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

Final Report submitted after review

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

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Abstract: The broad objective of this study is to examine the feasibility of applying the TEEBAgriFood Evaluation Framework for the wheat value chain in Punjab and illustrate how a holistic assessment of agriculture and food systems change the perspective with which we look at the AgriFood systems. The Punjab case study illustrates how an exclusive focus on yields to achieve self-sufficiency and maintain surplus and misaligned policies of rampant subsidies, free power, use of high intense inputs, and little emphasis on crop diversification, created a perverse scenario of excessive depletion of groundwater, decline in soil quality and productivity, loss of biodiversity and severe environmental pollution, culminating in adverse impacts on human health.

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Acronyms and Abbreviations

APMCs	Agricultural Produce Market Committees
CH4	Methane
CO2	Carbon dioxide
FAO	Food and Agriculture Organization
FCI	Food Corporation of India
GDP	Gross Domestic Product
GHG	Greenhouse gas
GSDP	Gross State Domestic Product
MSP	Minimum Support Prices
Mha	Million hectares
NBS	Nutrient Based Subsidy Scheme
NMHC	Non-Methane Hydrocarbon compounds
NMVOC	Non-methane volatile organic compounds
PAIC	Punjab Agro Industries Corporation
PDS	Public Distribution System
PM10	Particulate matter (less than 10 micrograms)
PM2.5	Particulate matter (less than 2.5 micrograms)
PSWC	Punjab State Warehousing Corporation
TEEB	The Economics of Ecosystems and Biodiversity
CSO	Central Statistical Organization
MCM	Million cubic metres
₹	Indian Rupee (INR)
USD	US Dollar (1USD = 70.09 INR in 2018, 67.8 INR in 2017, 66.46 INR in 2016, 44.9 INR in 2000
kWh	Kilo watt hour

1. Introduction

Agricultural systems are complex and unique as they are both consumers and providers of ecosystem services and disservices. Agriculture provides significant positive and negative externalities to society. Positive environmental externalities are provided in the form of aesthetic landscapes, recreational services, soil formation, groundwater recharge, biological control, pollination services, nutrient supply, and carbon sequestration. Negative externalities on the other hand occur in the form of greenhouse gas emissions (GHGs), soil erosion, eutrophication, health impacts due to pesticide use, contamination of ground and surface water (mainly from the intensive chemical inputs used by the farmers), harvesting, and other farm management practices (Swinton et al. 2007, Zhang et al. 2007). These negative externalities impact both environmental and human health (Pretty et al. 2000). Social benefits provide better livelihoods for small and marginal farmers, as well as creating jobs and supporting systems in the form of credit, technology and extension services, while reviving rural economies. Social impacts include the loss of livelihoods due to land degradation, and unpredictable weather results in crop failure and therefore pushes small and marginal farmers to poverty as well as suicides. Technological innovation has increased both agricultural output and inputs, some of which have negatively impacted the environment. Thus, agriculture and food systems have been providing more food, but also more negative externalities per unit of food produced, which are not being considered in the policies, in consumption behaviour, or by the producers (The Economics of Ecosystems and Biodiversity (TEEB), 2018).

The primary purpose of this study is to illustrate the application of the TEEBAgriFood Evaluation Framework for the wheat production system in Punjab. Punjab has conventionally been a wheat-growing state, but most farmers have adopted rice-wheat farming systems after the Green Revolution. Punjab has been chosen in this study due to a disproportionate impact on the environment compared to achievements in production. The Punjab case study illustrates how misaligned policies of rampant subsidies, free power, and price supports created a perverse scenario of excessive depletion of groundwater, a decline in soil quality and productivity, loss of biodiversity, and severe environmental pollution, culminating in adverse impacts on human health.

The state of Punjab in northwest India, often cited as the "Granary of India", has been a post Green Revolution success story due to bumper productivity of crops. Although it covers only 1.53% of the Indian geographical area, the state contributed 10% and 20% of the rice and wheat production in India in 2018 and 25% and 35% of rice and wheat to the central grain procurement pool (Punjab Economic Survey, 2019-20). The agricultural and allied sectors contribute 28.1% of the gross value added and employ 26% of its workforce (Punjab Economic Survey, 2019). Punjab has conventionally been a wheat (Rabi crop) growing state and the area under wheat increased 2.5 times from 1400,000 ha in 1960-61 to 3480,000 ha in 2018 (Figure 1a). The production of wheat increased 9.4 times from 1,742,000 tonnes in 1960-61 to 16,360,000 tonnes in 2018. However, 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, while the production increased 50 times from 342,000 tonnes in 1960-61 to 16,985,000 tonnes in 2018 (Figure 1). The area under maize (Kharif crop) on the other hand, has drastically declined from 327,000 ha in 1960-61 to 166,000 ha in 2017-18, and the production has only roughly doubled from 371,000 tonnes to 610,000 tonnes. As seen from Figures 1a and 1b, paddy is the dominant Kharif crop and wheat the winter crop followed by cotton and sugarcane. The increase in production has been possible due to well-developed irrigation facilities, free power, private investment in irrigation, high yielding varieties of seeds, accessibility to chemical fertilizers, pesticides, mechanized farming, adequate marketing infrastructure, regulated markets, and procurement facilities - all these elements facilitated increases in the yield, in particular for paddy and wheat.

Another factor that changed the agricultural landscape in Punjab, is the availability of short-duration, high-yielding rice and wheat crops, which enabled farmers to grow rice crops during June/July – October/November (Kharif season). Earlier it was not feasible to grow both paddy and wheat in the same field as they had to be grown for a longer duration. The average number of months that different crops stay in the field in Punjab are: 5 months for wheat, 4 months for paddy, 3.2 months for maize and 6.25 months for cotton. While the average value of yield for maize is ₹ 48,660/ha (USD 732.2)[1], the average value of yield for paddy and wheat for the year 2016-17 was ₹ 1,07,163/ha (USD 1612.44) and ₹ 80,764/ha (USD 1215.33) respectively. Cotton being a cash crop fetched ₹ 4,66,210/ha (USD 7015). As a result, Punjab from being a dominant wheat producer during the winter season (Rabi season, from October to March/April), has been cultivating rice (Oryza sativa) in the monsoon season (Kharif season, June to September/October). However, other crops such as maize, pearl millet, oilseeds and cotton are grown in minor pockets. Sugarcane is also grown throughout the entire season but to a minimal extent in a few areas. Rice comprises 75% of the net area sown during the Kharif season, while wheat comprises 86% of the net area sown in the Rabi season in 2018. The rice-wheat cropping sequence is not typical of the state

[1] I USD = 66.46 INR at the end of 2016 (average values) and I USD = 67.79 in 2017 (average values)

of Punjab but is practiced in the entire Indo Gangetic plain and is a dominant agricultural production system in the world (Bhatt et al. 2016). It is possible to opt for the maize-wheat cropping sequence as well or for other crops before wheat.

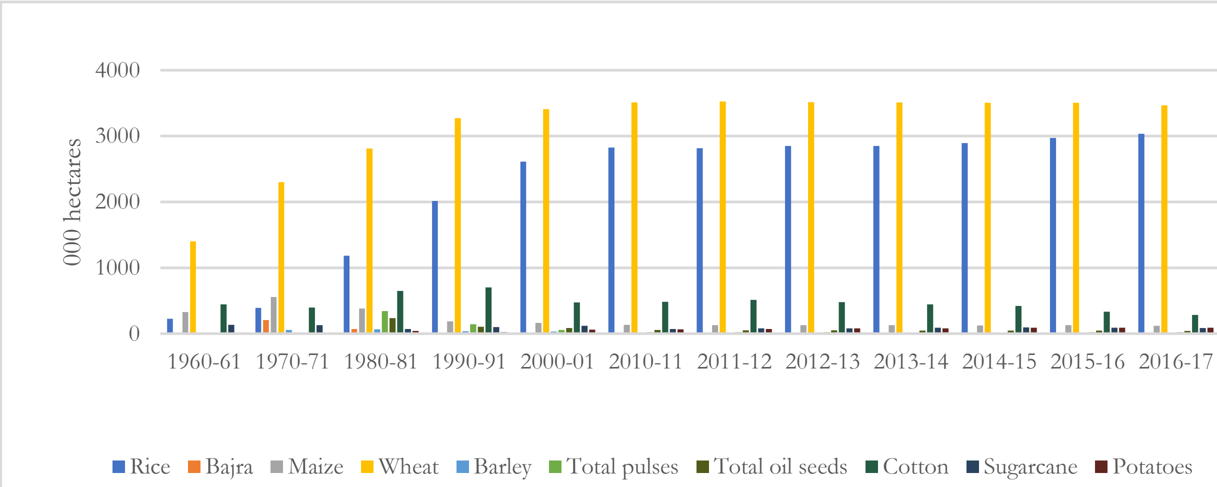

FIGURE 1A. AREA UNDER DIFFERENT CROPS IN PUNJAB

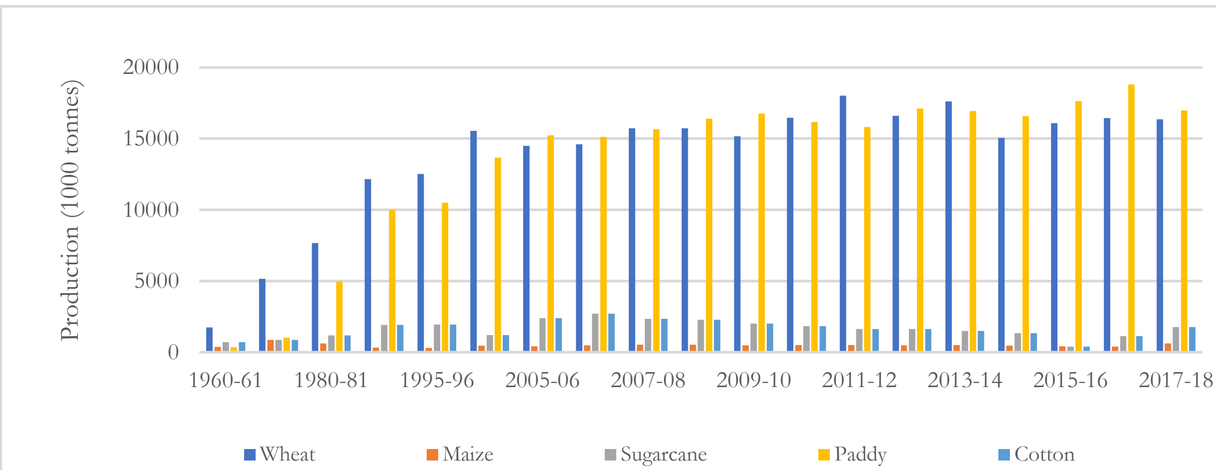

FIGURE 1B. PRODUCTION OF DOMINANT MAJOR CROPS IN PUNJAB

Source: Figures created based on data from Statistical Abstract of Punjab

The TEEBAgriFood foundations report highlighted that farms are managed ecosystems, and their final impact depends not only on the choices that farmers make but also on the actions of other farmers and consumers, policymakers as well as market conditions (chapter 7, TEEBAgriFood framework). Thus, the sequencing of rice before wheat in Punjab is one such example of farmers and external conditions that favored such an adoption. Government policies have also favored the adoption of specific crops and external impacts. A significant increase in the minimum support price of rice and wheat and subsidies on power and fertilizers have caused external impacts in terms of falling groundwater levels, overuse of fertilizers, and the deterioration of soil. Due to the focus on increasing yields per hectare, and incentives such as free electricity, interventions in production, procurement and distribution, and technology such as combined harvesters and tube wells, farmers have adopted a water-intensive rice-wheat system in place of the traditional maize-wheat rotation.

For applying the TEEBAgriFood framework to the wheat value chain, the following considerations are to be noted. Rice production precedes wheat, and as rice is a water-intensive crop, the early transplanting of rice before announced data in June is prohibited under the Preservation of Subsoil Water Act of 2009. Any delay in harvesting rice leaves little time for farmers to prepare the land for wheat. The choice of rice harvesting method, the variety of wheat sowed and the date of wheat sowing determines the extent of inputs used as well as the externalities generated. Wheat should be sowed on time to conserve moisture, and if the sowing date is delayed, dwarf varieties of wheat are planted while the long varieties should be grown on time. The paddy farmers (80% of the farmers) use combined mechanized harvesters to harvest rice. Combined mechanized harvesters perform several operations – cutting, threshing, cleaning and discharging grains into bags (Singh et al. 2005). However, the use of this technology spreads the rice residues and some intact stubble in the field. Some farmers on the other hand harvest paddy manually with sickles.

Two options are available for preparing the land for wheat sowing; 1) Burning the residues; 2) leaving the straw intact and using the residues as mulch, by using technologies such as happy seeder which combine stubble mulching and seed drilling functions into one machine, thereby offering means of drilling wheat into the rice stubble and avoiding the loss of nutrients and organic carbon (Sidhu et al. 2007). The soil fertility is improved through the first option but can also reduce the nitrogen absorption potential of soils. The field experiments showed that the technology is as effective as that of the conventional methods (stubble burning and then sowing). However, the farmers get rid of the stubble through open burning to prepare the land for wheat, which has huge negative impacts on the farm as well as off-farm.

A similar approach is adopted for wheat post-harvesting, but as wheat stalks make valuable fodder for cattle (and can also be stored), manual harvesting very close to the ground is adopted by few farmers, along with combined harvesters by others (which wastes valuable fodder). The burning of wheat and rice residues releases aerosols that contribute to the Particulate Matter (of less than 2.5 microns, PM2.5)

(Hays et al. 2005). The rice residue harvesting (post-monsoon) lasts longer with increased aerosol distribution across the Indo-Gangetic Plains (IGP) while in contrast, wheat burning (pre-monsoon), is not the dominant contributor to air quality degradation (Singh & Kaskoutis, 2014). In addition to burning, the hazards also arise from the extensive use of pesticides and fertilizers in the production. The farming practices lead to the depletion of groundwater, contamination of water, depletion of nutrients from the soil, increased greenhouse gas emissions and other pollutants that result in negative 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 of the agrifood systems?

The research questions are addressed through the following objectives.

1. Quantify the role of produced, natural, human and social capitals and the tangible and intangible flows from different capitals in the production of wheat.

Identify the value addition of wheat from the production at farm level to the processing at mills.

1. Quantify the positive and negative externalities of wheat production during the land preparatory phase and the production phase.
2. 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 it with the base scenario:

1. Base scenario: Wheat production is characterized by mechanized farming, high labour inputs, surface and groundwater irrigation, high chemical inputs and 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 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.
2. Scenario B – The same conditions characterize the management system as that of the base scenario except that no chemical inputs are used, 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.

The report adopts the following approach: section 3 discusses the TEEBAgriFood Framework, while section 4 sets out the contextual conditions for Punjab to draw elements to integrate into the TEEBAgriFood framework. Section 5 highlights the economic flows (from produced, natural, social and human capital) that go into the production of wheat. Section 6 suggests a way to quantify the intangible value contributed by flows from different capitals in the production of wheat. Where it is not possible to quantify, we provide some indicators and metrics for comparison. In section 7, we present the outcomes and impacts of wheat production (for the existing scenario of stubble burning as a pre-sowing condition) and in section 8, different elements from the previous sections are integrated into the TEEBAgriFood framework. Section 9 illustrates how we can compare two alternate scenarios – 1) stubble burning (paddy) as a pre-sowing condition vs. the use of technological interventions as a pre-sowing condition, and 2) comparison of returns between conventional farming (involving the use of chemical inputs) and organic farming (chemical-free inputs) under the scenario of transferring the subsidy from inorganic wheat production to organic wheat production. Section 10 concludes with limitations and scope for future extensions of the study.

3. The TEEBAgriFood framework and scope in the present study

Agriculture depends on ecosystem services as inputs as well as provides many ecosystem services – provisioning, regulating, supporting and cultural services. "The food produced by farmers goes through stages, from land clearance and preparation to planting, growing, harvesting, preparing products for the consumer market, consumption, and final disposal of any wastes. At each stage, several economic impacts are generated: income to producers, wages to employees, tax revenues to the government or subsidies from the government, possible imports of inputs, and exports of outputs, for example. Some of these impacts are captured through market transactions or flows of financial resources from one agent in society to another, while several other intended (positive) and unintended (negative) impacts on the economy and well-being are not captured. Some modern industrial food systems also pose health hazards for consumers, which are not appropriately valued" (Chapter 7, TEEBAgriFood foundations report, p. 253). However, the productivity measures of agriculture – the yield per hectare, net returns to farmers, or value of output do not explicitly highlight these dependencies and impacts. TEEBAgriFood has therefore developed a framework that can aid in a comprehensive evaluation of eco-agri-food systems, covering positive and negative dimensions of environmental, economic and social impacts and dependencies.

The TEEBAgriFood framework (Figure 1) suggests identifying the stocks (the four different capitals – produced, natural, human, and social capitals) that contribute to the flows, outcomes and impacts of eco-agri-food systems. Thus, identifying the stocks that contribute to the flows is crucial for the TEEBAgriFood framework (see chapter 6, TEEBAgriFood foundations report, 2018). The framework can be simplified as follows:

1. The stocks within a given sector generate returns or flows over a period of time. Examples of stocks include agricultural land, farm machinery and equipment, labour, social capital and environmental capital. The flows include wheat, wheat products, wages, and ecosystem services (e.g. water flow, greenhouse gases, oxygen, nutrient flows and water recharge).
2. Some of the flows from other sectors act as inputs and stocks within the sector to produce the output – e.g. fertilizers, pesticides, electricity, irrigation, fuel, ecosystem services from nature other than agriculture such as sunlight, rainfall, freshwater, and pollination. These sectors also have significant value addition to the economy because of agricultural systems and food systems.

3. Several outflows from agriculture are produced along the value chain on its way to its final consumption – for example, through the stages from harvesting, preparing products for the consumer market, consumption and final disposal of any waste.
4. Several outcomes result from the flows – for example, in the form of incomes to producers, wages to employees, tax revenues to the government or subsidies from the government, possible imports of inputs and exports of outputs, atmospheric emissions, and excess fertilizer in runoff leading to adverse environmental outcomes.
5. The outcomes lead to associated negative or positive impacts that affect/benefit different sections of society differently (e.g. health impacts) and also feed back into agricultural systems and food systems (e.g. agricultural land degradation makes land unfit and reduces the natural capital stock, while soil quality depletes the environmental stock).

It is envisaged that such a comprehensive framework would provide useful indicators and metrics for informing decisions regarding the real sustainability of agricultural incomes for different stakeholders (not only the farmers but also manufacturers and local communities). These metrics and indicators (qualitative, quantitative and monetary) enable a comparison over a period of time and also facilitate a comparison among different alternatives. The framework can also support the assessment of and comparison between trade-offs of different agricultural and food policies for public and private investments.

