Application of the TEEBAgriFood Evaluation Framework to the wheat value chain in Northern India

Executive Summary

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Photo credit: Nupur Dasgupta (wheat, 16 Feb 2012, available at https://flic.kr/p/bExio6

1. Introduction

Agriculture and food systems can, if well-managed, lead to food security, and if sustainably managed would provide several positive externalities. However, due to unsuitable policies and the lack of a holistic analysis of production systems, agriculture contributes to negative externalities. Negative externalities occur in the form of greenhouse gas emissions (GHGs), soil erosion, eutrophication, health impacts due to pesticide use, and the contamination of ground water and surface water. Thus, along with providing more food, agriculture and food systems have been providing large negative externalities per unit of food produced, which are not being considered in the policies, nor by consumer behaviour or by producers (TEEBAgriFood report, 2018). This study is carried out as part of the United Nations Environment Programme (UNEP) initiative of The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood) aimed to provide a comprehensive economic evaluation of the 'eco-agri-food-systems' complex, and the nature of dependencies and interactions between the wheat-producing sector, ecosystem services, economy and well-being. This study's primary purpose is to illustrate the application of the TEEBAgriFood Evaluation Framework using Punjab wheat as an example. Punjab has conventionally been a wheat-growing state but the majority of farmers have adopted rice-wheat farming systems after the green revolution. Thus, achieving food security is the key priority in a highly populous country, which can be primarily achieved by improving yield and agricultural intensification. Wheat and rice are the two most important crops grown in India. The wheat acreage in India increased from 13.3 million hectares (Mha) in 1960 to 31.5 million hectares in 2020, and the yield increased from 0.77 tonnes/hectare to 3.332 tonnes/hectare. The production increased from 10 million tonnes to 103 million tonnes during the period 1960 to 2000.

"Along with providing more food, agriculture and food systems have been providing more negative externalities per unit of food produced, which are not being taken into consideration in the policies, consumption behaviour and the producers alike (TEEBAgriFood Foundation Report, 2018, 3).

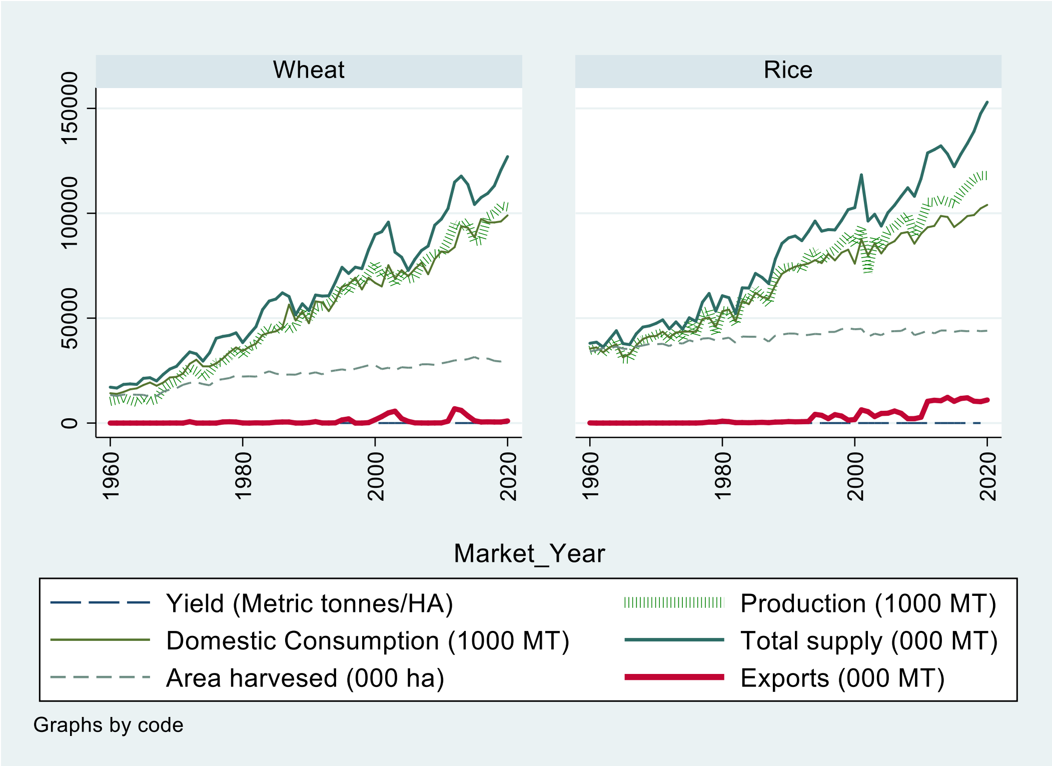


Figure 1: Yield, acreage, production, consumption and exports of wheat and rice in India

Source: Created by author based on data from USDA, production, supply and distribution database.

During the same period as seen in Figure 1, the rice acreage across all of India increased from 34 million hectares to 44 million hectares between 1960 and 2020. Still, the production increased from 34 million tonnes to 118 million tonnes. The average rice yields increased from 1.5 t/ha to 4 t/ha from 1960 to 2020. The increased yields have been facilitated by the Green revolution in the 1970s through an improved and high yielding variety of seeds, along with investments in irrigation, infrastructure, increased use of fertilizers, and favorable policies towards the production of wheat and rice. The essential enabling policy for an increase in India's rice and wheat output is the price support to the farmers in the form of minimum support prices (MSP) for wheat and rice, which is revised annually by the Government of India based on the cost of production. Farmers get paid directly when they sell wheat and rice in the primary market at the minimum support price. Part of the rice and wheat procurements go into buffer stock and the rest is made available for distribution whilst the surplus is exported. Other enabling policies that mainly supported rice and wheat are the subsidies on fertilizers, power and irrigation water.

However, this intensification has exerted pressure on soils and groundwater and the marginal gains have therefore been declining, indicating diminishing returns to the inputs. Due to its disproportionate impacts generated on the environment compared to its production achievements, the state of Punjab has been chosen as the focus area in this study. The Punjab case study illustrates how misaligned policies can create perverse incentives which lead to adverse impacts. Rampant subsidies, free power and an excessive focus on increasing the output with little emphasis on crop diversification, created a perverse scenario of ground water depletion, a decline in soil quality and productivity, loss of biodiversity and severe environmental pollution, culminating in adverse human health impacts.

