Farm Sustainability Assessment Report

The Future of Food and Agriculture:

Quantifying the Social and Environmental Benefits and Costs of Different Production Systems

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Flinders University Australia

Sustainable Food Trust

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Executive Summary

The current economic and policy environment in the agriculture sector fails to account for various environmental and social benefits and costs. This results in making intensive agricultural systems – dependent on inputs of large amounts of agrochemicals and fossil fuel-based energy – more profitable than sustainable alternatives. What is not accounted for in intensive agricultural systems is the environmental and public health impacts this kind of system causes, the cost of nature's 'ecosystem services' and the social benefit of farms. Without these impacts and costs figured in, it is impossible to determine the 'true cost' of varied farming systems.

There is need to assess, monetise and reflect the social and environmental benefits and costs of different production systems for the sustainability of agriculture. Public health impacts, such as antibiotic resistance and the risk it poses to humans and animals through resistant diseases, that are associated with intensive farming systems must be included in future assessments of the sustainability of varied farming systems. Revealing the actual monetary value of the costs and benefits of these can encourage farmers and practitioners to adopt technologies and practices that have less detrimental impacts on human health and the environment. Further, consumers can make informed decisions based on the benefits and costs of different production systems and choose products that have higher environmental and social benefits and less environmental costs.

A conceptual framework and farm sustainability assessment method to determine social and environmental externalities (benefits and impacts) has been developed in this study, which could guide management practices at farm level, raise consumer awareness and influence agriculture policies. Unrecognised environmental and social benefits are generated on some farms and this contributes to natural and social capital. The four farming systems investigated in this study are delivering more positive externalities than negative ones due to the sustainable practices already in place at these farms. There is a need to apply the same methods used here to industrial farming systems such as confined animal feed operations (CAFOs), confined dairy systems and high input farming systems to determine their positive and negative externalities.

The sustainability assessment method developed in this study can supplement wider global assessments investigating the benefits and costs of different farming systems. More studies are required to standardise methodology in order to develop a uniform metric system

that can be used by the food and agriculture industry to develop a standard for farm sustainability or packaging labels for consumers with this vital information. The assessment of environmental and social benefits and costs can help illustrate the long-term sustainability of production systems that supply nutritious food in required quantities without impacting on environment and human health.

Using the new farm sustainability assessment method developed for this study, the following costs were determined:

- A bushel of conventionally produced corn generates environmental benefits worth $0.40, social benefits of $0.60 and has an environmental cost of $1.00 as compared to its farm gate value of $4.00.

- A bushel of conventionally produced soybean generates environmental benefits worth $1.29, social benefits of $1.90 and has an environmental cost of $3.17 as compared to its farm gate value of $10.00.

- A gallon of certified organic milk generates environmental benefits worth $0.08, social benefits of $0.20 and has an environmental cost of $0.25 as compared to its farm gate value of $3.44.

- A pound of Polyface beef, the diversified farm, generates environmental benefits worth $0.70, social benefits of $2.67 and have an environmental cost of $0.63 as compared to its farm gate value of $1.60; a pound of Polyface pork generates environmental benefits worth $0.71, social benefits of $2.70 and have an environmental cost of $0.63 as compared to its farm gate value of $3.67; a pound of Polyface poultry meat generates environmental benefits worth $1.91, social benefits of $7.20 and have an environmental cost of $1.70 as compared to its farm gate value of $3.50; a dozen of Polyface poultry eggs generates environmental benefits worth $3.40, social benefits of $13.00 and have an environmental cost of $3.06 as compared to its farm gate value of $3.75.

- A pound of organic rice generates environmental benefits worth $0.01, social benefits of $0.06 and have an environmental cost of $0.003 as compared to its farm gate value of $0.25.

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Table of contents

1. Introduction

Current agricultural production systems have been calibrated to maximise return on investment, and utilise large amounts of inputs in terms of agrochemicals and energy (Schutter, 2010; Wratten et al., 2013). However, such production systems often ignore, (i) the contribution of ecosystem functions and services to the production systems, (ii) social aspects of farming, and (iii) the impact of intensive practices on public and environmental health (Pretty et al., 2000). Thus, these systems are increasing financial capital at the expense of both social and natural capital (Sandhu et al., 2015, 2016).

Moreover, the current economic and policy environment also supports such systems by subsidising agriculture with the costs to public and environment health. At the same time, these systems can appear to be more profitable than some of the sustainable alternatives due to the unrecognised and unaccounted costs associated with the previously mentioned damages that they are not being charged for. Therefore, there is need to recalibrate current agricultural systems by understanding, assessing and monetising the social and environmental benefits and costs of different production systems. This information then can be used to influence policies that may favour practices which enhance social and natural capital in agriculture and optimise food production systems.

