in gathering fuel–wood and suffer from indoor air pollution. Any efforts to improve efficiencies and introduce cleaner burning fuels thus not only help save lives but also considerably reduce the drudgery that women in rural areas face. For this, hot water chullahs, solar home lighting systems, solar street lights, solar parabolic cookers, biogas plants, need to be promoted.

Delivering alternate systems to remote locations is an energy and money-intensive process. In order to lower the emissions and amount of money flowing out of the village economy, local entrepreneurs need to move up the value chain and become product designers and assemblers. This would not only help reduce the emissions but also enhance livelihood opportunities for villagers.

### *Local markets and livelihoods: reducing road miles*

In order to reduce the road miles of goods and services, the producer and consumer should be brought closer to each other. This implies local markets, locally produced goods and services and healthy ecosystems which provide free resources required for local livelihoods. Local markets can be held on a weekly basis and there could be some theme markets, e.g. for agricultural equipment, local spices, home furniture, etc. followed by an annual livelihoods festival and *melava*. A serious and concerted effort is needed to revive traditional markets like local, general and special fairs and markets that cater to a group of villages.

## Mitigation potential of the proposed interventions – an example

The current emissions of the village have been calculated using IPCC Good Practice Guidelines 2006. The primary data have been used for different sources of emissions, collected from WOTR's project village in the Ahmednagar district of Maharashtra. Major sectors that have been considered are agriculture, energy and transportation as the sources and forests and agricultural soils as sinks of emissions (Tables 1 and 2). Wherever possible, country-specific emission factors have been used. This is a sample case study and data from various WOTR project villages of the Ahmednagar district have been collected. Though the data do not represent the actual situation of any one village, the villages have been observed to share more or less the same situation with respect to energy use and emissions. The data have been organized such that it represents the energy use, emissions and sequestration of a particular village.

From this exercise it seems that in the current situation, the village emits more carbon than locally sequesters. If the proposed interventions are implemented the village would move from being carbon-positive to carbon-neutral or negative. The impact of proposed intervention in reducing emissions is based on various literature sources.

## Conclusions

The approaches and strategies laid down towards developing carbon neutral clusters are neither complete nor exhaustive. However, they represent good starting points to enable constructive dialogues for a concrete plan to evolve. We need to test them through pilot studies. Many such approaches need to be supported by small experiments performed in different ecosystems and cultures; based on their responses the frameworks can be further strengthened.

1. IEA, Global energy-related emissions of carbon dioxide stalled in 2014, International Energy Agency (online) 2015; available at: http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html (accessed on 25 May 2015).
2. IPCC, Summary for Policymakers. In *Climate Change 2014, Mitigation of Climate Change*, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, USA, 2014.
3. NASA, Global Warming. NASA Earth Observatory (online); available at: http://earthobservatory.nasa.gov/Features/GlobalWarming/page2.php (accessed on December 2014).
4. IPCC, Summary for Policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, 2014, pp. 1–32.
5. Joos, F. and Bruno, M., A short description of the Bern model. *Climate and Environment Physics*, University of Bern, Bern, Switzerland, 1996.
6. Lal, R., Carbon emission from farm operations, *Environ. Int.*, 2004, **30**, 981–990.
7. Hemme, T., Garcia, O. and Saha, A., A review of milk production in India with particular emphasis on small scale producers. *Pro-Poor Livestock Policy Initiative Working Paper*, Food and Agricultural Organization, Rome, 2003, **2**.
8. WOTR, *Livestock Systems, Vulnerability and Climate Change*, Watershed Organization Trust, Pune, 2013, p. 23.
9. World Bank, *Enhancing Carbon Stocks and Reducing $CO_2$ Emissions in Agriculture and Natural Resource Management Projects*, World Bank, Washington, 2012.
10. Narayanamoorthy, A., Potential for drip and sprinkler irrigation in India. Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, 1996.
11. IPCC, IPCC Guidelines for National Greenhouse Gas Inventories, The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, Hayama, Kanagawa, Japan, 2006.
12. Ch. Srinivasrao, *et al.*, *Assessment of Carbon Sequestration in Agriculture and Agroforestry System*, Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 43.

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