2. Study Objectives

This study was commissioned to pilot the application of the TEEBAgriFood framework for the state of Punjab in Northwest India. The study tries to address the following two broad research questions:

1. What is the feasibility and potential of applying the TEEBAgriFood framework to the wheat production system?
2. How would a holistic assessment of agriculture and food systems change the perspective with which we look at the agri-food systems?

In order to address the research questions the study will address the following objectives:

1. Quantify the role of produced, natural, human and social capitals and the tangible and intangible flows from different capitals on the production of wheat.
2. Identify the value addition of wheat from the production at the farm to the processing at the mill.
3. Quantify the positive and negative externalities of wheat production during the land preparatory phase and the production phase.
4. Estimate the economic, environmental, social and human capital outcomes and impacts of wheat production.
5. Illustrate the application of the TEEBAgriFood framework for two scenarios and compare them with the base scenario:

5a. Base scenario: Wheat production is characterized by mechanized farming, high labour inputs, use of surface and groundwater irrigation, use of high chemical inputs, pesticides to control pests and herbicides for removing the weeds. The field is cleared for wheat production through open-field burning of the paddy stubble (post paddy production) Vs. Scenario A – The management system is the same as in the base case except that the field is prepared through the use of technology (i.e. Happy Seeder) which removes the stubble and simultaneously inserts the wheat seeds directly into the soil.

5b. Scenario B – The management system is characterized by the same conditions as that of the base scenario except that no chemical inputs are used, and the paddy stubble remaining is cleared through manual labour and some remaining straw is left on the field in-situ. A cash subsidy switch from inorganic to organic is assumed in this scenario.

3. Contextual setting of the study area

The state of Punjab, the case study chosen for this report, is located in northwest India and has gained popularity as a post green revolution success story due to bumper productivity of crops. Punjab has conventionally been a wheat (Rabi crop) growing state, and the area under wheat cultivation increased 2.5 times from 1400,000 ha in 1960-61 to 3480,000 ha in 2018 (Figure 1). The production of wheat increased 9.4 times from 1.7 million tonnes in 1960-61 to 16. 4 million tonnes in 2018. The area under paddy (mainly grown as Kharif crop) in Punjab has increased 12-fold from 227,000 ha in 1960-61 to 2,845,000 ha in 2017-18, and the production of paddy increased 50 times from 342,000 tonnes in 1960-61 to 16,985,000 tonnes in 2018 (while the overall production in India increased by only four times). Although it only covers 1.53% of the Indian geographical area, the state's contribution to India's rice and wheat production has been 10% and 20% respectively. It has contributed 25% and 35% of rice and wheat to the central grain procurement pool The Food Corporation of India, through various state agencies, procures food grains (mostly rice and wheat) for storage, public distribution systems and movement of surplus stocks to other states (Punjab economic survey, 2019-20). The agricultural and allied sectors contribute 28.1% of the gross value added and provide employment to 26% of its work force (Punjab economic survey, 2019-20). The acreage under maize, which was 327,000 in 1960-61, has declined to 166,000 in 2017-18 and rice has taken over in this area. The cropping intensity (ratio of gross sown area to net sown area) has increased from 1.8 in 1991 to 1.90 in 2018, which implies that 190% of the land under agriculture is utilized (due to cultivating the land more than once).

98% of the crops in Punjab are High Yielding Varieties (HYV). A majority of the wheat-growing farmers grow paddy as their first crop before wheat which reduces the crop diversity in the region. Very few leguminous crops which fix nitrogen in the soil are planted, impacting the nitrogen availability in the soils. Tube wells are the dominant source of irrigation in the state. In 2018-19, there were 14,76 lakh tube wells in the state, of which 13.4 lakh tube wells operated on electricity. The average landholding size in Punjab is 3.77 hectares, and out of this 15.6 % are marginal farmers, 18.5% small farmers, 30.8% semi-medium farmers, 28.3% medium farmers and 6.6 % are large farmers (Agricultural Census, 2015-16). The soil organic carbon is quite low (<0.40%) and most of the districts in Punjab are deficient in nitrogen. Moderate-low phosphorous and high potassium levels necessitate the need to supplement the soils with fertilizers or manure.