An attempt has been made to capture all the feasible elements in the framework based on the available data. The following are the key aspects regarding the scope and methodology used in the study. The definition of the tangible flows for produced capital will follow the Central Statistical Organization's (CSO) classification in India. In this study, agricultural land is categorized as a non-reproducible tangible asset. Buildings and agricultural implements, machinery, animals, any land improvement, dams and irrigation projects are categorized under the reproducible fixed tangible assets.

The scope of the analysis is set from farm to farm gate. i.e. the impacts are measured only along the primary value chain – agricultural production, manufacturing and processing of wheat products to the flour and the wheat products for household consumption. For example, the by-products from wheat straw are used by the livestock industry for biofuels and industries that make use of flour as a primary processing input. The impacts caused by the livestock industry, biofuel industry or flour-based industries are not covered in this study. Similarly, the contribution of wheat flour to restaurants has not been considered for further analysis, and the study has not attempted to estimate the impacts of an increase in wheat-based diets on health either.

It should be noted that some of the flows, outcomes and impacts are visible through market transactions (e.g. all produced inputs and outputs, income and consumption). The farm dependencies on ecosystem services can only be inferred through observing the output of the farm, farming practices and the local environment. The output from a farm depends on the ecosystem services, some of which are specific to the farm and farming practice, while some may be from local environmental conditions. For example, the nutrient recycling service is specific to farms while that of pollination services can be drawn from local conditions (as farmers benefit if some farmers manage beehives and other farmers cannot be excluded from using the services of the beehive). Temperature, rainfall and sunlight conditions can also differ across the farms. Similarly, the farms' ecosystem services and disservices can benefit/impact the farmers and the local, regional and global communities differently. The report tries to estimate the aggregate value of the ecosystem services as input to the farming sector, where these could not be identified separately.

While identifying the value of ecosystem services used or generated by agriculture, the following aspects as highlighted in Gundimeda, Markandya & Bassi, 2018, should be noted:

1. It is challenging to value ecosystem services provided by agriculture and to agriculture due to spatial variation (e.g. agricultural land next to green cover is different from agricultural land next to urban dwellings).
2. The level of ecosystem services/disservices from or to agriculture depends on the farmer's management practices.
3. The scale of operation of ecosystem service changes is essential and may impact the farm and society differently. For example soil carbon changes only affect the farm whilst soil erosion affects the farms downstream.
4. Ecosystem services and impacts have temporal dimensions, and
5. The risk of double-counting has to be avoided (for example, diversity in crop pollinators increases the crop yield, and thus this is an intermediate value and cannot be counted twice).

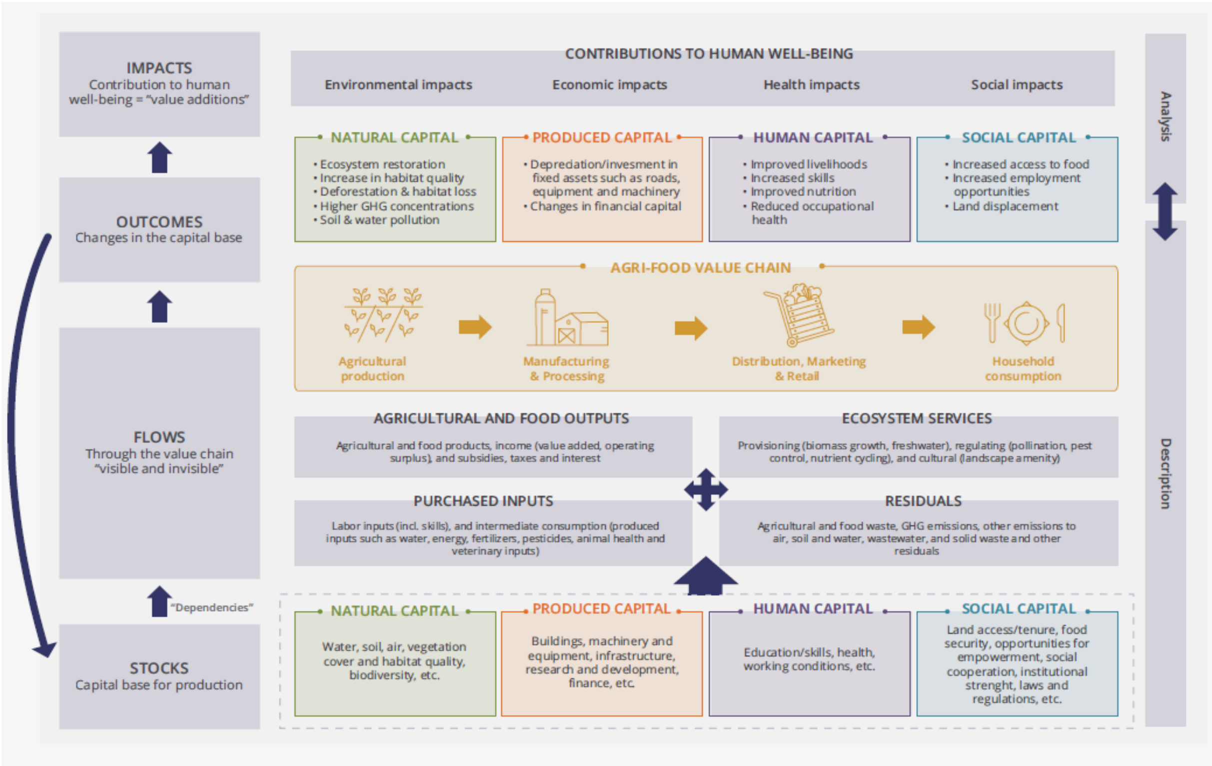

FIGURE 2. TEEBAGRIFOOD FRAMEWORK

Source: The Economics of Ecosystems and Biodiversity (TEEB) 2018

The discussion has been structured in different sections, and the information from each section is integrated to illustrate the TEEBAgriFood framework for wheat in section 8. Section 4 outlines the profile of the study area to give contextual conditions from which some information on the extent of stock and inflows into and output from the wheat sector is computed. Section 5 looks into different aspects of the wheat value chain so that the relevant elements required for integration can be extracted. The roles of human and social capital are highlighted and the role of natural capital has been explicitly considered in section 6. Agriculture draws upon several ecosystem services, and the marginal contribution of different ecosystem services to the output is estimated in section 6. It must also be noted that it may be difficult to separate each ecosystem service's contribution separately (e.g. temperature, rainfall and sunshine are all critical and they work as a system).

4. Overview of the study area: Punjab

Punjab is situated in the North-Western part of India, between 29’30’’ N to 32’32’’ N latitudes and 73’55 E to 76’50 E longitudes and is located in the Agri-Climatic zone – VI (Trans-Gangetic Plains). Known as the “Land of Five Rivers”, the state is very fertile and based on homogeneity in rainfall and cropping patterns. The state can be divided into five agro-climatic zones: the sub-mountain undulating zone, the plain undulating zone, the central plain zone, the western plain zone, and the western zone. The state is at the confluence of five rivers – Beas, Chenab, Jhelum, Ravi and Sutlej. Figure 2 shows the location and the district profile of Punjab. As it borders hilly states in the north, a desert in the southwest, and is located in the fertile Indus basin, the state has a mixture of climatic conditions. The state is subject to vagaries of monsoon and has experienced severe drought in 1987, and moderate droughts in 2002, 2004, 2007, 2014 and 2015 (based on the IMD dataset for different years).

FIGURE 3. LOCATION AND DISTRICT MAP OF PUNJAB

Source: Government of Punjab, India, http://punjab.gov.in/districts

Agriculture is an important sector in Punjab. In the state, agriculture and allied activities contribute 29% to the gross state value-added in 2019, with a majority of the industries in Punjab being agro-based industries. A 1 unit increase in Punjab's agricultural sector increases the services by 1.4 units and 1.77 units in the industrial product (Economic Survey of Punjab, 2019).

Figure 4 shows the percentage of land utilized for various uses in Punjab. Of the total geographical area of 5.036 million hectares, the net sown area under agriculture in Punjab has only decreased marginally from 4,218,000 ha in 1990-91 to 4,118,000 in 2018-19. However, the gross sown area (area sown more than once) has increased from 7,502,000 ha in 1990-91 to 7,839,000 hectares in 2018-19. The area under forest cover has increased marginally from 222,000 ha to 253,000 ha. 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).

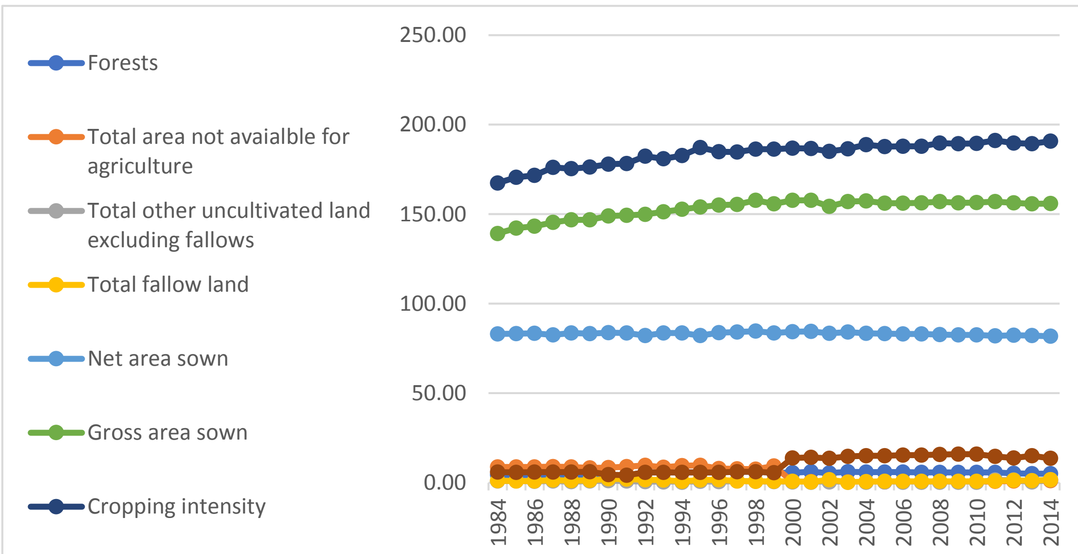

FIGURE 4. PERCENTAGE OF LAND UNDER VARIOUS LAND USES IN PUNJAB

Source: Figure created based on data from Statistical Abstract of Punjab

Figure 5 presents the net area sown and area sown more than once in different districts of Punjab, and it is clear that with the exception of a few districts (SAS Nagar, Hoshiarpur and Jalandhar), the cropping intensity is high (e.g. in Moga, Muktsar, Patiala, Sangrur). The productivity of rice and wheat in Punjab is the highest in India, and rice and wheat productivity has tripled post Green Revolution at approximately 3.7 t/ha and 4.9 t/ha.

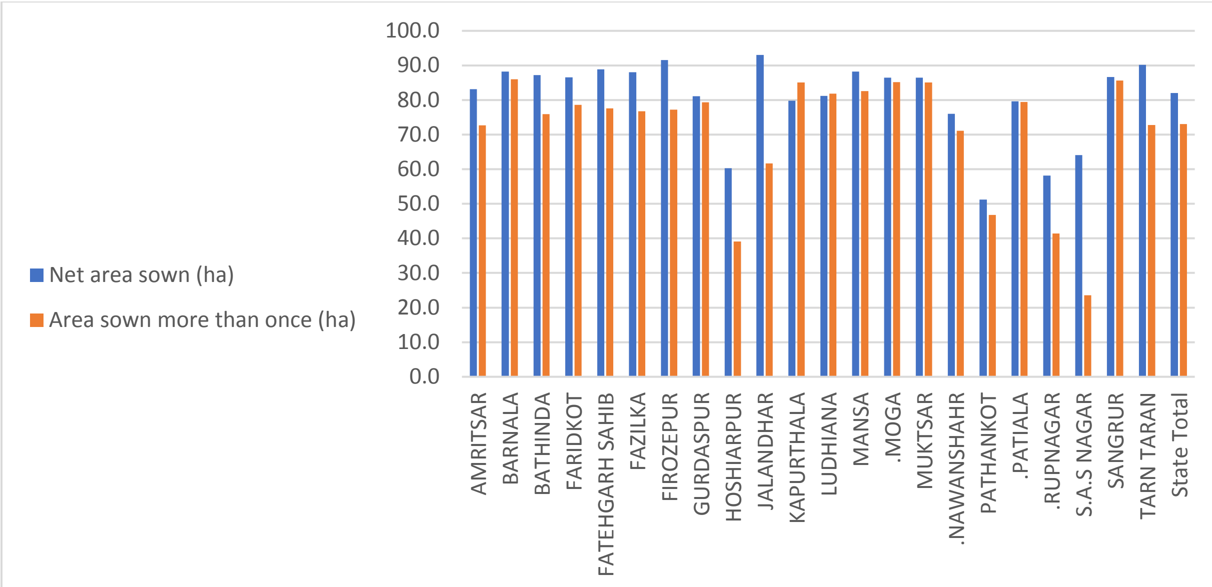

FIGURE 5. NET AREA SOWN AND AREA SOWN MORE THAN ONCE IN PUNJAB

Source: Graph created by the author based on data from the Ministry of Agriculture and farmers welfare

As Punjab is a rice and wheat surplus state, it contributes to almost 10% and 20% of the rice and wheat production in India and is a very important contributor to the central procurement (Figure 6). Although the contribution declined from 73% (4.2 million tonnes) in 1980-81 to 35.51% in 2018-19 (12.7 million tonnes), the absolute quantities have increased (Ministry of consumer affairs, Government of India).

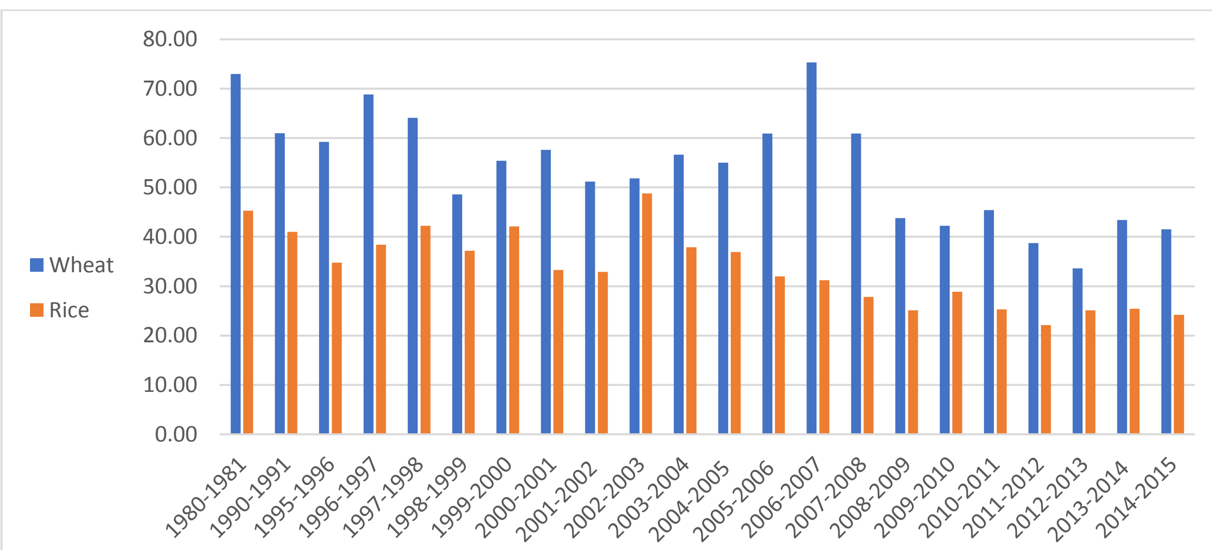

FIGURE 6. CONTRIBUTION OF WHEAT AND RICE TO THE CENTRAL POOL IN PUNJAB

Source: Figure created based on data from Statistical Abstract of Punjab (various years)

98% of the crops in Punjab are currently high yielding varieties. The increased profitability from the rice-wheat farming system reduced the crop diversity. It can be seen from Figure 1a that the total area under rice has increased from 0.3 million ha before the 1970s to 3.1 million ha by 2018, and similarly, the area under wheat crop also increased from 1.6 million ha in 1970 to 3.5 million ha in 2018. Fewer leguminous crops that fix nitrogen in the soil are being planted (as seen from Figure 1 that area under groundnuts and pulses have declined), which in turn impacts the nitrogen availability in the soils (Figure 9).

Mechanized farming is quite rampant in the State, with 18% of total tractor usage in India from Punjab. The state has on average 79 tractors per 1000 ha of net area sown. The high yields have been possible due to the high yielding seeds, which require well-irrigated conditions (Figure 7). In Punjab, 98.9% of the net irrigated area and 99.5% of the gross area was irrigated in 2018, and the gross cropped area and gross irrigated area per 100 persons is 28.4 ha and 27.9 ha respectively, which is much higher compared to the all-India figures (16.2 ha and 7.5 ha respectively).

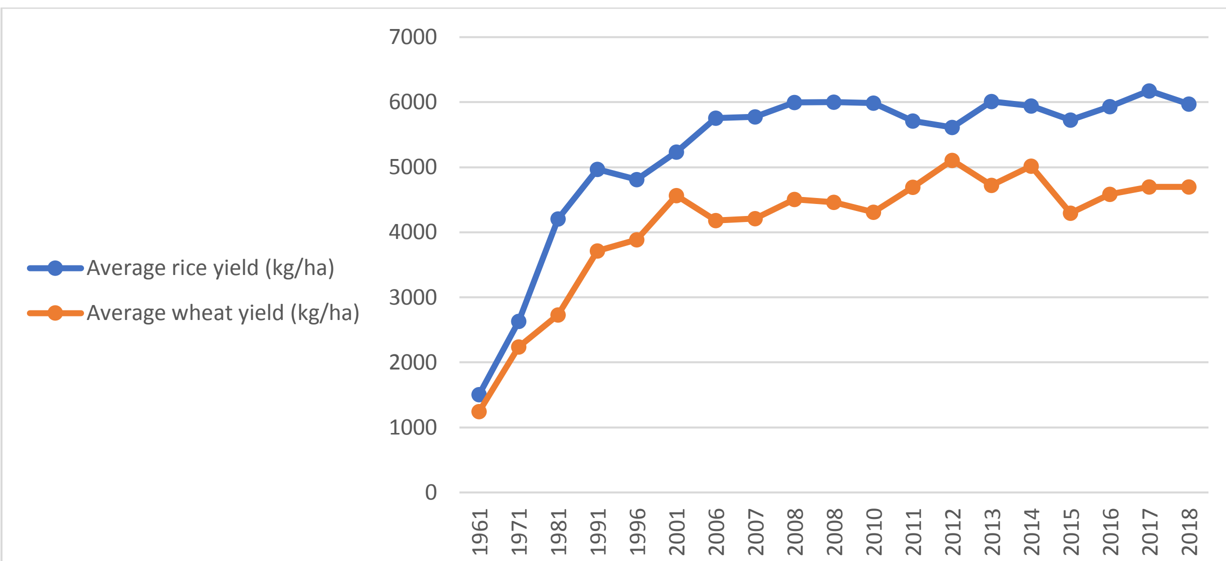

FIGURE 7. YIELD OF RICE AND WHEAT IN PUNJAB

Source: Figure created based on data from Directorate of economics and statistics for various years

Most of the irrigation in Punjab is through tube wells with implications for groundwater availability and soil fertility (26.2% through canals, 72.5% through tube wells and 1.3% through others). The number of tube-wells in the state increased from 1.07 million in 2000-01 to 1.48 million in 2018-19, and the number of tube wells operating on electricity increased from 0.79 million to 1.37 million during the same period (Statistical Abstract of Punjab, 2019). Furthermore, the state had 0.14 million diesel operated tube-wells in 2018, which had declined from 0.22 million in 2001.