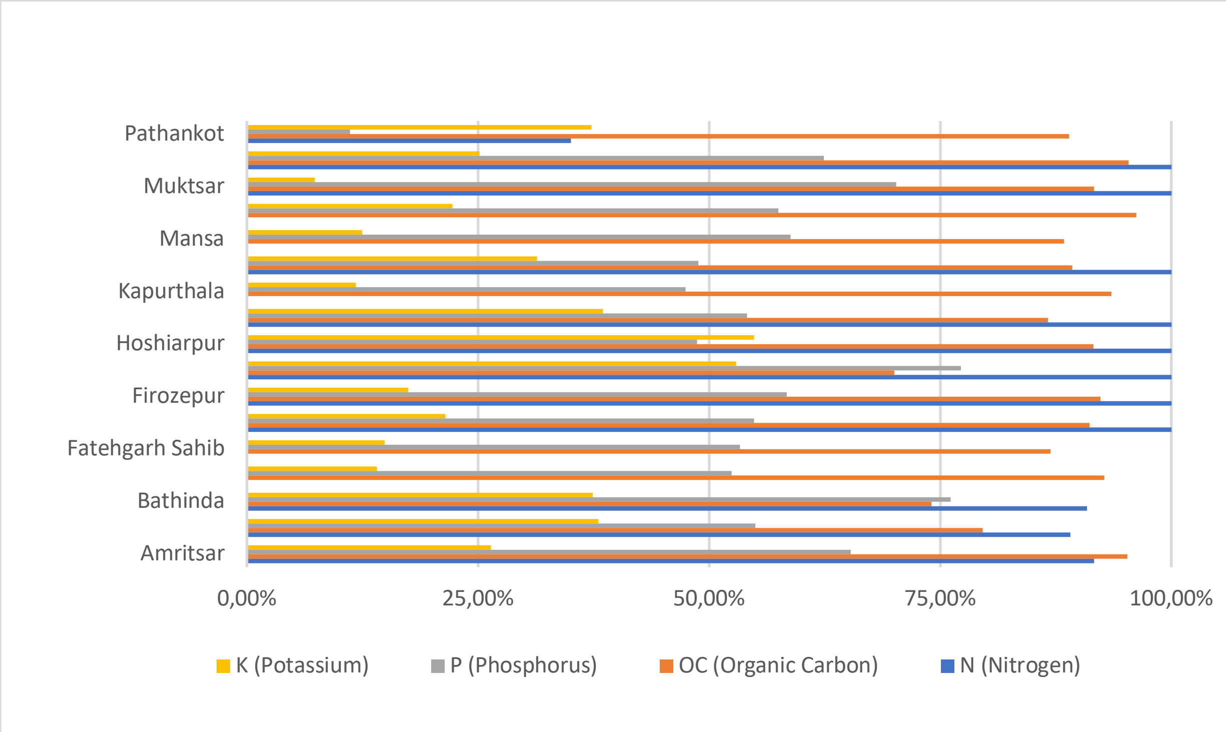


Figure 2: Soil deficiency in terms of nutrients in various districts in Punjab, 2018-2019

Source: Figure constructed by the author from data based on District soil health cards (www.soilhealth.dac.gov.in) Notes: 100% deficient means 0 availability for crop intake.

The increase in production has also increased the consumption of chemical inputs, with a very high intensity of fertilizer, insecticide and water use. In Punjab, 82% of 138 blocks assessed were categorized as 'over-exploited,' 2 blocks were 'critical,' 5 were 'semi-critical,' and 22 were 'safe.' The report further highlighted that 95% of the water extracted was for irrigation purposes (Ministry of Jalshakti, 2019), which means that farmers have to dig deeper to reach the water level. As the water is overexploited, farmers have to use deep tube wells to irrigate the fields, which increases the cost of irrigation. Electricity on the other hand, has been given to farmers at no cost since year 2000, after which the state has heavily extracted its water resources.

4. Quantifying the tangible input flows into the production of wheat

This section identifies and quantifies different flows used to produce wheat. Labour is an important input in the production of farm output. 15.4% of the total population in Punjab are agricultural workers and the gross area sown per agricultural worker in 2019 is 2.71 ha. Seeds are also critical inputs for agriculture, and quality seeds are important for improving yields. Seeds, if used in the production, are treated under intermediate consumption but if stored, they are treated as stocks.

Hence, it is an organized sector and several seed companies operate in Punjab and around India. Fertilizers are the second major inputs used in the production of wheat. Fertilizers are subsidized in India and the maximum retail price is set by the Government of India, lower than the delivery price and the difference between the delivered cost of fertilizers at farm gate and the maximum retail price (MRP) payable by the farmer is given as subsidy to the fertilizer manufacturer/importer by the Government of India (www.fert.nic.in). While India meets 80% of the urea requirements through domestic production, it is heavily dependent on imports of potassium and phosphorous. The price of urea and complex fertilizers has been regulated and the subsidized price of urea has been stable, unlike potassium and phosphorous, which are covered under the Nutrient Based Subsidy scheme (NBS). Due to the susceptibility of agricultural crops to pests, farmers use pesticides as the last produced input in agricultural operations. In India, technical grade pesticides with more than 85% of the active chemical ingredients are manufactured, which are then mixed with inert ingredients for easy handling, spraying and coating on plants. Pesticides are available as insecticides, fungicides, herbicides, biopesticides and other chemicals. In addition, farmers deploy various farming equipment such as tractors, power tillers, combined harvesters, diesel pumps, electric motors, sprayers, and dusters for farming practices. In Punjab, there is one tractor for every 9 hectares of net cultivated land of the state (the national average is one tractor per 62 hectares) and the state also has the highest farm power availability in the country (2.6 kW/ha) against the power availability of 1.5 Kw/ha in India (Economic Survey of Punjab, 2018). The farm equipment adds to the gross capital formation in the agricultural sector. Electricity is also an important input for farm irrigation, and irrigation is important to improve yields. In Punjab, most of the fields are irrigated either through canal irrigation or tube wells using diesel operated pump sets. The average energy sold in 2019 is Rs 41,718.5 per consumer in the agricultural sector (Punjab state power corporation limited). In Punjab, the electricity is completely free, and 1.3% worth of state domestic product and 18% of the value of wheat is given away for free to farmers in Punjab, which is substantial. This amount is lost due to subsidies in addition to creating more externalities. Financial credit also plays an important role in the agricultural growth of the country.

5. Quantifying the value of capital flows into the production of wheat

Agriculture is highly dependent on flows from ecosystems. Temperature, rainfall, the timing of rainfall, wind velocity, the direction of sunshine, sunshine hours, soil quality, quantity and quality of water, general climatic conditions, nutrient flows in the soils, the condition of neighboring farms and also how these variables interact with each other determine the farm output in addition to the technology, human, produced and social capitals. Several of these inputs are not tangible and several non-market valuation techniques have to be used to quantify these inputs. The study uses different valuation techniques, as discussed in (Gundimeda, Markandya, & Bassi, 2018). Alongside natural capital, social capital is also important in determining the output and institutional support and the knowledge support the farmer receives are also extremely vital. The Government also reduces the risk through assured price supply MSP (Minimum Support Price) and procures wheat. The MSP also incentivizes farmers to produce more wheat.

The value of capital flows in the production has been estimated using the ***"Production function approach".*** The study uses the Cobb-Douglas production function approach, taking into account all possible on-farm and off-farm natural and produced inputs, including biophysical conditions and ecosystem processes. From the estimated Cobb-Douglas production function, the value of the marginal product of ecosystem services, and the value of flows from social, produced and human capitals have been estimated. The results from the Cobb-Douglas production function show diminishing returns to scale in Punjab for wheat production. A 10% increase in all inputs would increase the wheat production by 5.2%, indicating decreasing returns to scale. As farm size increases by 1%, the output increases by 0.03%. Labour and capital contribute positively to the output, with labor being more responsive than capital. Pesticides and fertilizers contribute significantly to the output, corroborating the fact that farmers increase their usage due to the declining productivity of the land.

The management and the quality of the land and soil, has a significant impact on the output. The higher the value of seeds, the lower the output is that shows that stocking would not improve the yield. Social capital can also have a positive but insignificant impact. In addition, the technological and institutional factors are positive and significant, except for the years 2001, 2002, 2003, 2004 and 2005 when the coefficients have been negative. The year 2003 experienced a severe drought which was also the time when agriculture in Punjab was under severe pressure. The year 2009 has also seen a change in institutional structure through the Groundwater Protection Act 2009 in Punjab, and as a result, the years 2009 and 2010 have seen a decline with a subsequent decline in wheat yield. The output has been fluctuating, showing the impact of several complementary institutional and natural factors on the output.

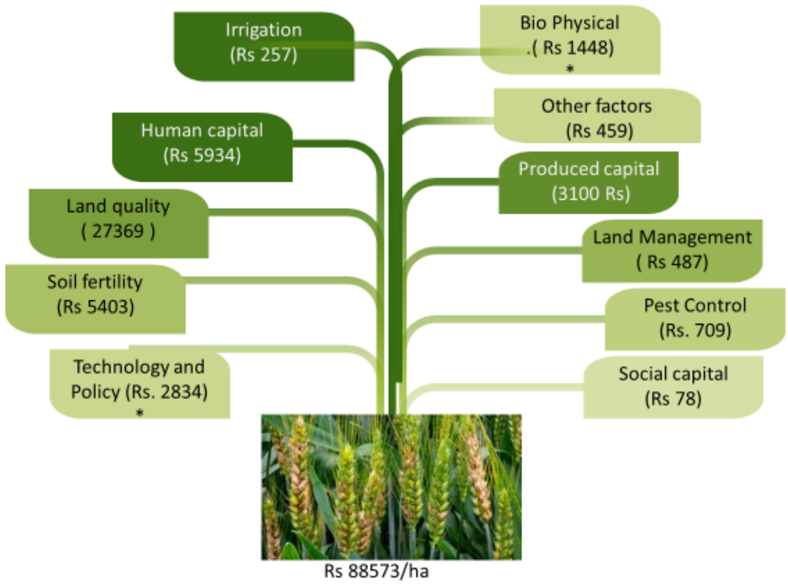


Figure 3: Contribution of different capital flows to the value of wheat, 2016-17 (Rs/ha)

Source: Author's creation based on model estimations.

6. Estimating the Impacts of wheat production

The environmental impacts due to wheat production are assessed using the "**Lifecycle impact assessment"**. These units are reported in physical units and all the inputs and outputs are related to one ton of production of wheat for comparability. The inputs and outputs are translated into different environmental impacts, which include emissions to air, water and soil. The emissions are aggregated into equivalent functional units in terms of their global warming potential, acidification potential and eutrophication potential

Around 8-10 inches of paddy stubble remain on the ground after the rice is harvested, and farmers prefer to burn the field to get rid of the remaining residue instead of opting to sow the wheat directly. The study treats these emissions as part of preparing the field for the wheat crop. The emissions from plot-level residues are estimated based on the residue to rice ratio, dry matter content, and the fraction of the residue burnt, which depend on the inherent farm-level characteristics. The study estimated that the burning of paddy residues releases 23.3 MT of emissions, of which 21.7 MT is CO_2, 1.3 Mt is CO, 0.18 MT is total particulate matter, and the rest is shared by non-methane hydrocarbon compounds (NMHC), non-methane volatile organic compounds (NMVOC), and ammonia (NH_3). The particulate matter stays in the atmosphere for a significant duration, impacting people in Punjab as well as the neighboring states. The emissions from clearing the fields through stubble burning to make way for wheat production impacts not only the local air quality but also impacts the air quality of neighboring states. This has been a recurrent phenomenon since farmers adopted the short-rotation paddy variety as the first crop on the field during the previous season.

The study estimated the health impacts of particulate matter from stubble burning using the **"Cost of Illness method"**. As the residues are burnt in winter, the temperature inversion causes pollutants to be trapped at the ground level which causes more harm. Smog reduces visibility, increases road accidents and also increases the cost of travel time along with associated health problems. In India, the leading cause of death is respiratory infections such as chronic obstructive pulmonary disorders, emphysema, asthma and others, indicating a sign of poor air quality (IHME, 2019). The mortality estimates in India due to PM 2.5 (Particulate Matter < 2.5 micro grams) was around 66,000 in 2015, of which 50,500 were in rural areas according to the Global Burden of Disease study (WHO, 2015). However, deteriorating air quality is not only because of stubble burning but can also be due to other causes such as an increase in vehicular emissions or emissions from thermal power plants for example. Based on estimated health impacts from previous studies, this study estimated that approximately 22,09,140 people suffered in a year from acute respiratory infections on average in the states Delhi, Haryana and Punjab. The annual health costs (direct admission costs and indirect costs) due to clearing paddy stubbles for sowing wheat ranged from Rs 1000–2864 million. One person suffered out of every 10 ha of fields burnt. The external burden imposed is estimated to be Rs 390-Rs 1150/ha (in 2016-17). This estimate however does not include the cost of suffering, averting, productivity loss nor mortality losses.