In India, the size of the agricultural landholding is on the decline on average, but in Punjab the trend has been reversed. The average landholding in Punjab increased from 2.89 ha in 1970-71 to 3.77 ha in 2010-11 as per the agricultural census (see Figure 8). However, there has been a decrease in the workforce engaged in agriculture. 43.3% of the total workers in the state are agricultural workers (as per 2011 Census). The state's net area sown per agricultural worker in 2018 was 1.4 ha (Punjab Economic Census, 2019). The total number of landholdings is 1,052 million, of which 0.64 million are marginal farmers (15.6 %), 0.195 million are small holder farmers (18.5%), 0.32 million are semi medium farmers (30.8%), 0.30 million are medium farmers (28.3%), and 0.06 million are large farmers holding land above 10 hectares (6.6 %) (Agricultural Census, 2015-16).

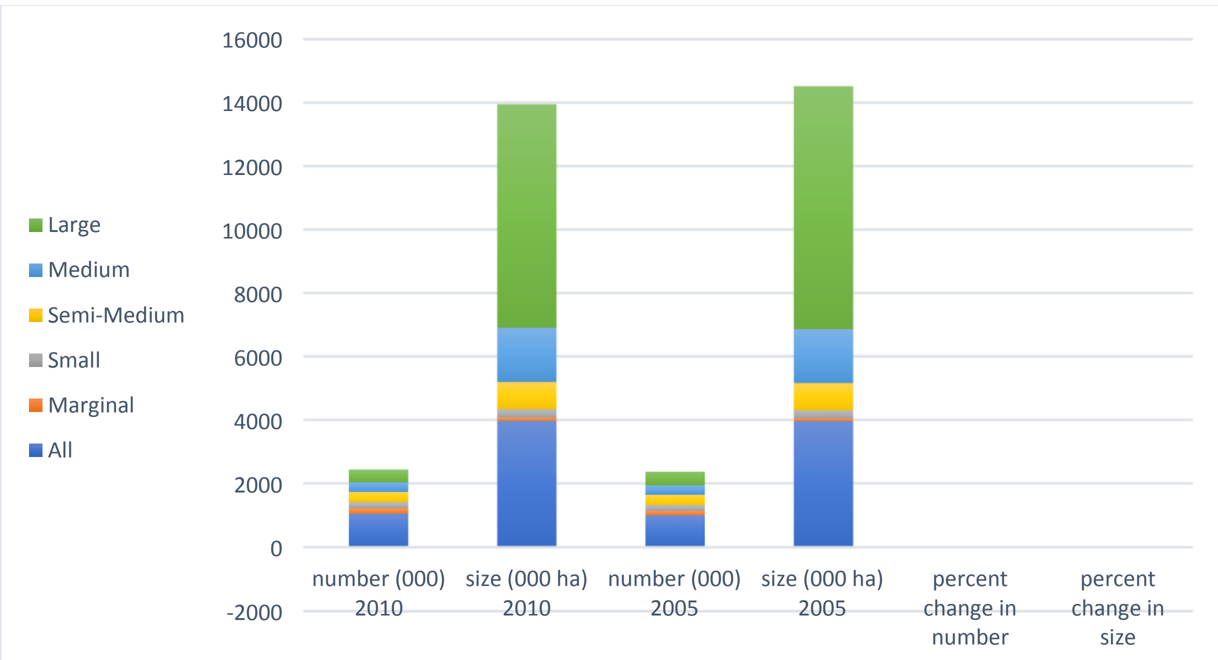

FIGURE 8. NUMBER OF LANDHOLDINGS BY SIZE GROUP IN PUNJAB

Source: (Agricultural Census, 2015)

The intensive agricultural practices in the state have resulted in the decline of the soil organic carbon and nitrogen levels, as seen in Figure 9. Figure 9 shows that most of the districts in Punjab are 100% deficient in Nitrogen, while soil organic carbon is low in the majority of the districts (<0.40%). Soil organic carbon levels are indicators of the nitrogen supplying capacity of the soils. As such, farmers replenish the soils through the excessive use of fertilizers. Although the soils in Punjab contain moderate levels of Phosphorous (12.4 – 22.4 kg/ha), the soil status shows that some of the districts are low in Phosphorous (< 12.4 kg/ha) indicating that levels have declined. Potassium levels on the other hand are high (> 22.4 kg/ha) in the soils. Deficiency in soil nutrients mean that farmers have to supplement the soils through fertilizers or manure. For example, soils that contain low levels of carbon, are 100% deficient in Nitrogen, Phosphorous and Potassium in Bathinda, have to use 454 kg/ha of neem coated urea, 650 kg/ha of single superphosphate and 83 kg/ha of Potassium chloride, raising the farmers´ private costs as well as the externality costs to society. This requirement comes down to 91.3 kg/ha of urea, 131.2 kg/ha of single superphosphate, and 16.67 kg/ha of Potassium chloride if the soils contain very high levels of these nutrients (author's compilation of information based on recommended dosage of fertilizers from soil health cards). This requirement changes depending on the region.

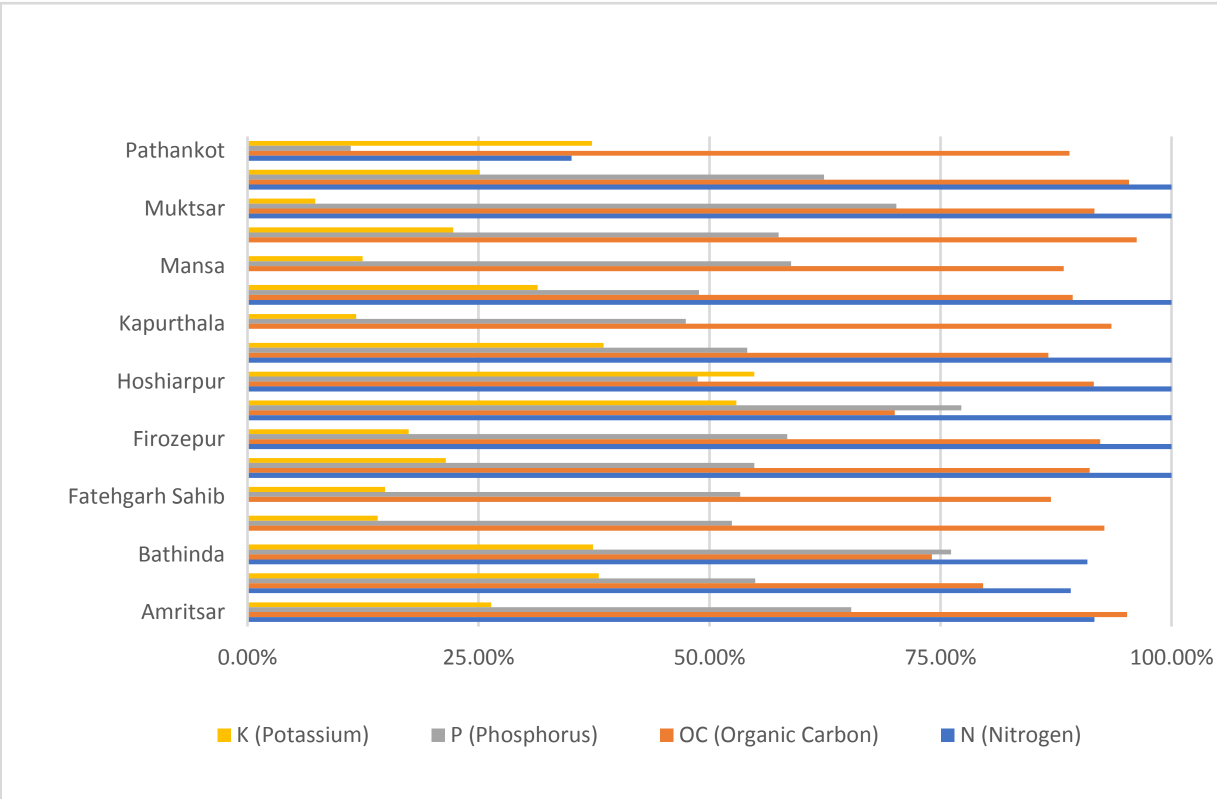

FIGURE 9. SOIL DEFICIENCY IN TERMS OF NUTRIENTS IN VARIOUS DISTRICTS IN PUNJAB, 2018-19

Source: Figure constructed by the author from data based on District soil health cards.

Notes: 100% deficient means 0 availability for crop intake.

The increase in production has increased the chemical inputs that adversely impact human health and the health of the ecosystem. The state has a very high intensity of fertilizer, insecticide, and water use which can be seen in Figure 10. In the initial years of the Green Revolution, the fertilizer use in Punjab was 37.5 kg/ha in 1970-71 which increased to 243 kg/ha in 2010-11 before then decreasing to 228 kg/ha in 2018-19, which is higher than the all-India average by 1.77 times (see Figure 10). While the suggested ratio of N:P:K is around 4:2:1, in Punjab it is 28.8:6.9:1, while the all India average stood at 6.1:2.4:1 in 2017

(Agricultural statistics at a glance, 2018). The decline in fertilizer use has been mainly due to the shift to nutrient-based subsidies.

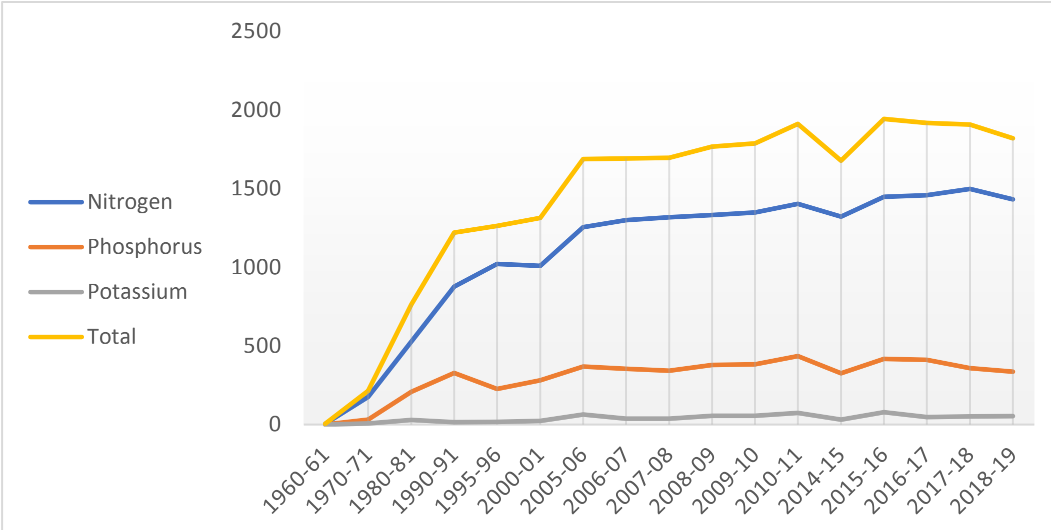

FIGURE 10. TOTAL USE OF NPK FERTILIZERS IN DIFFERENT YEARS IN PUNJAB (IN METRIC TONNES)

Source: Graph prepared using data from the Fertilizer Authority of India

The average pesticide use in Punjab peaked in 2000-01, reaching 6970 metric tonnes, which decreased to 5943 metric tonnes in 2016-17 (see Figure 10) and 5650 metric tonnes in 2018-19 (Department of agriculture and farmers welfare, Punjab). Due to the shift to BT cotton in the state[2], there has been a reduction of fertilizers.

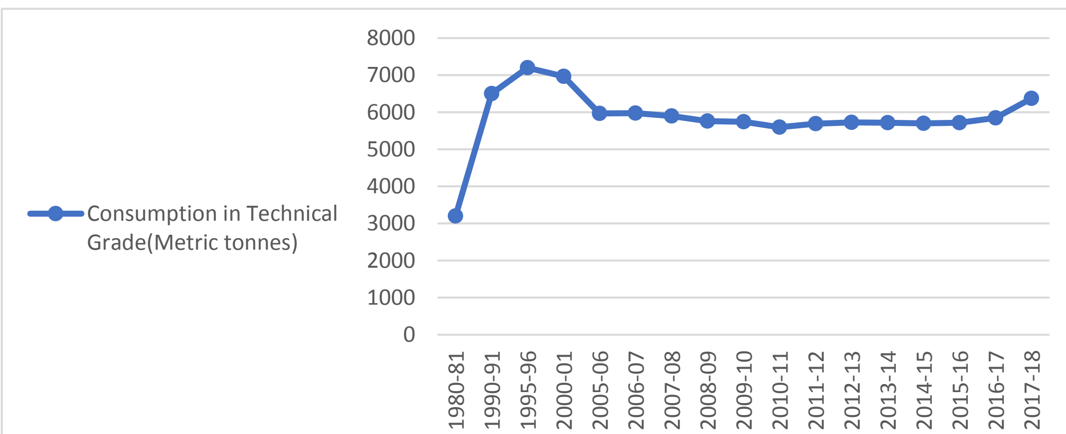

FIGURE 11. TOTAL CONSUMPTION OF PESTICIDES IN METRIC TONNES

Source: Data from Department of Agriculture and Farmers welfare, Punjab

As the electricity is subsidised and farmers have been given free electricity since 2000, the state has heavily extracted the water resources. As the total available surface water resources are 31.91 million

[2] Insect resistant Transgenic crop

acre free (MAF) against an estimated demand of 50 MAF (State water policy Punjab, 2008), the state relies on groundwater to meet its irrigation needs. The groundwater recharge in Punjab is low compared to its exploitation. Figure 11 shows the exploitation of groundwater in various districts of Punjab. According to Central Ground Water Board (CGWB) (Gupta, 2011)[3], "net dynamic groundwater resources of Punjab State are 21.443 Million Cubic metres (MCM), whereas net draft is 31.162 MCM, leading to groundwater deficit of 9.719 MCM". According to the Ministry of Jal Shakti 2019, the groundwater extraction most of which is for irrigation purposes, has exceeded the annual extractable source. 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 Jal Shakti, 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 in turn increases the cost of irrigation. As the electricity is provided free to the farmers, this would increase the government's subsidy burden. As the water levels reach their critical zone of exploitation, the quality of water may turn saline and increase the electrical conductivity, thereby impacting the crop productivity.

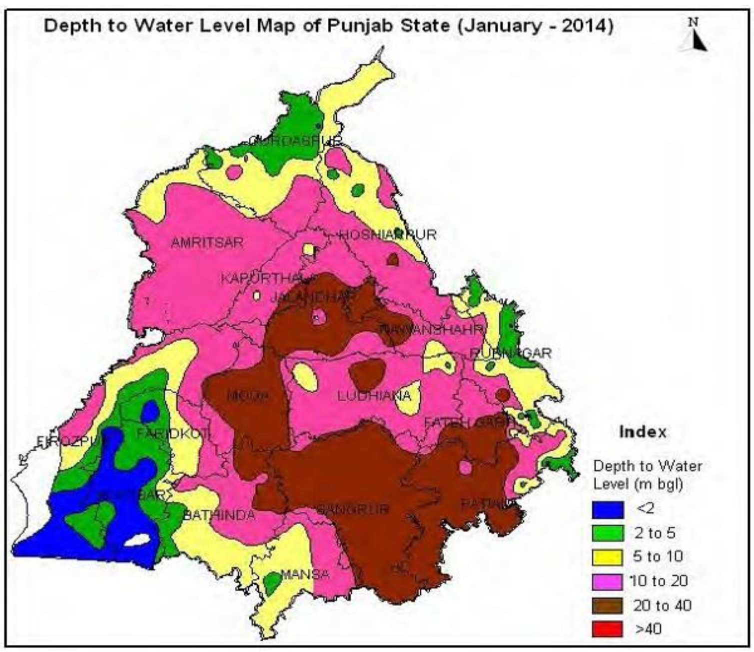

FIGURE 12. GROUND WATER LEVELS IN VARIOUS DISTRICTS OF PUNJAB

Source: Central Ground Water Board (2014), accessed from punenvis.nic.in

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[3] See *Ground Water Management in Alluvial Areas* (2011) by Sushil Gupta http://cgwb.gov.in/documents/papers/incidpapers/Paper%2011-%20sushil%20gupta.pdf

5. Quantifying the tangible and intangible flows in the production of wheat

This section identifies the quantity and economic value of tangible inputs (stocks and flows) used to produce the output, in this case, wheat (stocks and flows) and the services and disservices provided by agriculture to the economy. The section is sequenced as follows: in section 5.1 the pre-sowing condition for sowing as done by the majority of the farmers is explained. In section 5.2, the value of tangible inputs (from other sectors and from within agriculture) used in the production of wheat is quantified. Section 5.3 estimates the value of intangible inputs or non-marketed inputs (e.g. natural and social capital), while section 5.4. illustrates the direct value-addition to society through wheat production (e.g., processing wheat for different products).

The data for this section is mainly drawn from various secondary sources of information such as the Punjab Statistical Abstract, Ministry of Agriculture and farmers' welfare, Directorate of Economics and Statistics, Government of India. For estimating the value of intangible and non-marketed inputs into the production of wheat, the farm level data for the period 2000 to 2016-17 carried as part of the cost of cultivation studies, by the Ministry of Agriculture and Farmers welfare has been used. The data for estimating the above equation comes from the plot level cost of cultivation data of farmers' usage of different inputs and the output produced from the farm, collected by the Ministry of Agriculture and farmers welfare in India. The study used the data for the period 2000-2017 for estimating the production function. The farm data collected by the Ministry of Agriculture and farmer's welfare uses a three-stage stratified random sampling, with tehsil ("township") as the first stage, the village as the second-stage unit and landholding in the third stage to collect data on the cost of cultivation. The state has been demarcated into different zones based on cropping patterns, soil type, rainfall, etc. The farmers do not value several of the inputs (e.g. value of land, own seeds, own labour used in agriculture and own machinery). These costs are also imputed, and the data includes the paid-out costs and imputed costs along with the following information: 1) physical inputs - the value of seeds (purchased or homegrown), the value of insecticide and pesticide, the value of manure (owned and purchased), the value of fertilizers, irrigation charges, the value of own or hired machinery; 2) human labour; 3) animal labour: hired or own; 4) family labour; 5) machine labour, both owned and hired; 6) land revenue; 7) rent paid for leased -in-land or rental value of own land; 8) other costs: interest on working capital, land revenue, depreciation of machinery; and 9) miscellaneous expenses. The capital assets (e.g. land, buildings, storage sheds, implements, machinery, livestock) have also been evaluated using the prevailing market rates.

5.1. The pre-production conditions of wheat

In Punjab wheat is grown in the cold and dry season from November to March and is preceded by rice during the monsoon season from June to October. Such a rice-wheat cropping sequence is also followed by many other countries in South and Southeast Asia such as Pakistan, Bangladesh, Nepal, Indonesia, and the Indo-Gangetic Plain in India. Due to falling water tables, rice sowing is delayed until June, encouraging farmers to use shorter high yielding varieties of rice before wheat, which leaves a short window between the harvest of rice and sowing of wheat, around 7–10 days for Basmati and 15–20 days for coarse-grain rice (Gupta, 2012). Wheat is grown in aerobic conditions while rice is grown in anaerobic conditions. Thus, most of the farmers use combined harvester and thresher to harvest the rice at the earliest stage to prepare their fields for the wheat crop. The harvester cuts the top portion of the plant but leaves some stalk, measuring 8-10 inches in the soil. Due to threshing, some loose residue is spread on the field which is challenging to clear. Delayed sowing of the wheat crop would reduce the wheat yields, and farmers therefore get rid of the loose paddy stubble through burning, except for the long-grown varieties such as Basmati, where the rice straw is manually harvested. An alternative to residue burning could be zero tillage practice which involves planting wheat into unprepared soil at a certain depth and retaining crop residues as mulch (Laxmi, Erenstein and Gupta, 2007).

5.2. Quantifying the tangible input flows and capitals in the production stage

Crops are treated as produced economic assets in the national accounts, while agricultural land and soil are treated as non-produced economic assets. Inputs from soil (e.g. soil nutrients), water, and air are natural inputs. The value of different inputs and the flows and capital generated by these inputs is discussed below:

5.2.1 Seeds

Seeds are fundamental and 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, are treated as stocks. The seed sector is an organized sector with several seed marketing companies operating in the states, and for these enterprises seeds are the final outputs. The private sector plays a significant role in the seed sector in India. Certified seeds are produced by the Punjab State Seeds Corporation and by other agencies https://punjab.gov.in/department-of-agriculture/ and are distributed to the farmers at a subsidized rate to encourage the adoption of high yielding varieties. In addition, private companies and farmers also produce some certified seeds (and save the seeds after the harvest). Wheat is a high volume low margin crop, and the public sector companies are dominant[4]. According to the National Food Security Mission (NFSM) of India, the extent of assistance in case of high yielding variety seeds of paddy and wheat, is ₹5 per kg or 50% of the costs, whichever is lower. According to the agriculture state work plan, the subsidy is ₹50/ tonne or 50% of the cost, whichever is lower[5,6]. The Punjab State Seeds Corporation uses different distribution channels - the government, cooperatives, Punjab Agro, Indian Farmers Fertiliser Cooperative (IFFCO), Krishak Bharati Cooperative Limited (KRIBHCO), National Seeds Corporation Limited (NSC LTD), and private certified dealers. The seed industry has received strengthening from the National seed policy of 2002. Farmers in Punjab used on average 106 kg of wheat seeds per hectare, and expenditure on seed increased from 684 in 2000 – 1979 per hectare in 2016, mostly due to the increasing price of seeds (based on the cost of cultivation data for various years, Ministry of Agriculture and Farmers welfare)

5.2.2 Fertilizers

Fertilizers are important inputs in the production of wheat. Historically, fertilizers have been subsidized to make farmgate prices affordable to farmers due to rising production and import costs. The maximum retail price (MRP) of urea is fixed by the Government of India, which is lower than the delivery price, and the difference between the delivered cost of fertilizers at farm gate and MRP payable by the farmer is passed on to the fertilizer manufacturer/importer by the Government of India[7]. Government agencies sell the fertilizers to all registered members at a subsidized rate through Government cooperatives and Indian Farmers Fertilizer Cooperative (IFFCO) (see the fertilizer marketing and distribution channel in Figure 14). While India meets 80% of the urea requirements through domestic production, the country is still heavily dependent on imports of potassium and phosphorous. ***Punjab state has 11,848 registered retail and wholesale dealers*** in fertilizers (based on the data from the fertilizer authority of India).

The prices of urea and complex fertilizers are regulated, and the subsidized price of urea has been stable, unlike potassium and phosphorous, which are covered under the nutrient-based subsidy scheme (NBS).

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4 www.seednet.gov.in

5 https://www.thehindubusinessline.com/news/national/punjab-farmers-to-get-subsidy-on-wheat-seeds/article23086505.ece

6 https://seednet.gov.in/Material/Prog-Schemes.htm

7 Fertilizer association of India

Under the NBS, the subsidy is fixed by the Government (in Rs/kg basis) on each nutrient of subsidized P&K fertilizers, namely nitrogen (N), phosphate (P), potassium (K) and sulphur (S), on an annual basis taking into account all relevant factors including international prices, exchange rates, inventory levels and prevailing Maximum Retail Prices of phosphate and potash fertilizers. As of 2018, the maximum retail price of a 45kg bag of urea (excluding taxes and neem coating) has been fixed at ₹242 per bag (₹5.4/kg)[8]. The per kg subsidy rates on the nutrients N, P, K and S are converted into per tonne subsidy. Since August 2019, the per kg subsidy on various nutrients are as follows: nitrogen (18 ₹/kg of nutrient), phosphorous (15 ₹/kg of nutrient), potassium (11 ₹/kg of nutrient) and sulphur (₹ 3/kg of nutrient). Due to the seasonality of use, fertilizers are stored in various warehouses or by farmers at their homes. Figure 13, indicates the fluctuation of fertilizer prices in terms of nutrients in different years. Using the data from cost of cultivation studies (for various years), the study estimated that the farmers on average used ***162 kg of N/ha*** (with an increase from 144 kg/ha in 2001 t0 172 kg/ha in 2014); 64 kg phosphorous/ha (in the range 63-64 kg/ha over the study period); and 37 kg potassium/ha (varied between 32kg/ha in 2000 to 52 kg/ha in 2013).

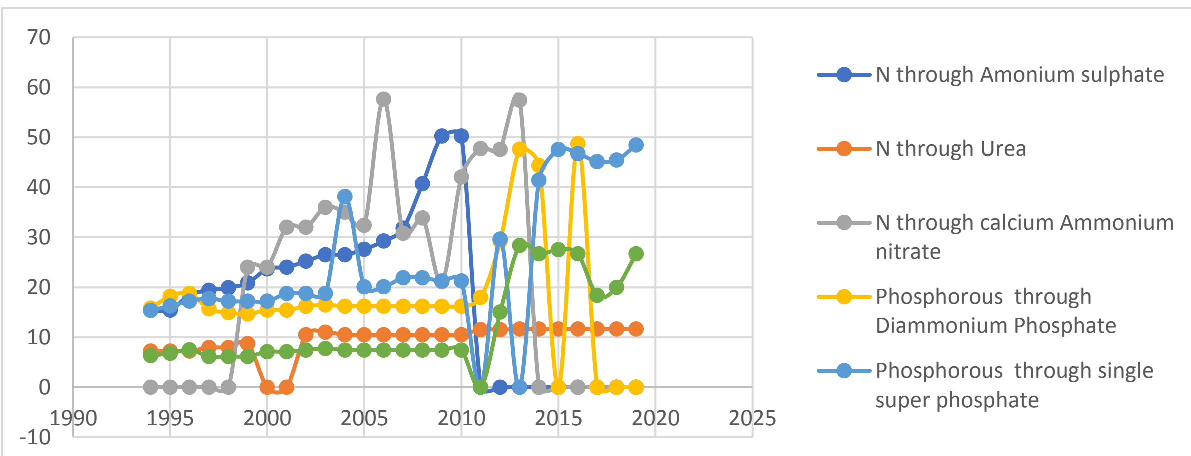


FIGURE 13. MAXIMUM RETAIL PRICE OF VARIOUS NUTRIENTS (RS/KG) THROUGH VARIOUS COMPOUNDS

Source: Figure created by the author based on data from the Fertilizer association of India (various bulletins).

Note: Average prices taken

As the farmers use various combinations of fertilizers, the prices incurred for the subsidized potash nutrient varied from 16 Rs/kg in 2000 t0 52 ₹/kg in 2016 although the quantity did not vary much, and the average price of subsidized phosphorous varied from 9 ₹/kg in 2000 to 43 ₹/kg[9] in 2016), while the

8 In 2018, 1 USD = 70.09 INR

[9] In 2000 1USD = 44.9 INR and in 2016 1USD = 66.5 INR

subsidized price of nitrogen (urea) remained stable between 9 and 13 ₹/kg. The farmers used 0.74 tonnes of manure on average and the usage decreased from 1.4 in 2000 to 1 tonne in 2016. The price of manure varied from between 0.4 ₹/tonne to 1.5 ₹/tonne. A diverse mix of macro and micronutrients are used by farmers to enhance productivity. Data reveals that farmers use on average 230kg of fertilizer per hectare (for the period 2000-2016), with an increase from 211 kg/ha in 2000 to 223 in 2016 in wheat production.

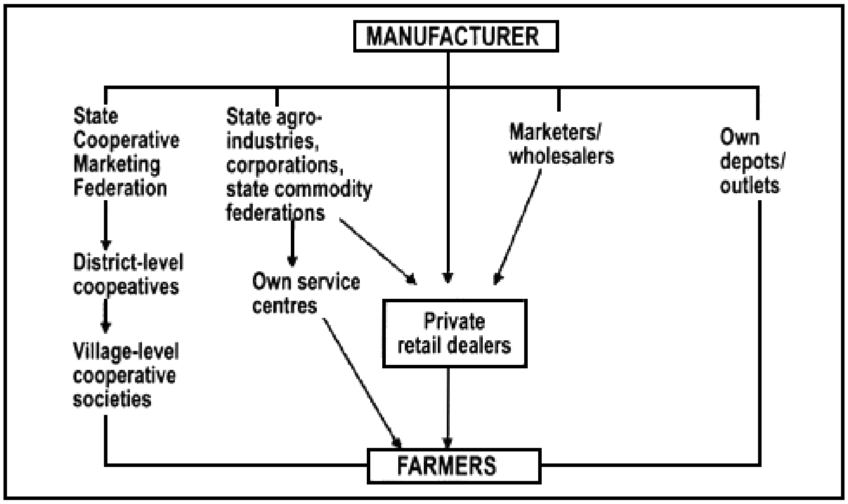


FIGURE 14. FERTILIZER MARKETING AND DISTRIBUTION CHANNELS

Source: FAO (2005), Fertilizer use by crop in India, Food and Agriculture Organization, Rome

5.2.3 Pesticides

Wheat is less susceptible to pests than other crops are, but due to intensive farming, minor pests inflict greater damage[10]. Farmers use pesticides as last produced input in agricultural operations. In India, technical grade pesticides with more than 85% of the active chemical ingredient are manufactured and are mixed with inert ingredients for easy handling, spraying, and coating on plants. Pesticides are available as insecticides, fungicides, herbicides, biopesticides, and other chemicals. The pesticide consumption depends on the rainfall conditions, with higher demand for pesticides during the Kharif season. There are 60 major pesticide producing companies in India, producing around 256 registered products. In Punjab, pesticide distribution is handled through 260 sale points of the department of agriculture, 1033 of the cooperative department, and 8453 private dealers (based on data compiled by the author from www.agripunjab.gov.in). Based on the data analyzed, farmers spend on average ₹ 1,160/ha on

[10] https://www.iiwbr.org/project-management-of-major-insect-pests-of-wheat-under-field-and-storage-conditions/

insecticides (increased from ₹728/ha to ₹1536 /ha (USD 16.2 – USD 23.12) during 2000 to 2016). The government has not been providing subsidies for pesticides in Punjab since 2016.

5.2.4 Machinery

Punjab has been a highly mechanized state, and various farming equipment such as tractors, power tillers, combined harvesters, diesel pumps, electric motors, sprayers and dusters are deployed for farm practices. In Punjab, there is one tractor for every 9 hectares of net cultivated land of state (the national average is one tractor per 62 hectares) and the state also has the highest farm power availability (2.6 KW/ha) against the power availability of 1.5 kWh/ha in India (Economic Survey of Punjab, 2018). The mechanization of farms has also been incentivized by the shortage of labour and efficient utilization of seeds, fertilizers, and irrigation water. The farm equipment also adds to the gross capital formation in the agricultural sector. Based on the data analyzed from the cost of cultivation studies, the farmers in Punjab for the wheat production on average used 10 hours of own machines and 7.4 hours of hired machines with an increase in own machine hours and a decrease in hired machine hours. The price of hired machines averaged ₹ 668 per hour and increased from ₹376 (USD 8.4) in 2000 to 1125/hour (USD 17) in 2016.

Key points for framework

- Seeds used per hectare – 106 kg/ha
- Subsidy – 5Rs/kg or Rs 500 whichever is lower
- Average fertilizers used per hectare = 223kg
- Nutrient based subsidy – 18Rs/kg of nitrogen, 15 Rs/kg of phosphorous and 11 Rs/kg of potassium (since August 2019)
- Purchased pesticide input in 2016-17 per ha – Rs 1536
- Economic impact – 60 pesticide producing companies (256 registered products)
- Subsidies since 2016 – Nil
- Social capital – 8453 private dealers, 260 sale points, and 1033 of the cooperative department
- Hours of machine use per ha – 10 hours of own machines and 7.4 hours of hired machines
- Hire charges for machine per hour Rs 668
- Free subsidized units of electricity per capita for the agricultural sector 426 Kwh (in 2019)
- Hours irrigated (2016-17 data) - 46

5.2.5 Electricity

Electricity is an important input for farm irrigation. In Punjab in 2018, according to data by the central electricity authority, **11226.74 million kWh** of electricity has been supplied to agricultural consumers, for 1,378,960 agricultural consumers (comprising 14.55% of the total consumers). Consumption of electricity per capita by agricultural sector is **426 kWh** (out of 1592 kWh across uses). The average energy sold in 2019 is ₹**41718.5** (USD 592.6)[11] per consumer in the agricultural sector (Punjab state power corporation limited), which is lost due to subsidies in addition to creating more externalities.

5.2.6 Irrigation

The productivity of irrigated fields is higher than in unirrigated fields. Wheat requires 1,654 cubic meters/tonnes of water (National water footprint account, UNESCO-Institute for Water education, May 2011). 99% of the area of Punjab is under irrigation, and the fields are irrigated either through canal irrigation or tube wells using electricity and diesel operated pump sets. The extent of reliance on surface irrigation has declined, and farmers increasingly rely on private tube wells. The field data in the study indicated that the farmers used 47.9 hours of their own irrigation machines on average to irrigate one hectare over the period 2000-2016. The time operated decreased from 60 hours in 2000 to 46 hours in 2016 due to an increase in the horsepower of the motors, and the farmers used 2.44 hours of hired irrigation machines (with a decline over the years due to an increase in ownership). The investments in their own irrigation sets will increase the gross capital formation in the agricultural sector. The price of hired irrigation machines per hour increased from **₹26 to ₹52 per hour**. However, the cost of electricity consumed is not included in the value of irrigation because electricity is free and the costs accounted only include rental charges and imputed rents in the case of their own machines.

5.2.7 Financial Credit

Financial credit plays an important role in the country's agricultural growth, especially when the farming is highly capital-intensive and there is uncertainty in weather conditions. Credit by commercial banks especially is a valuable source. In Punjab, commercial banks account for 80% of the total outstanding loans, and the rest are accounted for by co-operative banks (14%) and regional rural banks (6%). According to the debt investment survey of NSSO (2012-13), 33% of the rural households (40% of cultivators and 32% of non-cultivators) in Punjab are estimated to be indebted. A study by Narayanan (2015)[12] showed that a 10% increase in credit flow to farmers increased the fertilizer use, pesticide use, and tractor purchases by 1.7%, 5.1% and 10.8% respectively at all India level,

[11] 1 USD = 70.4 INR
12 http://www.igidr.ac.in/pdf/publication/WP-2015-01.pdf

5.3. Human capital

Punjab's population is 27.7 million according to Census 2011, with a decadal growth rate of 13.9%, of which 9.9 million make up the working population. Punjab has the largest share of workers in the agricultural and allied sector, employing nearly 26% of workers (Punjab economic survey, 2019). Labour is an important input in the production of farm output. The state has 1.93 million cultivators (main and marginal) and 1.58 million agricultural labourers (main and marginal) (Census, 2011). 15.4% of the total population in Punjab area agricultural workers, and the gross area sown per agricultural worker in 2019 is 2.71 ha. Family labour is an important input but not valued easily, and thus an imputed value based on the prevailing wage rate in the locality has been used for the work done on the farm. Male, female, children, and elderly were converted to equivalent units of labour by using male equivalent factors. On average, families spent 117 hours of labour/ha/growing season for wheat production (decreased from 164 to 106 hours during 2000 to 2016). In addition, the farmers hired 35 hours of attached labour per hectare and 35 hours of casual labour per hectare in 2016 for the wheat-growing season. The mean wage of hired labour increased by 2.8 times during 2001-2016.

5.4 Estimating the value of natural, human and social capital to wheat production

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 the neighbouring farms and also how these variables interact with each other determine the farm output in addition to the technology, human, produced and social capital **(see Figure 15 for interdependence).** Several of these inputs are not tangible, and several non-market valuation techniques have to be used to quantify these inputs.