7. Integrating the elements of the framework

The values of different elements have been integrated into the TEEBAgriFood framework. The framework enables us to visualize the interconnectedness between different capitals, economies and well-being. The figure shows that in 2016-17, 3.5 million hectares of agricultural land has been utilised for wheat production, and 99% of the land is irrigated. ₹ 1273 billion (USD 19.15 billion) worth of *produced capital* stock has been used (value of land, buildings, farm equipment) for wheat production. The production of wheat has been supported by ₹ 25,098 million (USD 370 million) worth of *human capital* and, *social capital* in terms of several supporting institutions such as storage facilities, guaranteed procurement, regulated physical markets, cooperative institutions provided the needed pillar for producing wheat. Wheat production draws flows from within this sector as well as external sectors. The total production of wheat used ₹ 7843 million (2.56% of total value) (USD 115.7) worth of seeds (including the imputed value of seeds saved from production), ₹.34,207 million (USD 504 million) (11.2% of the gross value of output) worth of machinery (own machines were valued at imputed rent), ₹ 25, 101 million (USD 370 million) (8.2%) worth of human labour (includes imputed value of own labour, attached and casual labour). The production of wheat required ₹ 16,310 million (USD 240.6 million) (5.31%) of subsidised fertilizers and ₹ 5,407 million (USD 79.7 million) (1.8%) worth of pesticides. Thus, wheat production in Punjab drives value addition in machinery and equipment, fertiliser, pesticide and the seed industry. The subsidies on fertilizers however, are hidden and have to be shown explicitly in the economic outcomes. In Punjab, water and electricity are free and the irrigation charges shown reflect only the rental value of the irrigation pumps used. Most of the farmers own tube wells, but these are valued at imputed rents depending on the hours used. As the electricity is free, farmers may be over-pumping water, imposing huge costs on state exchequer. The burden on the state Government because of electricity subsidies has been shown under purchased inputs (although they are free). **₹ 57,528 million (USD 848.5 million) (1.3% of state domestic product and 18% of the value of wheat output) worth of electricity is given away for free to farmers in Punjab, which is substantial.** Most of the farmers own agricultural land which is treated as fixed capital. Land has an opportunity cost, and thus the rental value of land has to be considered which is included under the cost of fixed capital. The interest on working capital, fixed capital, land rent (owned and leased-in land), taxes and cesses are showed under the cost of fixed capital. However, in the financial profit and loss these are not added, which is the case while computing the economic profits.

The agriculture input market is distorted due to subsidies, taxes, and regulated prices, and thus, the cost of purchased inputs may not always reflect the real marginal costs. The study estimates the efficient prices from the marginal value contributed by each factor of production, and the values are illustrated in Figure 20. If markets work efficiently, the market prices of purchased inputs equal the marginal value. For many of the natural resources, markets do not exist (for example irrigation water, soil quality, land quality, land management practices, soil nutrition etc.). The marginal value of each factor to the gross value of wheat has been estimated from the production function and is shown in Figure 20. The human capital at purchased economic cost is ₹ 25,098 million (USD 370.2 million) but if the skills are valued at their real opportunity costs, it is worth ₹ 20,388 million (USD 300.1 million) (governments set the minimum wages which distorts the markets). Similarly, machines are overused when at optimality they contribute ₹ 10, 912 million (USD 160.9 million) to the gross value added. The markets overestimate some of the production factors because other factors of production often remain hidden or not seen. For example, the role of technology and policy cannot be captured through market prices. Some of these values captured by the machinery have been because of enabling technological innovations and supporting government policies such as the minimum support price. Irrigation is charged based on hours used minimally, but at the margin it contributes ₹ 905 million

(USD 13.35 million) (0.30%) to output. The quality of land and soil (soil and land are inseparable) are the key determinants of productivity. The rental value of land captures the inherent qualities, and it contributes 96,338 million (USD 1421 million) (31.5%) to the gross value. If the land quality degrades, the contribution of the value of production decreases accordingly. The productivity also depends on the investments in land, soil and assets (proxied by the land management variable), which contributes ₹ 1,714 million (0.56%) (USD 25.3 million) to the gross value. This is roughly equal to the depreciation value. The climate, rainfall, temperature and biophysical factors contribute ₹ 5,082 million (1.7%) (USD 74.95 million) to the output, whilst soil nutrition contributes ₹ 19,108 million (USD 381.82 million) (6.2%) to the gross value. Thus, the efficient fertilizer purchase cost should be equal to its marginal product (it is lower now because of subsidies). The pest control contributes ₹ 2,490 million (USD 36.72 million) (0.8%) to the output. The farmers' network and associations are important as well, as this contributes ₹ 294 million (USD 4.33 million) (0.1%). The per-unit shadow prices/marginal prices can be derived by dividing with the quantity of wheat produced or area under wheat production. Wheat further contributes to value addition due to processing, grading, transportation, bagging and milling, captured in the Figure 4 under the value added. The remaining wheat after consumption and storage (for seed production) contributes 44% of value addition. For each ₹ 1 of wheat procured, the additional value added is 0.44 ₹.

As a result of the use of various assets and production, the capital value may either appreciate or depreciate, as shown in Figure 4. There is depreciation in farm equipment and buildings, but at the same time, new capital is being added to the farm which increases the state domestic product estimates. In addition, wheat production impacts the natural capital. The groundwater tables have fallen by 9.72 mcum (CGWB, 2011), the organic carbon content is only 40% in the soils and 100% of the soils in Punjab are nitrogen deficient though the levels of P and K varied from low to high. Entire degradation is not attributed only to wheat but also to other crops grown in Punjab. The value of degradation due to wheat is estimated through the ***replacement cost method***. The loss in nutrients is compensated through the addition of fertilizers which would diminish the profits. The value of nutrient loss has been estimated at ₹16,094 million (USD 237.37 million) which is 5.3% of the value of output. This value includes the value of additional fertilizers required to be compensated for lost nutrients.

The lifecycle of wheat production involves several activities which release emissions to air, water and soil. These emissions are shown in Figure 4 under impact on capital. Eutrophication of land and acidification erodes the value of useful land available, whilst global warming impacts the carbon stock variable. Under the impacts on natural capital, these have been captured under global warming potential, eutrophication and acidification. Any changes to the human capital are shown in Figure 4.

Finally, any changes to the stocks and flows impact human well-being. The impacts are shown in Figure 4. Here the health impacts and the economic impacts are captured. ₹ 1 of wheat production creates an economic flow worth ₹ 0.68 of economic flows outside (within the wheat production boundary) besides the value-addition by wheat. However, at the same time it creates negative flows in terms of pollution. Due to pro-farmer institutional support, the food security issue was addressed as 94.6% was procured in 2018 and 64.5% in 2016-17. Punjab contributed to the nutritional security needs of the country by providing 18% of the wheat production to the central pool and the public distribution system. Punjab has good social capital through agricultural extension, as there is one extension officer per 753 operational holdings in the state. Agriculture has increased the people's economic well-being in Punjab as it has the highest average monthly income from farming (₹ 23,133). Institutional support also exists in the form of a crop loan waiver schemes.