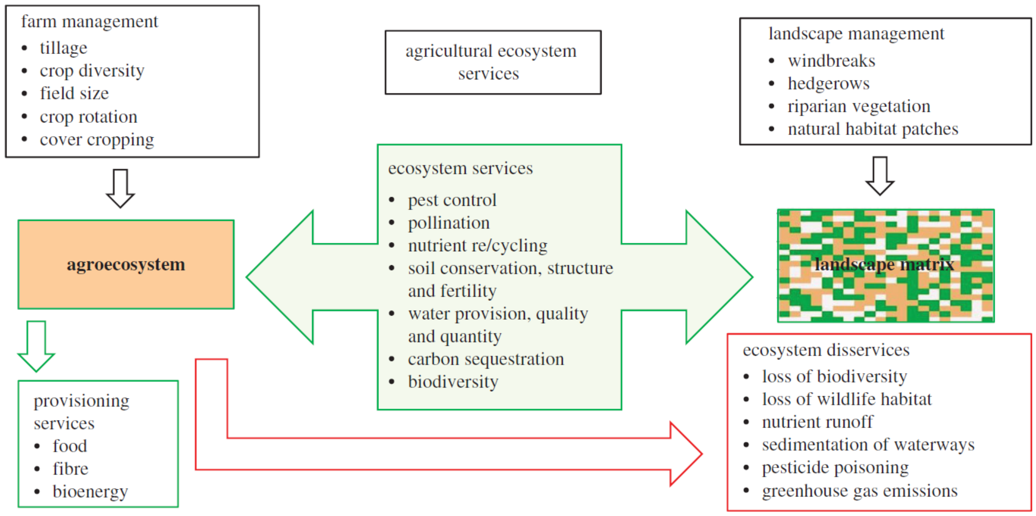


FIGURE 15: INTERDEPENDENCE AMONG THE NATURAL, ECONOMIC AND SOCIAL FACTORS
Source: Figure from (Power, 2010)

Different valuation techniques have been discussed in Gundimeda, Markandya and Bassi (2018). Along with natural capital, social capital is essential in determining the output. The institutional support and the knowledge support that the farmers receive is incredibly vital. The Government also reduces the risk through assured price supply (Minimum support price) and procures them. The MSP incentivizes farmers to produce more wheat.

When the inputs are related to the output, one can use a **production function approach**. Several inputs are used together to produce output and the production function approach estimates the function linking the inputs and output together. The use of a production function approach in agriculture has been very common. The production function is estimated by taking into account all possible on-farm and off-farm natural and produced inputs, and will give an accurate estimate of the values. The intercept term represents the outputs achieved naturally without additional inputs (or it takes into account the impact of the factors not considered in the estimation).

In this section, a production function has been estimated to assess each input's marginal contribution to the output (marginal value product). For estimation, Cobb – Douglas production specification has been used as it enables the addition of all relevant inputs, estimates the factor use intensities, and returns to scale. The model has been estimated using the ordinary least squares technique, which is described below:

Let Q = f (x) be the production function, where Q is the quantity/value of wheat produced and X represents a vector of inputs (x1, x2,,,,,, x_n). The Cobb- Douglas production function is written as

Q = $A\prod_{j=1}^{n} x_i^{\propto i}$, where $\alpha_i > 0$, $\forall$ i= 1……. N

A is the total factor productivity.

By taking logarithms we have expressions that are linear in parameters

Ln(Q) = $\alpha_0 + \alpha_1 \sum_{i=0}^{n} \ln(xi)$, where α_0 = ln (A)

The estimated coefficient gives the marginal productivity of each input

α_0 measures the factor productivity of all the inputs that are not under the strict control of the farmers (sunshine, natural capital, soil conditions, disease outbreaks etc). We estimated a double log production function along with the year dummies to capture the technological changes.

The transformed equation is as follows:

$\ln Q = \ln(A) + \sum ßi \ln (Xi) + \sum \delta_j D_j + \varepsilon$, i=1 j=1 $ß_i > 0$ i =1,2,....n, j=1,2,... J

The following variables are considered

Q: the gross value output per hectare/net value of output per hectare received by farmers at the farm gate. Quantity can also be used as a dependent variable but the value can estimate the quality of production as well and is therefore used. The unit is in Rupees.

X1: area cultivated under the crop (in ha).

X2: value of the seeds used per hectare (in kg). The costs include both purchased as well as the imputed costs in case own seeds are used.

X3: value of labour used per hectare (own labour, attached labour and casual labour). The differences in productivity across age and gender groups have been equalized into equivalent man hours.

X4: value of machinery used per hectare (own as well as hired machinery). All the machinery used by farmers for tilling, harvesting etc. have been included.

X5: value of fertilizers per hectare – the nutrient content of (N, P, K, S and other fertilizers and manure) has been aggregated into single figures.

X6: value of insecticide used per hectare on the farm.

X7: value of irrigation per hectare (hired and own machines) –the category includes the use of both own and hired irrigation hours. The value is expressed in hours as the machine is switched on and no monitoring of how much is withdrawn takes place. Only the time the moor pump is on is noted.

X8: zone codes. The data has been assigned to different zones based on the homogeneity in growing conditions.

X9: quality of land – quality of land represents the quality of soil, water available and the productivity. Hence, we approximated land quality by using the imputed land rent per hectare (assuming that differences in imputed rents reflect the quality of the land.

X10: year (dummy to capture the technological changes).

X11: number of farmers in the same zone cultivating the same crop, which is a measure of social capital. Farmers learn from each other and their practices.

X12: value of private capital (consists of land improvements, farm equipment and tools, private irrigation, agricultural machinery, farmhouses, livestock, and inventories).

X13: rainfall (average rainfall the area received in a year).

Dj – year dummies j – 2000 to 2016 which captures the technological developments.

5.4.1. Results of the production function estimation

Table 1 gives descriptive statistics for the variables used in the model. The mean area under wheat has remained approximately constant over the period 2000-2016. During the same period, the yields have fallen since 2000 except for the years 2013 and 2016. This shows that the productivity gains from the Green Revolution have levelled off. The value of wheat however, doubled by 2010 and tripled by 2016, because of an increase in the minimum support price of wheat by 1.63 times between 2000 and 2016. In comparison to the increase in inputs, the gains are low. The total fertilizer use (NPK) has increased from 211 to 345 kg/ha from 2000 to 2010 after which the fertilizer use gradually declined to 223 kg/ha by 2016. The increase has been mainly due to the increase in the use of nitrogen-based fertilizers until 2011, after which nitrogen fertilizer use has marginally declined to 158 kg/ha (although higher than the nitrogen use of 145 kg/ha in the year 2000). The mean potassium use has also gradually declined after peaking in 2005 at 4.3 kg/ha to 0.5 kg/ha in 2016. The cost of pesticides has been on the rise since 2000. Although the total fertilizer use in 2016 was at the 2004 consumption levels, the cost of fertilizers doubled from its 2000 levels in 2016. The total labour hours during the Rabi season have declined from 318 hours/ha in 2000 to 149 hours/ha in 2016, but the machine hours approximately remained the same i.e. between 18 to 19 hours/ha. The quantity of seeds have remained constant between 106-108 kg/ha although the cost increased 3.5 times between 2000 to 2016. In addition, there has been significant capital asset creation (almost double between 2000 to 2016). The rainfall in the state has been fluctuating, and the years 2002 and 2011 have experienced low rainfall.

TABLE 1. DESCRIPTIVE STATISTICS OF VARIABLES USED IN THE MODEL

Variable	Obs	Mean	SD	Min	Max
Yield (kg)	9,636	44.04	8.07	0	186
Total value of output (in ₹)/ha	9,636	52,660.48	22,138.87	0	144,300
Crop area (in ha)	9,636	1.59	1.43	0.1	14
Value of seeds/ha	9,636	1,440.57	719.70	0.0	1
Value of irrigated hours/ha	9,636	501.18	599.19	0.0	9000
Value of machine hours used/ha	9,636	5,874.06	2,950.72	14.7	48,737
Value of fertilisers used/ha	9,607	21.94	37.58	0.0	1608
Value of labour used/ha	9,636	4,373.15	3,451.22	223.3	26,624
Value of insecticides used/ha	9,636	1241.41	763.47	0.0	17875
Value of total capital stock/ha	9,636	251,496.50	377,339.10	311.2	5,138,825
Value of imputed rent/ha	9,636	13,719.61	9,613.20	0.0	44,444
Rainfall (mm)	9,599	399.13	243.43	11.9	1179

The results of the regression analysis are given in Table 2. The sum of the coefficients (excluding the time dummies) is 0.52, showing that there are 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 (an increase in inputs by 1% results in a less than proportionate increase in output) in production.

TABLE 2. RESULTS OF THE AGRICULTURAL PRODUCTION FUNCTION

Variable	Description	Coef.	t-Stat
Dependent variable	Log (value of wheat produced per hectare)		
larea	Log (area under wheat production in ha)	0.028***	10.64
zonecode	Zone code (1, 2, 3)	0.016***	8.07
llabourvalha	Log (value of labour hours employed/ha)	0.067***	19.93
lmachvalha	Log (value of capital employed per ha	0.035***	8.61
lseedvalha	Log (value of seeds used per ha)	-0.010*	-1.55
lfertivalha	Log (fertiliser value used per ha)	0.062***	6.93
lpestivalha	Log (value of pesticides per ha)	0.009***	3.11
lirrivalha	Log (value of irrigated hours per ha)	0.003*	1.63
lrain	Log (rainfall)	-0.001	-0.25
lassetvalha	Log (capital value of asset per ha)	0.006***	2.63
lrent	Log (imputed rent of land per ha)	0.309***	16.66
lfarmer	Log (number of farmers in the area)	0.001	0.35
d2001	Dummy for year 2000	-0.025***	-2.54
d2002	Dummy for year 2001	-0.071***	-7.27
d2003	Dummy for year 2003	-0.078***	-8.11
d2004	Dummy for year 2004	-0.056***	-6.01
d2005	Dummy for year 2005	-0.022***	-2.13
d2007	Dummy for year 2007	0.275***	18.96
d2009	Dummy for year 2009	0.230***	15.16

d2010	Dummy for year 2010	0.310***	16.77
d2011	Dummy for year 2011	0.422***	19.74
d2012	Dummy for year 2012	0.376***	18.17
d2013	Dummy for year 2013	0.467***	21.41
d2014	Dummy for year 2014	0.362***	15.39
d2015	Dummy for year 2015	0.480***	21.47
d2016	Dummy for year 2016	0.554***	23.1
Intercept	Log (other factors productivity)	6.127***	35.92

Source: computed by the author. Notes: *** indicates significance at 1% and ** significance at 5% level * indicates significance at 1% level. d2000 is the base dummy, and d2006 and d2008 dropped due to lack of data

The coefficient of farm size is positive, showing that as the farm size increases, the output increases, implying economies of scale. A 1% increase in farm size increased the value of output by 0.03%. Both labour and capital contribute positively to the output, and it is found that labour is more elastic than capital. Pesticides and fertilizers contribute significantly to the output, corroborating the fact that farmers increase their usage due to the declining productivity of land. The rental value of land (proxied in the model that captures the farm level characteristics such as soil structure, groundwater and fertility), has a positive and significant impact on the output. The asset value of the land variable in the model captures the land management factors (investments in capital assets to manage the land – e.g. private irrigation equipment, machinery and farm assets), which is positive and significant. Irrigated lands are expected to have a higher output than unirrigated, and the results show a positive and significant impact at a 10% significance level. The irrigation (both tube well and canal irrigation) has been captured through hours irrigated, the values are imputed values for pump sets, electricity is free, and the canal irrigation has been captured through the irrigation charges. The higher the value of seeds is, the lower is the output showing that beyond a point, further technological innovations do not yield returns.

The number of farmers in the locality (proxied to capture social capital) has a positive but insignificant impact. This variable has been included as the measure of the social network the farmer is associated with as the farmers share information. There can be both positive and negative impacts of social capital making, and the coefficient is not significant. An addition of each farmer to the area would imply more pressure on the groundwater and higher levels of pollution, but the positive factor is that they share information. Time dummies are included to reflect the changes in technology and institutional factors. It can be seen that most of the time dummies are positive and significant except for the years 2001, 2002, 2003, 2004 and 2005 when the coefficients are negative. The year 2003 experienced a severe drought, which was also the time when agriculture in Punjab was under severe pressure. The year 2009 also saw a change in institutional structure through the Groundwater protection Act, 2009 in Punjab, and as a result, the years 2009 and 2010 underwent declines in yields, although subsequently, the yield increased again. The output has been fluctuating, showing the impact of several complementary institutional and natural factors on the output.

5.4.2. Estimating the contribution of different factors of production to the value of wheat

The dependent variable is the value of wheat output produce, which is obtained due to the combination of several inputs. In agriculture, some of the inputs are combined in fixed proportions and are complements (if inputs are complements, they are all required to produce). The increase in revenue due to change in one unit of input is referred to as the marginal contribution or the value of marginal product (VMP). These are also the shadow prices. If markets function efficiently, the value of marginal product should be equal to the price of the product. The coefficients of the Cobb-Douglas Production function directly measure by how much output responds to change in different inputs and from this the contribution of each factor can be estimated through the share in total output. Figure 16 gives the contribution of different factors of production to the value of wheat in Punjab.

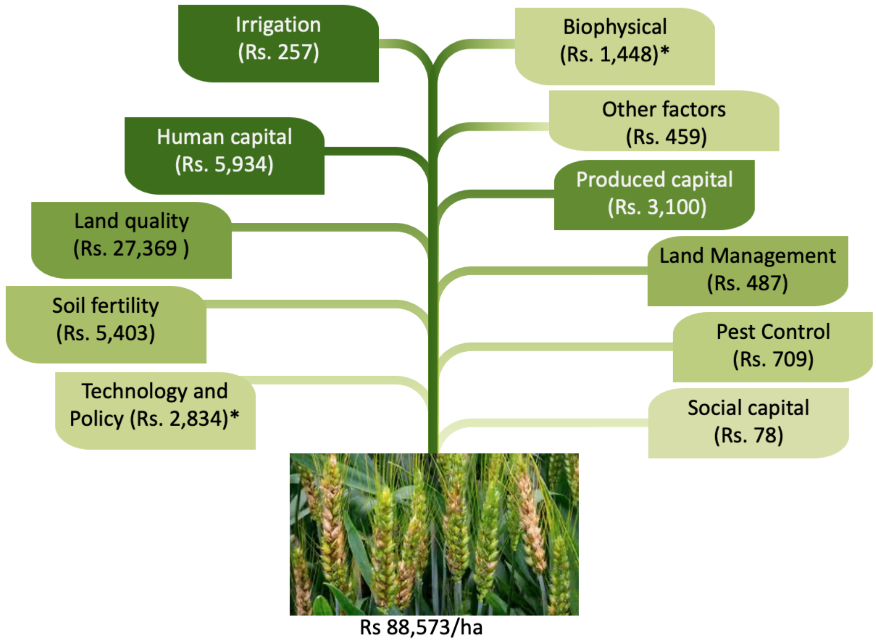


FIGURE 16. CONTRIBUTION OF DIFFERENT FACTORS OF PRODUCTION TO THE VALUE OF WHEAT (₹/HA)

Source: Author's creation based on model estimations

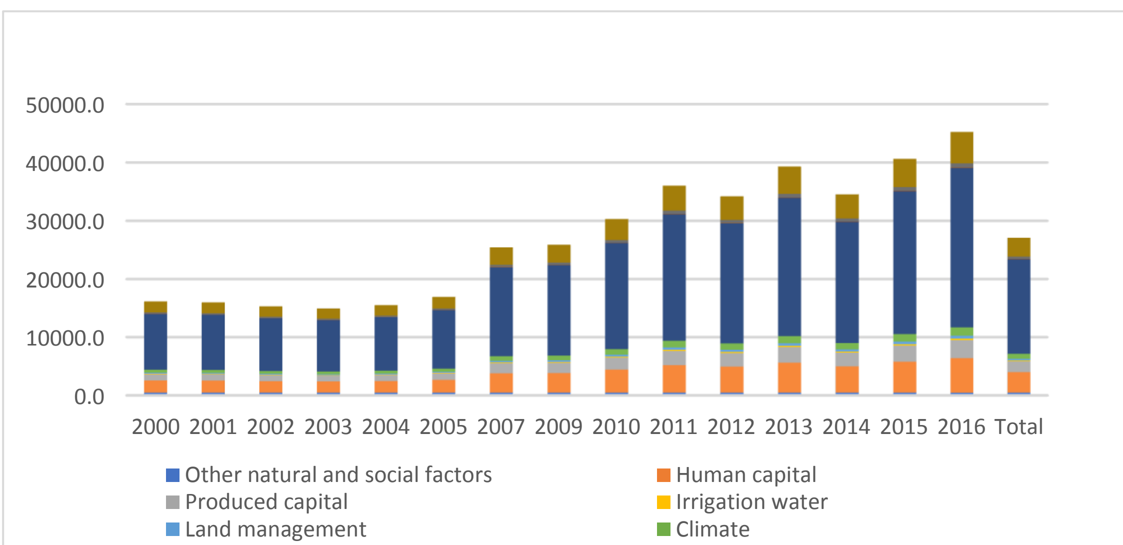


FIGURE 17. ESTIMATED VALUE OF DIFFERENT CAPITAL FLOWS TO WHEAT PRODUCTIVITY, 2000-2016

Source: Figure based on author's estimates

5.5. Estimate of the value addition in the post production stage of wheat

The wheat stalk is harvested and used as cattle feed and is recorded in the value of by-product. The stalk can be dried and stored for use over the entire year. The grain after harvest contributes to further value addition in the economy. The wheat is cleaned, dried, conditioned, transported, milled, packaged, and blended in the process of transforming to wheat flour, refined flour Suji, Dalia, and Pasta for use in bakery, bread, restaurants, and for exports. This section captures the value addition in the economy post production until it is transformed into flour at the mill.

The output is usually sold to local traders or in primary markets after keeping a percentage for own consumption and sowing for the next season. Some amount of wheat is also lost as post harvesting losses. According to a report on post-harvesting losses of wheat[13], approximately 1.79% is the post-harvesting loss at the producer level, while the rest after the harvesting loss is transported for sale. Based on the national sample survey data on situation analysis of farming households, it can be concluded that most small farmers sold to intermediaries due to their low bargaining power, while the large farmers directly sold in Mandi (NSSO, 2014). Traders in APMC operate through brokers or commission agents who deal with consolidators (representing small farmers) and wholesalers on behalf of retail traders. The consolidators and commission agents charge their fees as a percentage of the transaction. Sometimes there are direct contracts with the millers and the grain is then directly sold. The margin for traders is around ₹ 1 -2 per kilo of wheat. The grain is then transported through a bicycle (in case of less quantity), tractors or trucks and delivered to larger traders or directly to the millers. The government has fixed the Minimum support price for the farmers for wheat.