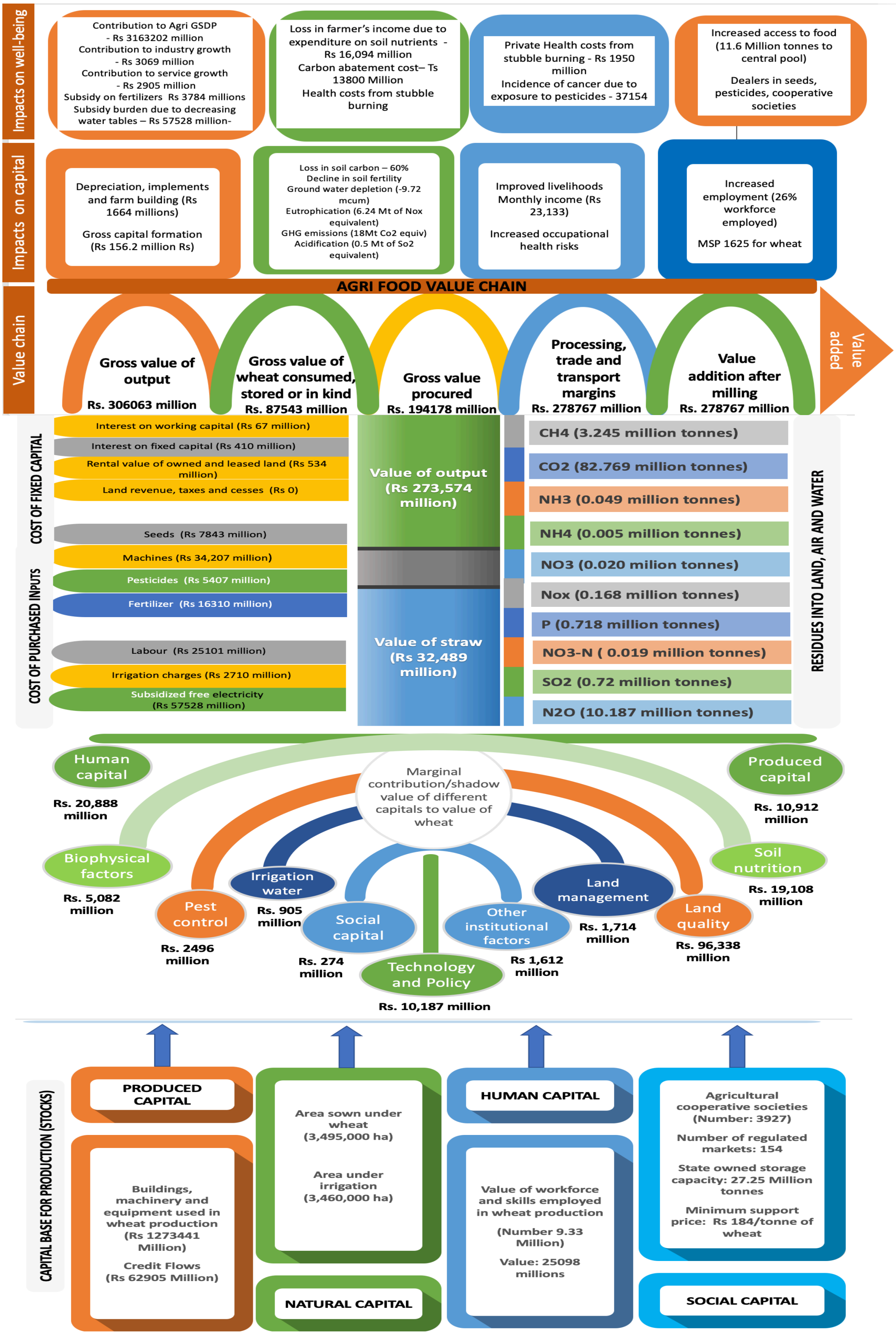


Figure 4: TEEBAgriFood illustration for the wheat value chain analysis

Source: Authors creation based on the analysis in the study

8. Illustrating the application of the TEEBAgriFood framework

The study illustrated how we could apply the TEEBAgriFood framework to two scenarios: Scenario 1 where the rice production precedes the wheat production, but technological alternatives are pursued to clear the field (in this case, use of so called Happy Seeder technology) vis-à-vis, stubble burnt through open field burning. In Scenario 2, we show how policy matters in generating the impacts. The study compares the net returns to organic versus conventional farms and how a subsidy transfer can equalize the returns.

8.1. Scenario A: Preparing the land for wheat production with residue burning vs preparing the land with technology-based interventions

The farmers harvest paddy using combined harvester and thresher, which spreads the residues on the field. How this residue is removed to sow wheat is a wheat management practice. Farmers might prefer to burn the fields to remove these residues or incorporate the rice-straw back into the soil. The farmers could directly drill the wheat into the standing rice stubble using expensive technological alternatives such as "Happy Seeder technology", implying a cost of 1.5 – 1.65 lakhs per machine currently. However, the avoided costs to society are health costs and the avoided fertilizer costs. A Happy Seeder is a tractor-mounted machine that cuts and lifts the rice straw, sows wheat into bare soil, and deposits the straw over the sown area as mulch. Farmers can, therefore, sow wheat immediately after the rice harvest, precluding the need for burning rice residue. The Government has subsidized 50% for individuals and for cooperative societies, while 8% of the machine costs are subsidized. Thus the cost to farmers of acquiring the machines is Rs 626 million, which translates to a cost of ₹ 32,937 per hectare over the lifespan of the machine, of which the individual farmers pay only 50%. Investments in the machine lead to the gross capital formation of ₹ 626 million. The total cost per acre of using this technology is ₹ 2,844, which, after subsidy is approximately ₹ 1440/ha for the individual farmer. The study shows that technology in addition to saving health costs, also saves chemical fertilizer costs, improves the pH, organic carbon, infiltration rate and water holding capacity. The cost savings in terms of the additional fertilizer use based on the sampled data in this study has been estimated to be ₹ 1697 million/annum and ₹ 1339/ha (20% savings to farmers as well as to the Government). The health benefits are the avoided health costs, which we estimated conservatively at ₹ 2,964 million/annum.