In 2018-19, according to the Department of food supplies and consumer affairs of the Government of Punjab, around 18.26 million tonnes of wheat were produced in 2018, of which 17.82 million tonnes were procured by different agencies as follows: Punjab grain (4.24 million tonnes), Food Corporation of India (1.42 million tonnes), Markfed (3.9 million tonnes), Punsup (3.14 million tonnes), PSWC (2.6 million tonnes), PAIC (1.95 million tonnes), and traders (0.06 million tonnes). The procurement rate was higher than the previous year when it was 65%. In 2018-19, 94.6% of the wheat was procured. The high procurement rate can be attributed to a well-developed market structure in Punjab. According to a report of the committee on doubling farmers' income in 2017, Punjab had 424 regulated markets, of which 150 were principal markets, and 274 were submarket yards. In 2018, the electronic National agricultural market, platform to create a network of physical mandis for buyers and commission agents, was launched by the Union government, which probably increased the procurement rate to 94.6%. Additionally, in 2013,

[13] www.agmarketnet.gov.in

Punjab passed a law on contract farming. However, this scheme did not have any takers among wheat growers.

There are several small flour mills (chakkis) and large flour mills (roller mills) in India, which contribute to value addition. Wheat flour is the basis for homemade bread, bread, biscuits, cakes, and other bakery products. The average retail price of Atta wheat in 2019 was 24.54 ₹/kg. The wheat consumption for 2018-19 was estimated to be 93 million metric tonnes (MMT) (ffrc.ffsai.gov.in). In India, according to an estimate by the Ministry of agriculture and farmers welfare, there were 300,000 chakki mills, and 1000 roller mills in 2010, and Punjab had only 5% of the mills. The study used the annual survey of industries data set to compute the approximate value addition, due to the manufacture of wheat flour in Punjab. For the year 2013 for the organized milling of wheat flour, around **1425** people were employed across **44** milling units, with annual gross wages and salaries of INR 100.2 million. The milling operations generated a net sale value of ₹ 7**020 million**. However, there are several millers in the unorganized sector whose values are not accounted for because of the lack of data.

Wheat from Punjab is transported to different parts of the country as well as exported abroad. Wheat is transformed into different value-added products. The market size of packaged wheat in India in 2015 was ₹ 75000 million and is approximated at ₹ 155,00o million in 2020 (Economic Times, 2015). Branded flour is a huge market in India with big giants ITC and Hindustan Unilever taking the lead, while the product is sold under different brand names. ITC captures 40% of the branded flour market in India (approximated at ₹ 400 million). The analysis is restricted to the processing of wheat, wheat flour, rather than the products made out of wheat.

6. Estimating the impacts from wheat production

The fertilizer use, pesticide use and water use has been higher than the national average as seen from the earlier sections and all these had undesirable impacts on the environment in terms of depleting groundwater, the degradation of soils, contamination of waterways and deteriorating quality of air, which would subsequently impact human health. The variety of wheat planted, the pre-sowing conditions and the choice of inputs matter in terms of calculating the impact on wheat production. In this section, the study analyses the emissions from wheat production and emissions from stubble burning as part of land preparation for wheat and their health impacts. We did not assume that post wheat harvest the wheat stubbles are burnt because wheat straw makes a desirable cattle feed, which can be stored throughout the year. The assumption is that all the farmers remove the straw closer to the ground, although some farmers use combined harvesters for wheat. As such, the emissions depend on the rice management practice.

6.1. Emissions from wheat production

n this section the environmental impacts of wheat production in Punjab are assessed using the lifecycle impact assessment (LCA). LCA examines physical impacts across the value chain. For each step, an inventory is made of the use of materials and energy and the emissions to the environment, creating an environmental profile that allows for identification of the weak points in the lifecycle of the system studied. In most cases, the impacts are reported in physical units (Gundimeda, Markandya and Bassi, 2018).

The emissions from wheat production have been adapted from Fallahpour et al. 2012 for wheat in Iran. The estimates in Fallahpour et al. (2012) are based on the coefficients and procedures listed in Brentrup et al. (2004) on arable crop production, which integrated all the relevant categories for arable land production. These coefficients have been adapted to the Indian conditions based on the study by Sapkota et al. (2019), which estimated GHG emissions for different crops in India based on the Coolcrop calculator. The main adjustments have been done for the GHG emission coefficients.

In this study, the system boundary has been set to the agricultural land in Punjab with the primary function to produce wheat, which uses inputs (consumption) to produce emissions (output). All the inputs and outputs are related to one tonne of production of wheat for comparability. The inputs and outputs are translated into different environmental impacts, including emissions to air, water, and soil. The data for this section is the same as that used in the previous section (as that used for estimating the production function in the study). Depending on the nitrogen use on the farm, various emission coefficients have been estimated based on Fallahpour et al. (2012) using data under the irrigated wheat category. These are then converted into equivalent functional units in terms of their global warming potential, acidification potential, and eutrophication potential using coefficients listed in Brentrup et al. (2004). The emissions in kg/ha and their equivalent conversion in terms of the global warming potential, acidification potential and eutrophication potential, are given in Table 3. In the emissions listed in Table 3, the whole set of activities involved in sowing, harvesting, production of wheat are considered.

TABLE 3. EMISSIONS IN KILOGRAMS PER HECTARE OF WHEAT PRODUCTION IN DIFFERENT YEARS IN PUNJAB

Year	NH3	NH4	NOx	NO3	P	NO3 -N	SO2	CO2	CH4	N2O	GWP	Acidification	Eutrophication
2000	17.0	1.8	5.1	5.4	93.2	0.2	3.1	2252.2	99.6	2894.1	11244.71	26.6	22.1
2001	16.0	1.7	4.8	5.2	88.2	0.2	2.9	2163.3	93.8	2748.2	10702.33	25.0	20.8
2002	14.0	1.6	4.2	4.8	78.2	0.2	2.5	1979.6	82.4	2475.1	9669.827	21.9	18.2
2003	13.6	1.6	4.1	4.8	76.7	0.2	2.5	1965.5	80.1	2448.7	9573.387	21.4	17.8
2004	13.2	1.6	4.0	4.8	74.7	0.2	2.4	1971.1	77.9	2419.1	9486.704	20.6	17.2
2005	13.5	1.6	4.1	4.8	76.0	0.2	2.5	1974.7	79.6	2439.8	9554.725	21.1	17.6
2007	14.3	1.8	4.4	5.3	81.4	0.2	2.6	2178.9	84.6	2661.5	10447.26	22.4	18.6
2009	12.7	1.6	3.9	4.9	73.1	0.2	2.3	1977.8	75.0	2393.8	9414.374	19.9	16.6
2010	12.7	1.7	4.0	5.2	74.5	0.2	2.3	2091.7	76.1	2481.0	9798.729	20.0	16.7
2011	14.1	1.9	4.4	5.8	82.6	0.2	2.6	2352.2	84.4	2785.9	11006.07	22.2	18.6
2012	13.2	1.8	4.1	5.3	77.1	0.2	2.4	2156.1	79.2	2561.1	10111.98	20.7	17.3
2013	14.5	1.9	4.5	5.8	84.1	0.2	2.7	2339.9	86.1	2801.0	11041.08	22.7	19.0
2014	12.1	1.6	3.8	4.8	70.3	0.2	2.2	1956.9	72.3	2345.2	9242.367	19.1	15.9
2015	13.8	1.8	4.3	5.4	80.2	0.2	2.5	2197.9	81.8	2636.8	10389.17	21.7	18.1
2016	15.7	1.9	4.8	5.8	88.8	0.2	2.8	2351.4	92.3	2894.8	11344.59	24.6	20.5
Mean	13.9	1.7	4.3	5.2	79.5	0.2	2.5	2119.5	82.6	2588.1	10159.92	21.9	18.2

Source: Estimated

6.2. Emissions from field clearance (through paddy stubble burning) for wheat production

The emissions from wheat production depend on the previous crop grown and how the field is cleared for wheat. As mentioned in the earlier section, 8 -10 inches of paddy stubble remains on the ground, and instead of opting to sow the wheat directly, farmers prefer to burn to get rid of the remaining residue. The study treats these emissions as part of preparing the field for the wheat crop. This study estimated the plot level residues burnt based on the residue to rice ratio, dry matter content, and fraction of the residue burnt. The burning of paddy fields releases carbon dioxide (CO_2), carbon monoxide (CO), traces of methane (CH_4), nitrogen oxides (NO_x) and comparatively less amounts of sulphur dioxide (SO_2).

Dobermann and Wilt, (2000) show that rice straw contains 5 – 8 kg of N, 0.7-1.2 kg of P, 12-17 kg of K, and 0.15-1.0 kg of S per tonne on a dry weight basis. Other studies estimate that one tonne of paddy residues contain 6.1 kg of N, 0.8 kg of P, and 11.4 kg of K (Teodoro, Mendoza, and Mendoza, 2016). The rice residue contains carbon to nitrogen in the ratio of 100:1, and entire carbon is lost (Lohan et al. 2014). Open field burning, in addition to contributing to air pollution, destroys valuable nutrients and microorganisms, and impacts the health of people, especially in terms of respiratory disorders. Brentrup et al. (2004) show that burning leads to complete loss in carbon, 80% loss in N, 25% of P, and 21% of K from the soils. These nutrients have to be replenished by the farmers through purchasing additional fertilizers or manures. Lohane et al. (2014) based on the literature review of other studies, notes that burning one tonne of paddy straw generates 3 kg of particulate matter, 60 kg of carbon monoxide, 1460 kg carbon dioxide, 199 kg ash, 2 kg sulphur dioxide and 2.1 kg of N_2O. Jain, Bhatia and Pathak (2014) based on the study by Gadde et al. (2009), estimated that burning 98.4 Mt of crop residues on farms emitted 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of So_x, 0.12 Mt of NH_3, 1.46 Mt of non-metallic volatile organic compounds, 0.65 Mt of NMHC, and 1.21 Mt of particulate matter for the year 2008-09.

Based on the emission coefficients, derived from various studies (Jain, Bhatia and Phatak, 2014, Gadde et al. 2009, Lohane et al. 2014, and Dobermann and Witt, 2000), the study estimated the total emissions emitted due to rice stalk burning and the soil nutrients lost. For the plot level data emissions from rice residue burning are calculated using the following equation: emissions = rice production **X** residue to crop ratio **X** dry matter fraction. We assumed that 80% of the rice straw is burnt. As per a report by the Government of Punjab, of the 19.7 million metric tonnes of paddy straw, 15.4 million metric tonnes are openly burnt (Punjab Government, 2017). The emission factors for air pollutants have been derived from the studies Jain et al., Gadde et al. and Lohane et al. 2014.

Table 4 gives the results, and the plot depicts the relationship between emissions and crop area. As can be seen from the plot (Figure 18), the emissions depend on inherent farm-level characteristics.

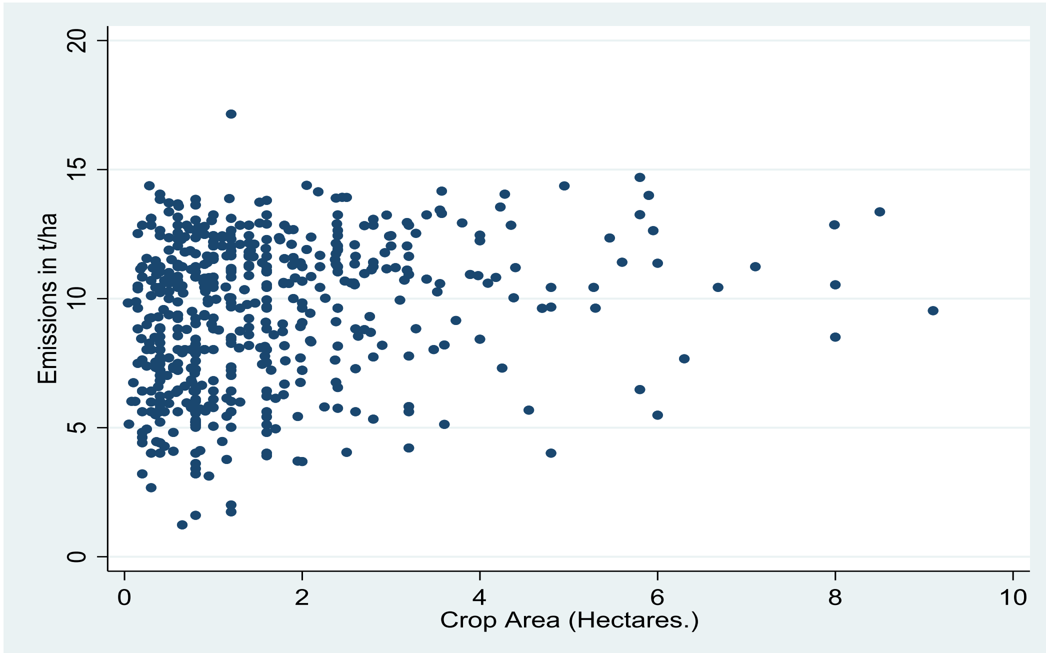


FIGURE 18: RELATION BETWEEN PER HECTARE EMISSIONS AND CROP AREA

Source: Plot based on estimations by the author

This study estimated that the stubble burning releases **23.3 Mt** of emissions, of which **21.7 Mt** is CO_2, **1.3 Mt** of CO, **0.18 Mt** of total particulate matter, and the rest shared by NMHC, NMVOC and NH_3. Several other pollutants are emitted as well, for which we did not have information. The particulate matter stays in the atmosphere for a significant duration, impacting people in Punjab as well as the neighbouring states. A study by CEEW (2018) showed that the PM 2.5 increased from 60 micrograms per cubic meter to 219 micrograms in Ludhiana and to 630 micrograms per cubic meter in Sangrur during October and November, 2018.

TABLE 4. ESTIMATED EMISSIONS AND NUTRIENTS LOST FROM THE SAMPLED FARMS FROM RESIDUE BURNING FOR 2013-14

	Mean	Min	Max	Total (million units)
Crop area in ha	1.56	0.0	9	2.36
Rice production in tonnes	6.18	0.1	45	138
Rice residue produced in tonnes/ha	7.98	0.1	59	18.91
Residue burnt in tonnes/ha	6.38	0.1	47	15.12
Loss of nitrogen (kg/ha)	31.14	0.5	228	73.79
Loss of phosphorous (kg/ha)	1.52	0.0	11	3.60
Loss of potassium (in kg/ha)	19.43	0.3	143	46.04
Emissions in tonnes/ha	9.93	0.2	73	23.53
PM (t/ha)	0.08	0.0	1	0.19
NMHC (t/ha)	0.04	0.0	0	0.095
NMVOC (t/ha)	0.09	0.0	1	0.21
NH3 (t/ha)	0.01	0.0	0	0.024
CO (t/ha)	0.56	0.0	4	1.33
CO2 (t/ha)	9.15	0.2	67	21.68

Source: authors estimates

The emissions from clearing the fields through stubble burning to make way for wheat production is a recurrent phenomenon, impacting not only local air quality but also the air quality of neighbouring states. Figure 19 illustrates the air quality in Delhi for the year 2018 in different months. It is visible that around October 19th, the air quality in Delhi turned hazardous (AQI > 400), and the air quality remains severe throughout all of November and December. The first episode of Delhi air turning hazardous coincides around the crop burning time (mid-October), and the burning continues mid-November, until the time wheat is sowed.

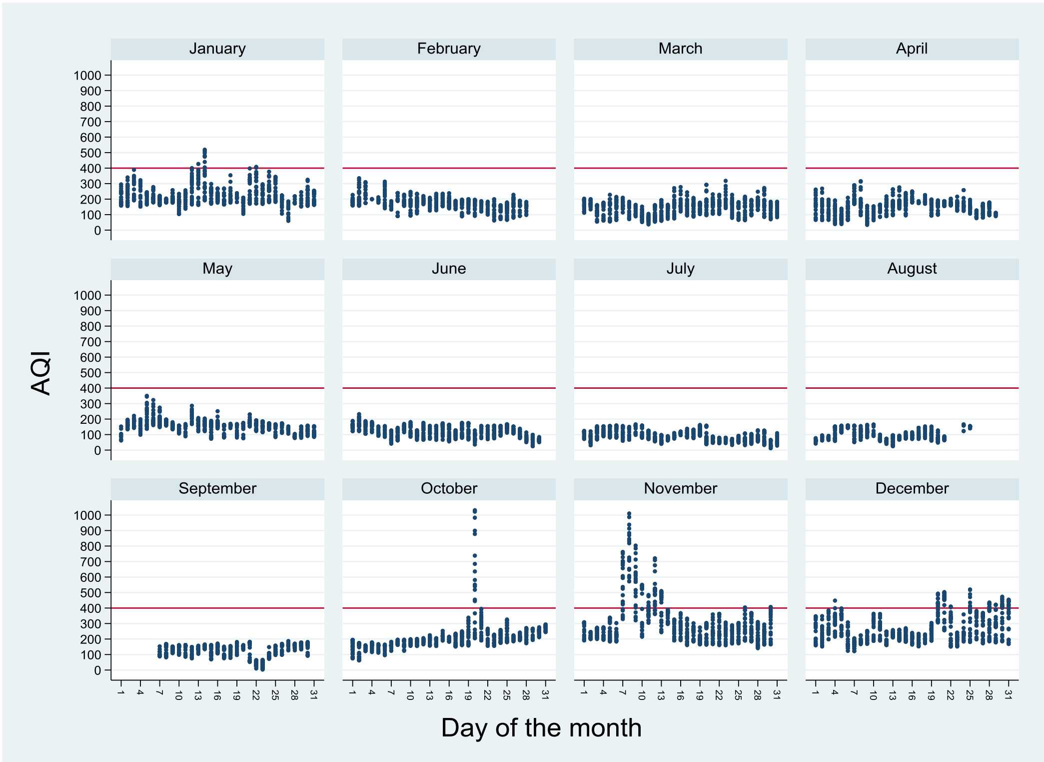


FIGURE 19: AIR QUALITY INDEX (AQI) IN DELHI IN DIFFERENT MONTHS, 2018

Source: authors analysis based on data published by CPCB on air quality
Note: the WHO guidelines for PM2.5 are 10µg/m^3

Categorisation based on the Air Quality Index

AQI	Air quality categorisation	Possible health risks
0 - 50	Good	No risk
51- 100	Moderate	Acceptable for healthy individuals but poses risks to sensitive individuals
101-200	Poor	Difficulty in breathing
201-300	Unhealthy	Risk to the health of young kids and old people
301 - 400	Severe	Chronic health issues
401- 500 +	Hazardous	Unacceptable to humans and leads to early death

6.3. Health impacts of particulate matter from stubble burning

As the stubble is burnt in winter, the temperature inversion causes pollutants to be trapped at the ground level, causing more harm. Smog reduces the visibility, increases road accidents, and also increases the cost of travel time along with the associated health problems (see for example, the air quality index in Delhi during different seasons to illustrate the deteriorating quality of air in the month coinciding with residue burning). In India, the leading cause of death is respiratory infections (chronic obstructive pulmonary disorders, emphysema, asthma etc.), a sign of poor air quality (IHME, 2019). The mortality estimates in India due to PM2.5 in India were around 66,000 in 2015 of which 50,500 were in rural areas according to the global burden of study (WHO, 2015). However deteriorating air quality is not only because of stubble burning but also because of other causes such as increases in vehicular emissions and emissions from thermal power plants. The health consequences of worsened air quality due to stubble burning, though perceived cannot be attributed. Few studies have examined the impact of stubble burning on health of rural residents. In a study based on a survey of 8,573 farmers in Bathinda, Punjab state by (Gupta 2017), a group of doctors showed that 84.5% of them were suffering from health problems because of smoke. Of these, a group of doctors showed that ca 25% visit doctors. 76.8% reported eye irritations, 44.8% reported nasal irritations, 41.6% reported having a cough, 18% reported wheezing, and 23.9% reported waking at night due to either cough or chest tightness[14] (Times of India, October 2017). In terms of economic burden of the health impacts to the farmers in Punjab, a study by Kumar, Kumar and Joshi (2014) revealed that the affected people in Punjab state suffered from respiratory problems for 15 days and paid Rs 300-500 per household on medicine in the year 2008-09. The estimates were based on the authors' primary data in three villages Dhanouri, Ajnoda Kalan and Simro of Patiala district of Punjab during 2008-09. Some family members had to be hospitalized for 3–4 days and additional costs were incurred. However, the study gives lower bound estimates as the productivity loss of illness and the cost of discomfort were not considered. The authors estimate that the total annual welfare losses due to air pollution triggered by burning paddy residues in Punjab, were **₹ 76 million**. Another recent study by Chakrabarti et al. 2019, estimated that 14.4% of all the acute respiratory infections were attributable to the crop residue burning in the year 2013. The study used satellite imagery and the district level health survey data. The study also estimated the health burden of the crop residue burning at US **$152 billion** over 5 years and concluded that it would avert 14.9 million disability-adjusted health years. Another

[14] https://timesofindia.indiatimes.com/city/chandigarh/stubble-burning-affecting-health-of-84-people-survey/articleshow/61136815.cms

recent study by IHME (2019) shows that India could save 1.5 years of life per person if the PM2.5 levels were reduced to the WHO prescribed limits.