Table 1. Comparison of Net Benefits to the society between the Base scenario (stubble burning to sow wheat) and Scenario A (use of technological alternatives to clearing paddy to sow wheat)

Category	Base scenario (stubble burning)	Scenario A (Happy Seeder technology)	Wheat system + stubble burning (Total, millions)	WS without stubble burning (Total, millions)
Residue burnt (tons/ha)	**6**	0	2.25	0
Loss of Nitrogen (kg/ha)	31	0	10.96	0
Loss of Phosphorous (kg/ha)	2	0	0.54	0
Loss of Potassium (kg/ha)	19	0	6.84	0
Emissions (tons/ha)	**10**	0	3.50	0
Cost to farmer to remove residue (₹/ha)	0	2844	0.00	1001
Capital Subsidies to remove residue		-1422	0	-550.5
External health cost to society (₹/ha)	839	0	295.33	0
Value of wheat Produced (₹/ha)	46521	46520	16375	16375
Operational costs to produce wheat (₹/ha)	23127	23129	8141	8141
Additional costs of fertilisers (₹/ha)	1339	-1339	471	-471
Net profits from producing wheat (₹/ha)	21216	23290	7468	8198
Gross capital formation in the economy				₹ 626 million

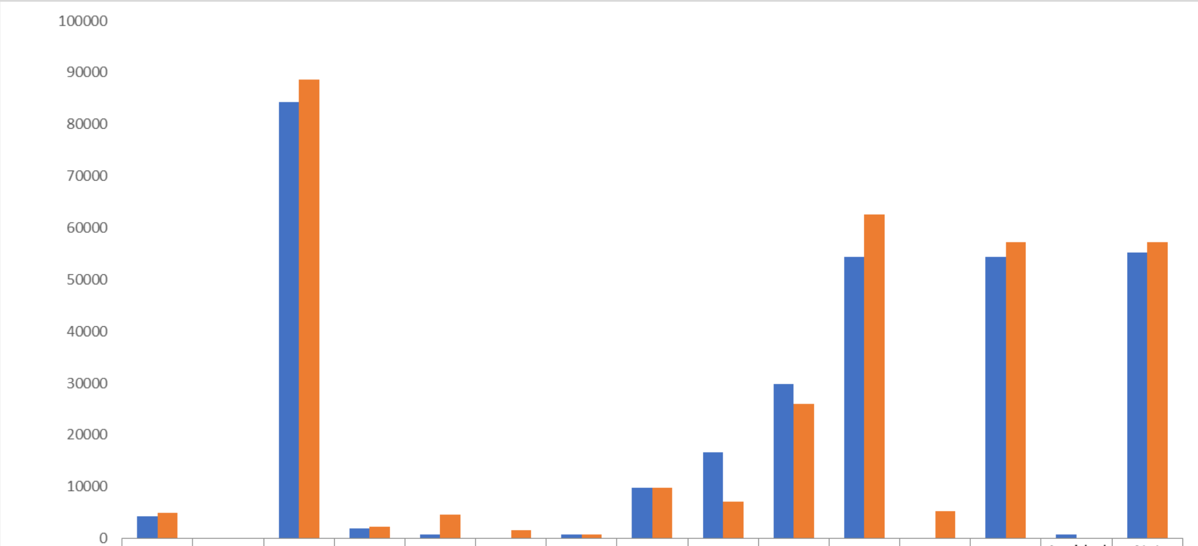
Source: Author's estimates

8.2. Organic vs conventional wheat production

Here the conventional scenario is compared with scenario B, in which the same conditions characterize the management system as that of the base scenario except that no chemical inputs are used, and the paddy stubble remaining is cleared through manual labour. A cash subsidy switch from inorganic to organic is assumed in this scenario. The main difference between the organic and conventional farming systems is that the chemical fertilizers and pesticides are replaced by bio-fertilizers such as cow dung, cow urine, vermicompost, jeevamrita, poultry waste, and agricultural residues.

The study estimated the average subsidies on fertilizer at approximately INR 8,428 million, with an increase from ***₹ 8030 to 20,182 million*** between 2002 and 2016. This study compared the net returns to farming under conventional farming and organic farming, where it was discovered that under conventional farming, the higher costs are due to the higher use of fertilizers, which are 6.2 times higher than that of organic farms. The yield is higher in the case of conventional farming compared to organic farming by 20%. However, in organic farming, the cost of fertilizer is low, but the cost of labour involved is very high as organic farming requires higher labour efforts in weeding practices and in the preparation and application of the bio-fertilizers. The study did not assume any change in other inputs – machinery and irrigation as drip irrigation systems were minimal in the study area. However, these farmers had lower irrigation requirements as they conserve the soil better, but the exact quantifications could not be made as the farmers did not provide the details. Most farmers use local seeds rather than high yielding varieties in organic farming, and there is no subsidy on local seed varieties. Hence, this study assumes similar irrigation charges to organic farming (because the rental value of equipment hired has been included as a cost of irrigation).

Figure 5 shows how the average returns compare between inorganic (includes inherent subsidy) and organic farming. Organic farmers do not have a cost advantage due to the lack of subsidized inputs (other than the free electricity and lowered irrigation charges which other farmers benefit from as well). In addition, the farmers have higher marketing costs due to the lack of established institutions that are otherwise available for conventional wheat farmers. The net returns between the two systems are comparable after a cash subsidy to the farmers (depending on the avoided use of fertilizers). Besides, the organic farmer benefits from the retained nutrients due to straw incorporation in the soil while preparing the land for wheat. The net returns to the organic farmer increases if these avoided costs are internalized. By avoiding the residue burning (saving the straws to be used as mulch), health costs are also saved and estimated at ₹ 839/ha. The gross returns are comparable despite lower yields because the farmers served their product to a premium segment that paid a 25% higher price for wheat. Furthermore, the health costs to society from carcinogenic diseases would be lower. This figure did not include the global warming, eutrophication and acidification costs of nitrogen-based fertilizers, as these are estimated in physical units.