> 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 at Rs 390-Rs 1150/ha. This estimate does not include the cost of suffering, nor the cost of averting, productivity loss or mortality losses.

We used the data from the National Health Profile (2018) on the number of people that suffered from and died due to acute respiratory infections in the states Haryana, Punjab, Delhi and Chandigarh to estimate the health damages due to crop burning. Approximately **22,09,140** people suffered in a year from acute respiratory infections on average in these three states, and there were 370 deaths per year in the two years. Assuming that 14.4% were attributable to ARI as assumed in Chakrabarthy et al. (2019), the number of people that suffered from ARI was **3,18,166**. The study by Peasah (2015) computed the cost of acute respiratory infections in Northern India in Delhi, Faridabad and Jammu and Kashmir between 2012 to 2013. The study found that the median days with symptoms varied between 7 to 9 days, and that children below the age of 5 and old people above 65 were severely impacted. The median cost of medications ranged from 0.6$ to 2.4$ in the case of non-medically attended ARIs. For the patients requiring outpatient care, the expenditures varied between US$4-6 for public hospitals, and $2-$10 for private hospitals depending on the age. In the case of hospitalization the cost ranged between $135-$355 in private hospitals and US$54-US$120 in public institutions. Higher costs were reported for the age group older than 65. The mentioned study also estimated the indirect costs due to loss of work as 16–25% of total costs, and the direct out of pocket health expenditure has been estimated at 34% of annual per capita income. Using this information (mean of the values), this study estimated the annual health costs (direct and indirect costs) due to paddy stubble burning in the range **₹ 1000-2964 million** (direct admission costs, outpatient costs and indirect costs (25% of total costs). As basmati stubble is not burnt, the study considered the area under coarse rice alone and of this 66% area under paddy, the study assumed that 80% of the fields are burnt. One person suffered for every 10 hectares of rice-wheat fields burnt, and this imposed a burden in the range **₹ 390-1157/ha** of external cost (conservative estimate taking US $120 and US $355 as admission costs and 20% inflation over four years). However, this estimate does not include the loss due to deaths as the expenses incurred on averting events, productivity loss due to illness and the monetary value of uneasiness. In addition, increased particulate matter leads to lower visibility leading to accidents, flight delays, time losses and shutting down schools. However, these values could not be considered.

7. Integrating the elements of the framework

Based on the discussions in the previous sections, all the capital, flows, dependencies, outcomes, and impacts are integrated into the TEEBAgriFood Framework (see Figure 20). The framework enables visualization of the interconnectedness between different capitals, economy 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, and cooperative institutions that provided the needed assistance for producing wheat. Wheat production draws flows from within this sector as well as external sectors. The total production of wheat used: ₹ 7843 million (USD 115.7 million) (2.56% of total value) 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), and ₹ 25, 101 million (USD 370 million) (8.2% of total value of output) 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 total value of output) of subsidised fertilizers and ₹ 5,407 million (USD 79.7 million) (1.8% of total value of output) worth of pesticides. Thus, wheat production in Punjab drives value addition in machinery and equipment, as well as the fertiliser, pesticide, and seed industry. The subsidies on fertilizers 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 a substantial amount. Most of the farmers own agricultural land, and this land 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) (it must be noted that governments fix 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 has been due to enabling technological innovation 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 (which are inseparable) are the key determinants of productivity. The rental value of land captures the inherent qualities, and 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. Soil nutrition contribute ₹ 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 too, and 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 20 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 20. There is depreciation in farm equipment and buildings, but at the same time, new capital is being added to the farm. Capital formation in turn increases the state domestic product estimates, while wheat production impacts the natural capital. The groundwater tables have fallen by 9.72 million cubic metres (CGWB, 2011), the organic carbon content is only 40% in the soils, and 100% of the soils in Punjab are nitrogen deficient although 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) (5.3% of the value of output), and includes the value of additional fertilizers required to be compensated for lost nutrients.

The wheat production involves several activities that release emissions to air, water and soil. The emissions during the lifecycle of wheat production has been shown in the Figure 20 under impact on capital. Eutrophication of land and acidification erodes the value of useful land available, while 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 the Figure 20.

Finally, any changes in the stocks and flows impact human well-being. The impacts are shown in the Figure 20. 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. At the same time however, this 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 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 e.g. one extension officer exists per 753 operational holdings in the state. Agriculture has increased people's economic well-being in Punjab as it has the highest average monthly income from farming (₹ 23,133). The institutional support also comes in the form of a crop loan waiver scheme in 2017.

As long as the positive flows outweigh the negative flows, agriculture is sustainable. The Figure 20 captures the trade-offs of different actions. An example, due to declining soil fertility, is that farmers use additional fertilizers, which reduces their profitability (although it contributes to the economic output). The declining ground waters increases the gross capital formation, which in turn drives the GDP up, but decreases the farmers' net operating surplus. A decrease in the consumption of fertilizers improves the health of the soils as well as people, but may have an impact on livelihoods as GDP declines. Investments in a technological solution to reduce pollution can lead to an increase in GCF with an increase in GDP, but the net income accruing to the farmer might change. Thus the TEEBAgriFood framework would help visualize the synergies and trade-offs more comprehensively.

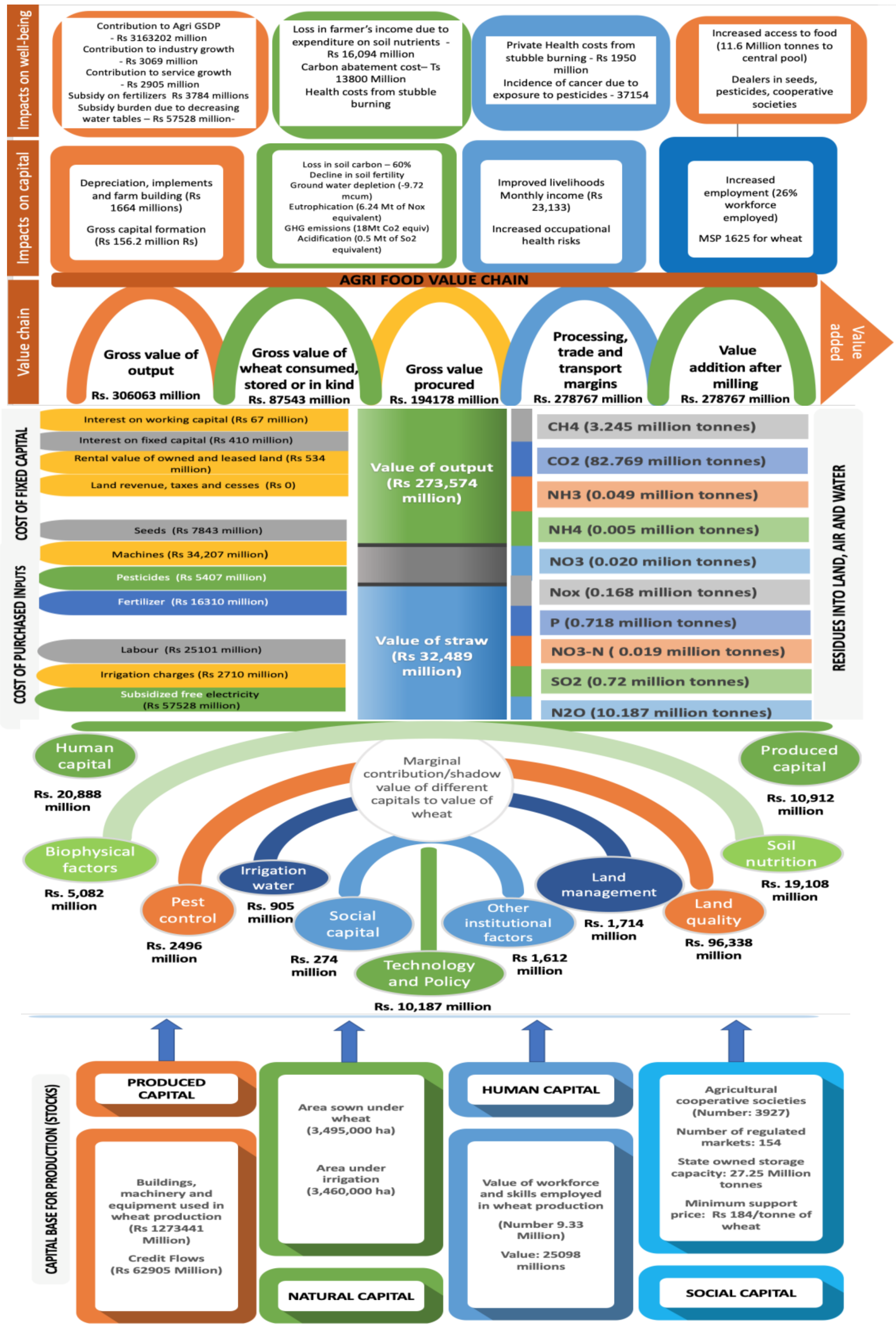


FIGURE 20: TEEBAGRIFOOD ILLUSTRATION FOR THE WHEAT VALUE CHAIN ANALYSIS

Source: Authors creation based on the analysis in the study

8. Illustrating the application of the TEEBAgriFood Framework

In this section, we use the elements of the TEEB framework to illustrate two scenarios. The base scenario is characterised by wheat production through mechanized farming, high labour inputs, surface and groundwater irrigation, high chemical inputs, and 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). This is compared with scenario A in which 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.

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

The farmers harvest paddy (sown before wheat) using combined harvester and thresher, which spreads the residues on the field. Stubble management is part of land management practice to prepare the land for wheat production. Farmers might prefer to burn the fields to remove these residues or incorporate the rice-straw back into the soil. However, as this causes immobilization of inorganic nitrogen, farmers do not prefer this because of the time taken by the rice straw to decompose, thereby impacting the wheat yield (Gupta et al., 2004). However, this trend could be off-set by additional N application. Another alternative is to directly drill the wheat into the standing rice stubble using expensive technological alternatives such as "happy seeder technology". The costs are currently 1.5 –1.65 lakhs per machine. However, the avoided costs to society are the health costs and the avoided fertiliser costs. Happy seeder is a tractor-mounted machine that cuts, 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 number of happy seeder machines in India in 2017 have approximately increased t0 10,000 and Lohan, et al. (2017) estimate that around 37,928 machines are required to cultivate 1.9 million ha of paddy fields in Punjab (assuming one machine can cultivate 50 hectares). The government has subsidized 50% for individuals, and for cooperative societies 8% of the machine costs are subsidized. Thus, the cost to farmers of acquiring the machines is ₹ 626 million, (USD 8.93 million) or a per hectare cost of ₹ 32,937 (USD 470) for the lifespan of the machine, of which the individual farmers pays only 50%. Investments in the machines lead to the gross capital formation of **₹ 626 million (USD 8.93 million)**. The total cost per acre of using this technology is ₹ 2,844 which is approximately **₹** 1440/ha for the individual farmer after subsidy. Table 5 gives an approximate comparison in net returns between the two systems. The technology in addition to saving the health costs, also saves chemical fertilizer, improves the pH, organic carbon, infiltration rate and water holding capacity. It is reported that an additional 36 kg per hectare of nitrogen and 4.8 kg per hectare of phosphorous (6 g of nitrogen and 0.8 g of phosphorous per kg of paddy straw) leads to saving of 15–20% of total fertilizer's use (Kumar, Kumar and Joshi, 2015, and Gupta et al. 2004). Thus, the cost savings due to avoiding additional fertilizer use has been estimated at **₹** 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 (USD 43.72 million/annum).

TABLE 5. COMPARISON OF NET BENEFITS BETWEEN CONVENTIONAL WHEAT PRODUCTION (THROUGH STUBBLE BURNING TO PREPARE THE FIELD), VERSUS A TECHNOLOGICAL ALTERNATIVE TO SOW WHEAT

Category	Paddy stubble burning to sow wheat	Sowing wheat after clearing fields through happy seeder	Wheat + stubble burning	Wheat production without stubble burning
Residue burnt (tonnes/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 (tonnes/ha)	10	0	3.50	0
Cost to farmers to remove residue from previous crop (₹/ha)	0	2844	0.00	1001
Capital subsidies to remove residue	0	-1422	0	-550.5
External health cost to society/ha	839	0	295.33	0
Value of wheat Produced (₹/ha)	46,521	46,520	16,375	16,375
Operational costs to produce wheat (₹/ha)	23,127	23,129	8,141	8,141
Additional costs of fertilisers (₹/ha)	1339	-1339	471	-471
Net profits from producing wheat (₹/ha)	21,216	23,290	7,468	8,198
Gross capital formation in economy	0	0	0	₹. 626 million

Source: Author's analysis

8.2. Organic vs conventional wheat production

In this scenario 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, and some remaining straw is left on the field in-situ. A cash subsidy switch from inorganic to organic is assumed in this scenario.

Organic agriculture is a production system that sustains itself through using its own inputs. The ecological, economic, social and health benefits offered by this type of production system has been illustrated in the literature (see Sandhu and Wratten, 2010, Reganold, Papendick and Parr, 1990, Mader et al. 2002, and Bharucha, Mitjans and Pretty, 2020). Sandhu et al. (2008) showed that organic farming had reduced variable costs and lowered external costs to human health for the New Zealand farms, and the returns for the organic system were twice as high compared to conventional ones. However, the adoption of organic farming in Punjab, the grain bowl of the country, has been slower than expected due to lack of adequate institutional support, lack of awareness, and the perception that organic farming is not profitable. According to the data from Organic World[15], the area under organic production in India is around 1.7 million ha, and the number of producers were around 8,35,000 in 2017. Madhya Pradesh is the area with the highest organic certified area, followed by Rajasthan, Maharashtra and Uttar Pradesh. Sikkim converted its entire cultivable land to organic farming in 2016. There has not been much adoption of organic farming in Punjab but some farmers have adopted it (approximately around 2361 ha is under organic farming as per the report from the Organic Council of Punjab 2007), and it is constantly gaining momentum. 2100 farmers are certified organic farmers and are cultivating 8000 acres [16]. However, the Punjab Organic Farming Council is merged with Punjab Agro, and has 1200 acres of certified farmers that sell wheat[17].

Based on the interviews with 20 farmers enrolled in the KhetiVirasat mission, the following conclusions emerged. The farmers mentioned the main differences between the two farming systems adopted in Punjab. 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 main input is jeevamrit, which includes the application of prepared homemade culture made of cow dung, water, urine, unrefined cane sugar, legume flour and soil. The farmers soak the seeds in cow's urine to protect it from pests and, the third practice

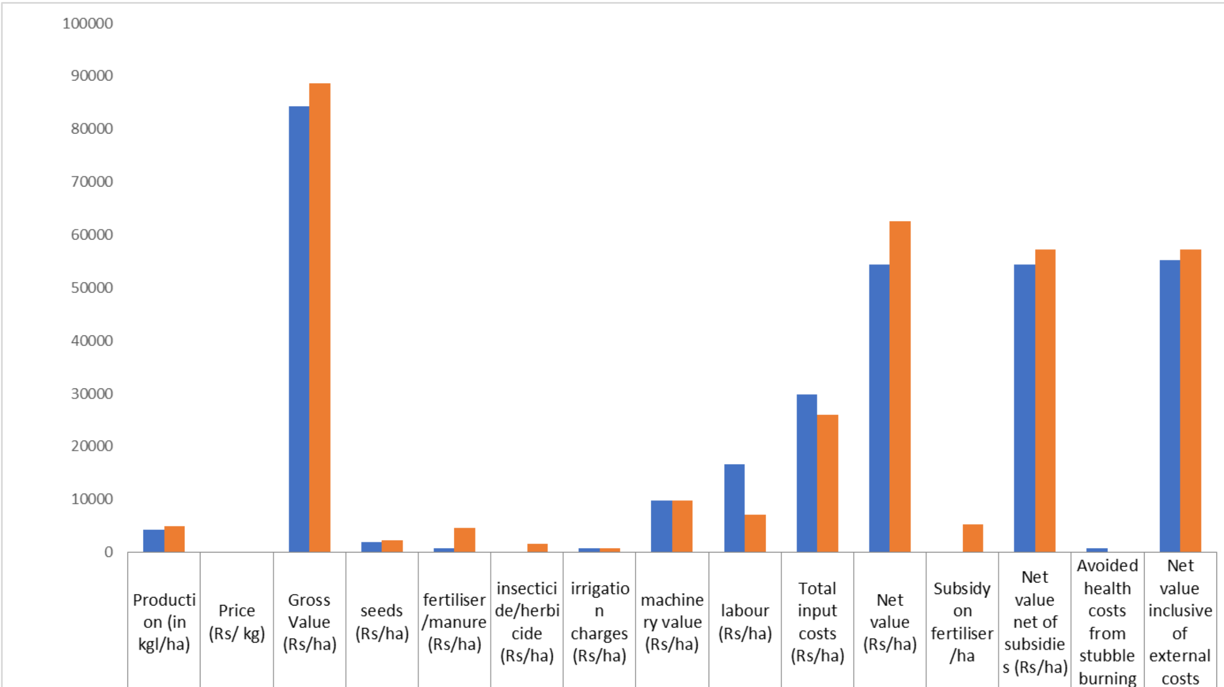
[15] Helga Willer and Julia Lenoud (2018), The World of Organic Agriculture Statistics and Emerging Trends 2018, FIBL-Frick and IFOAM – Organics International, Bonn.
[16] https://timesofindia.indiatimes.com/city/chandigarh/punjab-awarded-for-promoting-organic-farming/articleshow/67342201.cms
[17] http://www.punjabagro.gov.in/Ad%20Organic%20Wheat.pdf

involves mulching with straw and avoided tillage along with intercropping. These practices are meant to replenish the soil nutrients and improve the activity of soil biota (see Bharucha, Mitjans and Pretty (2020) for detailed practice followed in Andhra Pradesh). The farmers experienced a decrease in yield in the initial two years. The farmers were of the opinion that the net of costs and with higher prices, the net returns are equalized in later years as the farmers get used to the farming method. However, organic farming is labour-intensive as it involves the removal of weeds and requires more effort for preparing and applying the culture, aa well as harvesting and threshing. The enrolled farmers grew local varieties, the yield of which is low compared to high yielding seeds, and had to plant neem trees and had diversified farming practices. Some of the farmers set aside part of their land for organic farming, while continuing with chemical farming on the other plot as they are new to organic farming techniques. The inputs used as fertilizers are mostly homebased inputs and thus some of the farmers have not costed them. The respondents mentioned that they are costless as they are prepared from home ingredients and they relied on dung and urine from their livestock. However, this study imputes the costs to these ingredients based on the cost of farmyard manure.

Earlier researchers, have also shown in their findings that during the first four years of the transition period, the yield declines until the soil develops adequate biological activity (Ramesh, Singh and Rao, 2005). Bharucha, Mitjans and Pretty (2020) showed that the net returns from Zero Budget Nature Farming (ZBNF) were statistically significant compared to the non-ZBNF farms. Some earlier researchers have looked into the yield and differential returns between organic and conventional farming systems in Punjab (Singh and Grover, 2011, and Charyulu and Biswas, 2010). Charyulu and Biswas (2010) showed that the cost of production per hectare of wheat is higher under organic farming at ₹ 644, but in the case of conventional farming it was ₹ 315. However, organic products get a premium price, and thus according to these studies, the gross returns were 16% higher in the case of organic farming (₹ .28,747/acre and ₹ .24,755 per acre for organic and conventional respectively). Singh and Grover (2011) carried out a primary survey of 75 organic growers in Patiala and Faridkot in 2008-09 and concluded that the variable cost per acre is less for organic wheat farming when compared to inorganic wheat. They estimated the net returns over the variable cost as 21,895/acre and 16,700/acre for organic and inorganic growers in the case of wheat. According to them the yield was low, but due to higher prices fetched in the market, the net returns were higher.

Based on the data used in this study (same as the data used in section 5), the average subsidies on fertilizer alone has been estimated at around INR 8,428 million, and the subsidies have increased from ***₹ 8030-20,182 million*** between 2002 and 2016. This study compared the net returns to farming under conventional farming and organic farming. Under conventional farming, the higher costs are due to 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 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. The exact quantification could not be made as the farmers did not give 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 21 shows how the average returns compare between inorganic and organic farms when subsidies are inherent and when subsidies are netted out (netted out the fertilizer subsidy). It has to be noted that organic farmers do not get any subsidy (other than the free electricity and lowered irrigation charges which other farmers benefit from as well), and as such, organic farmers do not have any cost advantage. The farmers also have higher marketing costs as there are no established market institutions like that available for conventional wheat farmers. Assuming that the subsidy is transferred as cash to the farmers (depending on the avoided use of fertilizers), the net returns can be comparable. Besides, the organic farmer benefits from the retained nutrients due to incorporating the straw in the soil while preparing the land for wheat. The net returns to the organic farmer increases if these avoided costs are internalized. In addition, by avoiding the residue burning (as a practice they save the straws and use it as mulch), health costs are also saved. These benefits are estimated at ₹ 839/ha. The gross returns are comparable despite low 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 (section 8.3) would be lower. This figure did not include the global warming, eutrophication and acidification costs of nitrogen-based fertilizers (see Table 20 on the impacts) as these are estimated only in physical units (as shown in the integrated framework table).



	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 21. Net returns from organic and conventional wheat production

Source: Figure based on author's analysis

8.3. Value of health benefits from avoided chemical use

The additional benefits to the environment due to shifting to organic farming would accrue through lowered irrigation requirements, groundwater conservation, improvement in soil quality, and improved health not only to people in Punjab but also across the country as the wheat produced in Punjab is transported all over India. The adverse health impacts to pesticide exposure especially to farmers health is debated in the literature (see Antle and Pingali, 1994, Kim, Kabir and Jahan, 2017, Koutros et al. 2015, and Merhi et al. 2007). Kim, Kabir and Jahan (2017) carried out a detailed survey of health impacts of exposure to pesticides and found significant links with diseases such as cancer, hormone disruptions, asthma and allergies. Merhi et al. (2007) carried out a meta-analysis of 13 control studies between 1990 and 2005 and found a significant link between exposure to pesticides and all hematopoietic cancers and Non-Hodgkin Lymphoma (NHL). Koutroseqio et al. (2015) found links with herbicide applications and bladder cancer based on 57,310 pesticide applicators in USA and Amr et al. (2015) found an increased risk of bladder cancer in male agricultural workers in Egypt. Provost (2007) found an increased risk of brain tumors with pesticide exposure. Based on a study covering 30,003 female spouses, Lerro (2015) found that farmers who apply pesticides in North Carolina and Iowa have increased risk of contracting breast, thyroid and ovary cancer, and the farmers applying pesticides had an increased risk of lung cancer. Furthermore, Luqman (2014) found a strong association between pesticide exposure and lung cancer in Pakistan. In India, Indira Devi (2007) assessed the short-term health costs of pesticide exposure using used primary data of pesticide applicators and farm labour in Kerala and found that the health costs from pesticide exposure can be significant (US $ 0.86 per day) approximating a quarter of the daily earnings of the person applying the pesticide.

As per the national cancer registry prepared in 2012, Punjab has registered 10,203 cancer cases. The Government of Punjab has initiated a scheme called Mukh Mantri Punjab Cancer Raahat Kosh, where an amount of up to ₹ 1.50 lakhs is made available for the treatment of every cancer patient. Year-wise applicants from different districts and the cumulative money allocated under this scheme is given in Figures 22a and 22b. The number of cases reported in Amritsar has been the highest at 6594, followed by Ludhiana (4671) and Bhatinda (4012 cases). However, this number is confined to applicants for the funds and would not cover the cases of those already insured nor the Government employees. Under this scheme, *₹ 7,559 million* have been allocated during the period 2012-2019. According to another estimate, 2,85,800 cases of cancer were reported during the period 2012-2018, and 1,38,344 people died of cancer during this period[18]. The number of cases due to tobacco smoking in Punjab were 9,488 in 2016 (as per ICMR estimates). However, it is not easy to pinpoint exactly what proportion of cases are caused by exposure to chemicals. A study published by (CHEMTrust, 2010), showed that compared with the general population, farmers and people applying pesticides are most likely to die from several cancers including, Non-Hodgkin's Lymphoma, leukemia, multiple myeloma, prostate, Hodgkin's disease, and pancreatic and brain cancer..

Considering these cancer types and the risk factors, we assumed that approximately **13%** of the population is at risk of cancer due to exposure from pesticides. This figure has been approximated based on the number of people suffering in India from Non-Hodgkin’s Lymphoma, bladder cancer, and brain cancer where the major risk factors in addition to age, gender, and dietary practices are exposure to chemicals such as benzene and herbicides. However, the study did not attempt to monetize the mortality and morbidity.

[18] (loksabha started question no. 242, 296, 2865, 1798, 2163, 1819, 2052 during the sessions 2012-2018)

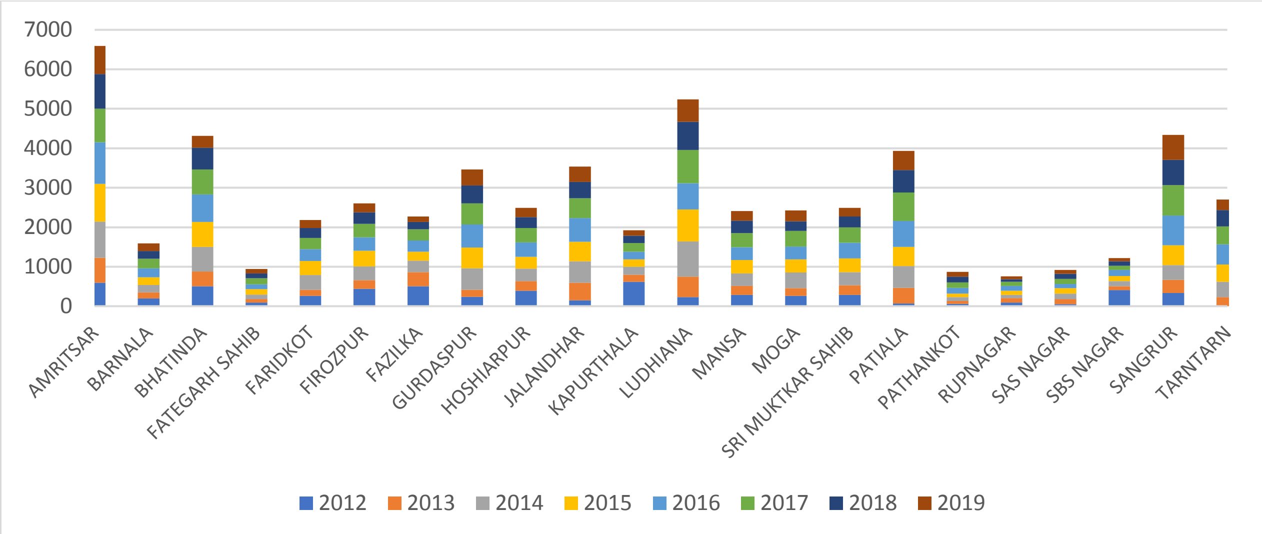


FIGURE 22A. NUMBER OF CANCER CASES REPORTED IN DIFFERENT DISTRICTS IN PUNJAB

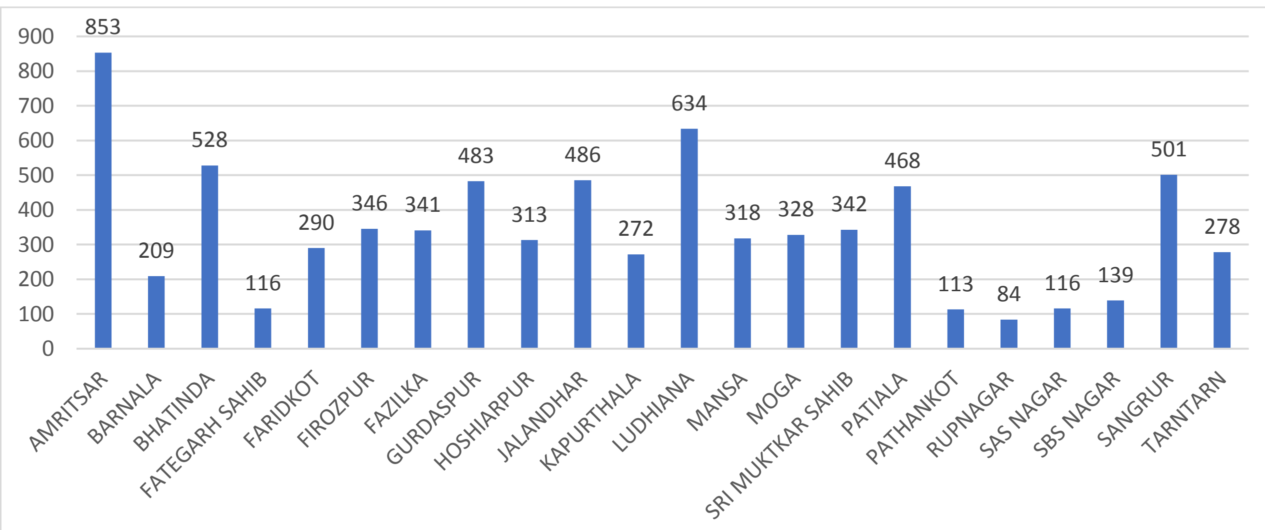


FIGURE 22B. CUMULATIVE TOTAL FUNDS ALLOCATED DURING 2012-2019 UNDER THE CANCER RAHAAT KOSH SCHEME IN PUNJAB (IN RS. MILLION)

Considering the probability of contracting cancer and the suffering it brings due to exposure to chemicals in water, air and food, organic farming (chemical free farming) appears to be profitable from a societal point of view, although the benefits could not be quantified in this study.

9. Conclusions

Agriculture and food systems are responsible for providing food security to humans and, if sustainably managed, would provide several positive externalities. However, due to misaligned policies and the lack of a holistic analysis of production systems, agriculture contributes more 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 groundwater and surface water. Thus, 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 behaviours and the producers alike (TEEBAgriFood report, 2018).

The study applied the TEEBAgriFood framework to the wheat value chain in the state of Punjab in India. The state of Punjab was chosen because it illustrates how an exclusive output-oriented approach of increasing the output for self-sufficiency and maintaining surplus, through promoting crop monoculture, high yielding seeds, rampant subsidies on energy, water, inputs etc. created a perverse scenario of excessive depletion of groundwater, decline in soil quality and productivity, loss of biodiversity and severe environmental pollution, culminating in adverse impacts on human health.

The framework in this chapter captured the trade-offs of different actions and policies. For example, the framework illustrated how due to declining soil fertility, farmers use additional fertilizers, which reduces their profitability (although it contributes to the economic output). However, the gross state domestic product increases because of the gross capital formation of private irrigation infrastructure and farm machinery and equipment at the cost of the farmers' net operating surplus. A decrease in the consumption of fertilizers improves the health of the soils as well as the health of the people, but might impact the livelihoods in the non-agricultural sector. Increasing the use of fertilizers also has a significant impact on global warming.

The yield had been a primary criterion to solve the food security issue, and thus several policies have subsidized the behaviour that causes harm to the environment. The study has shown the influence of technology and policy in changing the agricultural landscape of Punjab. The minimum support prices and the high yielding short-run varieties have incentivized farmers to adopt paddy as the first crop before wheat. The Green Revolution required a higher usage of water and soil nutrients. As agriculture is subject to vagaries of monsoon and the Governments need to ensure food security, the fertilizers and pesticides have been subsidized, which encouraged their inefficient use. The study highlighted that fertilizer use in Punjab has been 1.7 times higher than the national average. Excessive use of fertilizers depletes the soil quality further and also increases the greenhouse gas emissions, eutrophication and acidification. As there has been a mismatch between the water demand and public investments in irrigation infrastructures, farmers relied on groundwater for their irrigation needs. In Punjab, the cropping intensity 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 were deep due to the lack of incentives to conserve water which was driven by free electricity, the investments in high-powered tube wells increased. 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, which is a substantial amount.

To conserve 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 the 10th day of May and transplanting before June of the agricultural year or another date specified by the State Government by notification in the Official Gazette for any local area. By deferring the date of transplanting, the paddy crop receives more support from the rainfall in June and July. Although the policy had marginal improvements in the groundwater levels, farmers switched to short-run paddy crops (Gulati, Roy and Hussain, 2017) . The Employment Guarantee Act in India mandates minimum wages, and as paddy is labour-intensive, farmers relied on combined harvesters and threshers, which spread the paddy residue over the fields. A delay in sowing wheat leads to yield reductions, and due to the short window available to prepare the land for wheat, the farmers resort to stubble burning, creating negative impacts to the economy and health. The study estimated that the paddy stubble burning released **23.3 Mt** of emissions, of which **21.7 Mt** is CO_2, **1.3 Mt** of CO, **0.18 Mt** of total particulate matter, and the rest shared by NMHC, NMVOC and NH_3 in 2017-18. The particulate matter stays in the atmosphere for a significant duration, impacting people in Punjab as well as the neighbouring states. The annual health costs (direct admission costs and indirect costs) due to clearing paddy stubbles for sowing wheat ranged from ₹ 1000-2864 million in 2017. One person suffered out of every 10 ha of fields burnt. The external burden imposed was estimated at ₹ 390- ₹ 1150/ha in 2017. This estimate does not include the cost of suffering, cost of averting, productivity loss nor mortality losses.

Paddy straw management, a private action inducing social externalities, has proved challenging for the Government. The Government, despite announcing penalty from crop burning, has resorted to incentivizing farmers through subsidies to adopt agricultural mechanizations to manage crop residue. The Government spent approximately ₹ 2,400 million on managing crop residues during 2018-19 to fix the externality problem and free distribution of around 11,900 pieces of agricultural equipment to individual farmers and 16,450 pieces of agricultural equipment to primary agriculture and cooperative society farmer groups through a central government scheme. Comparing the net returns between open-field burning vis–a–vis use of technology, the net returns to the farmers are better using technological alternatives and increasing the GDP due to gross capital formation and health benefits occurring in the form of improved air quality.

Lessons have been learnt from the trade-offs faced due to misaligned policies, and several policy steps are being taken. One crucial step taken by the Government is to incentivize the farmers to save groundwater under the "Paani Bachao Paise Kamao scheme" (save water to 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 maintenance of canal irrigation systems. The Government proposes to levy a flat rate for power at ₹.100 per BHP[19] per month for farmers owning 4 hectares of land or more. This levy is 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 currently 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 emphasizes the importance of social capital by promoting 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 maintenance of the canal irrigation system. These steps are in the right direction. The draft state water policy had recommended cutting down power subsidies

[19] Break Horse Power – unit of power

to farmers who own more than four hectares of land to 33% but increase to 66% if adopting micro-irrigation.

For agriculture to be sustainable, the positive impacts should outweigh the negative impacts. It is not unusual for the governments to provide public support for agricultural sectors. The OECD countries, Japan, New Zealand, USA and Australia extend varying support to the farmers. However, we recommend that any policy needs to 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 a considerable positive effect. The farmers who promote sustainable practices can be offered direct cash subsidies (proportion to the reduction in environmental damage), and the subsidies for the conventional farmers can be reduced in a phased manner. The initial yield reductions from organic farming can be compensated through higher support prices for such farmers. Another significant shift in policy focus has been on crop diversification, which is another step in the right direction.

Our study recommends analyzing the impact of different policies by using a holistic framework developed in this report so that the trade-offs and synergies of different policies and actions on the economy can be better visualised.

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