	Production (in kgl/ha)	Price (Rs/ kg)	Gross Value (Rs/ha)	seeds (Rs/ha)	fertiliser /manure (Rs/ha)	insecticide/herbicide (Rs/ha)	irrigation charges (Rs/ha)	machinery value (Rs/ha)	labour (Rs/ha)	Total input costs (Rs/ha)	Net value (Rs/ha)	Subsidy on fertiliser /ha	Net value net of subsidies (Rs/ha)	Avoided health costs from stubble burning	Net value inclusive of external costs
Organic	4200	20	84231	2005	725	0	769	9718	16685	29902	54329	0	54329	839	55168
inorganic	4900	16	88572	2228	4605	1536	769	9718	7130	25986	62586	5324	57262	0	57262

Figure 5: Net returns from organic and conventional wheat production (Rs/ha/season)

Source: Figure based on author's analysis

9. Synergies and trade-offs of policy, and conclusions

Evaluating the complex food systems with a narrow metric such as "per-hectare productivity" of a single crop, has been the primary criterion in the discourse on food systems and food security, and thus several policies have subsidized the behaviour that causes harm to the environment. The minimum support prices and the high yielding short-run varieties have incentivized farmers to adopt paddy as the first crop prior to wheat, while the Green Revolution required higher usage of water and soil nutrients. As agriculture is subject to inconsistencies in monsoon occurrences as well as the Government's need to ensure food security, fertilizers and pesticides have been subsidized which has encouraged their inefficient use. The study highlighted the fact that fertilizer use in Punjab has been 1.7 times higher than the national average. Excessive use of fertilizers, not only degrades land and soil but also increases greenhouse gases, eutrophication, and acidification. As there has been a mismatch between the water demand and public investments in irrigation infrastructures, farmers have relied on groundwater for their irrigation needs. In Punjab, the cropping intensity (gross area/net area sown) is 1.9 and the crops are on the ground for 9-10 months, leaving very little time for soils to replenish naturally and the groundwater to recharge. As the groundwater tables went deep due to lack of incentives to conserve water driven by free electricity, the investments in high-powered tube wells increased.

With the intention of conserving the groundwater, the Government enacted the "Preservation of the Subsoil Management Act" in 2009. As evapotranspiration rates are high in April and May, the law does not allow farmers to sow nursery of paddy before May 10th, nor to transplant before the date announced by the Government in the Official Gazette for any local area. By deferring the transplanting date, the paddy crop receives more support from the rainfall in June and July. Although the policy resulted in marginal improvements in groundwater levels, it led farmers to switch to short-run paddy crops. The Employment Guarantee Act in India mandates minimum wages, and as paddy is labor-intensive, farmers relied on combined harvesters and threshers which spread the paddy residue on the fields. Delay in sowing wheat leads to yield reductions, and due to the short window available to prepare the land for wheat cultivation, the farmers resort to stubble burning, creating negative economic and health impacts.

As stubble burning creates negative externalities, the Government, announced penalties to disincentivize crop burning. Along with this, the Government has also given subsidies to encourage farmers to adopt agricultural mechanization (through technologies such as Happy Seeder) for crop residue management. Approximately ₹ 2,400 million have been spent on the management of crop residues during 2018-19, through central government schemes to fix the externality problem, along with the free distribution of around 11,900 types of agricultural equipment to individual farmers and 16,450 to primary agriculture and cooperative societies and farmer groups.

Lessons have been learnt from the tradeoffs faced due to misaligned policies, and several policy steps are being taken. One important step being taken by the Government is to incentivize the farmers to save groundwater under the "Paani Bachao Paise Kamao scheme" (save water, earn money). Under this scheme, each farmer is given a fixed allocation of electricity for day-time consumption, and any consumption less than their allocation would fetch them ₹ 4/Kwh for unconsumed electricity. The Government is promoting water efficiency through the scheme 'per drop more crop'. The state water policy promotes and regulates the conjunctive and optimum use of surface and groundwater. Under this, the Government proposes to levy water charges for the maintenance of canal irrigation systems. The Government proposes to levy a flat rate for power at ₹.100 per BHP (British Horse Power) per month for farmers who own 4 hectares of land or more, which is a system proposed to be utilized for the welfare of small, marginal, and landless farmers. The aim is also to consider putting a cap for such farmers. The farmers in Punjab have invested heavily in agricultural machinery, which is being underutilized. The marginal value product of machinery shows that the investments are three times higher than the return to machinery, which increases the costs to the farmers and decreases the net income. The state is emphasizing the importance of social capital by promoting access to farm machinery through primary agricultural cooperative societies, farmer producer organizations (FPO) and entrepreneurs.

The subsidy policy on fertilizers has been more inclined towards "per hectare/per drop," which would reduce the cost advantage for the farmers in Punjab. The state Government under the "State Water Policy" aims to use Abiana (water charges) for the use of maintenance of the canal irrigation system. These processes are a step in the right direction. The draft state water policy had recommended cutting down power subsidies to farmers who own more than four hectares of land to 33%, but increase to 66% if adopting micro-irrigation.

As long as the positive flows outweigh the negative flows, agriculture is sustainable, and it is not unusual for the governments to provide public support for agricultural sectors. The OECD countries, Japan, New Zealand, USA and Australia, do extend varying support to the farmers. However, we recommend that all policies must assess the benefits and costs holistically, as indicated by the framework illustrated in this study. Despite the many negative externalities imposed by chemicals, the state's adoption of organic farming is low. Farmers adopting sustainable agricultural practices should be given incentives which could have considerable positive effects. The farmers who promote sustainable practices could be offered direct cash subsidies (in proportion to the reduction in environmental damage), and the subsidies for the conventional farmers could be reduced in a phased manner. The initial yield reductions from organic farming could be compensated through higher support prices for such farmers. Another important shift in policy focus has been on crop diversification, which is another step in the right direction.

The study recommends visualizing the entire spectrum of impacts due to policy changes and action through using a holistic framework covered in this report, so that the tradeoffs and synergies of different policies and actions on the economy and livelihoods can be better visualized.