The social and environmental benefits and costs of agriculture are often termed as 'externalities' (Tilman et al., 2001, 2002). These externalities can be divided into two categories – social and environmental. There is increasing recognition of social capital associated with agricultural systems. Typically, it involves the well-being of the farmer, the farming family and farm workers, and also extends beyond the farm gate to rural communities. Production systems may have both positive and negative impacts on the social capital of agriculture. There are production systems that value social capital and enhance it, such as agroecology, organic agriculture and community-based farming. However, some high input/output and industrialised systems have a negative impact on social capital. These industrialised production systems only focus on maximising net returns without considering social capital.

Natural capital includes all natural resources and assets and provides a range of benefits to human society. These benefits are often termed 'ecosystem services' (Daily, 1997; Sandhu et al., 2008, 2010, 2015, 2016). For example, biodiversity provides functions such as beneficial insects to control pests, soil biota which aids nutrient cycling, aquifers that provide freshwater and vegetation to regulate the flow of water.

Soil and vegetation also sequester and remove carbon dioxide from the atmosphere.

Agricultural production is an ecological process and it depends on many ecosystem functions and processes to produce food, fibre, milk and other outputs. At the same time, it can have impacts on some ecosystem services, which can then result in the depletion of natural capital. For example, the addition of large amounts of agrochemicals can impact negatively on soil health by affecting nutrient cycling in soil microbes. Agrochemical use also impacts greenhouse gas emissions through its use of fossil fuels. Monocropping can result in a loss of biodiversity and the suppression of natural enemies, as well as problems with surface runoff and the pollution of waterways.

It is well established that different production systems either suppress social and natural capital or enhance them (Sandhu et al., 2008, 2015). However, in the absence of a monetary value on the positive and negative externalities associated with different production systems, it is impossible for this to be reflected in farm or national accounts (UNEP, 2015). Therefore, these social and environmental benefits and costs remain hidden and unnoted in national and global food and agriculture policies. Due to a growing realisation of the social and environmental impacts of food and agriculture amongst consumers, policy makers and the farming and scientific communities, there is a need to better reflect the economic value of all social and environmental benefits and costs associated with different production systems. This monetisation of all externalities can be one way to re-set the economic and policy environment for the future of sustainable food and agriculture production.

The impact on natural resources and biodiversity of the current food and agriculture production system, which has dominated since the second half of the 20th century, has caused global concern. To address some of these concerns and to develop sustainable food and agriculture systems that are less detrimental to public and environmental health and which promote social and natural capital, efforts at a global level are being increased. One such initiative that is widely known is The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEB AgFood; UNEP, 2015) project primarily driven by the United Nations Environment Program. This initiative advocates an "eco-agri-food" lens through which to examine and include all externalities in agriculture production systems. It aims to reflect the economic value of a range of inputs from nature, including nutrient cycling, pollination, freshwater flow, biological pest control, and others identified as ecosystem services (Daily, 1997; Costanza et al., 1997). Despite their immense value, these clear benefits are not typically accounted for in market transactions and are consequently viewed as "invisible" in economic terms.

The economic invisibility of these ecosystem services often leads to the degradation of ecosystems, with serious human and environmental costs. Unfortunately, there are very few incentives for farmers to maintain these ecosystem services eventhough they are vital to farm productivity. Instead, farmers tend to be rewarded on the basis of agricultural intensification and the expansion of agricultural land, both of which favour short-term gains. Maintaining healthy ecosystems and enhancing ecosystem services on farms – such as sequestering carbon, enhancing biological controls, managing crop residue and other ecosystem services – do not tend to generate direct income for farmers. Recognising these ecosystem services and demonstrating their economic value at farm and industry level, is the core value proposition of the TEEB AgFood project.

Drawing on the framework developed by the TEEB AgFood project to examine agricultural systems with an "eco-agri-food" lens, the current study aims to assess and monetise all positive and negative externalities associated with four production systems in the US – a conventional corn/soybean system in Minnesota, an organic dairy production system based in California, a diversified livestock system in Virginia, and organic rice farms in California.

A case study approach is used in the current work. This report comprises seven sections:

(i) an introduction that provides the background of and rationale for the study;

(ii) a conceptual framework developed to describe all externalities in terms of ecosystem services, using the concept of social and natural capital;

(ii) details about the ecological and economic methods used to evaluate all externalities;

(iv - vi) and case studies of the four production systemswith detailed descriptions and an assessment of their social and environmental benefits and costs, which are then presented in monetary units; (vii) a conclusion that provides recommendations for future research in development of sustainable agriculture and food systems.

2. Conceptual Framework to Assess Externalities

There are negative and positive externalities in agriculture, which are not accounted for by current policy and market environment, and thus they remain 'invisible' in the farm economy. Moreover, the dependency of agricultural production on healthy ecosystems is not being recognised either. These information gaps need to be filled to provide the right incentives for managing agricultural systems for productivity and environmental sustainability (UNEP, 2015). Therefore, the overarching aim of this study is to asses and highlight the economic value of all externalities at farm level.

The conceptual framework developed in this study to assess externalities is rooted in the economic and ecological theory of ecosystem services (Figure 1). Ecosystem services are typically classified into four categories – provisioning, regulating, supporting and cultural services (MEA, 2005; Wratten et al., 2013). Drawing from the description of these ecosystem services associated with agriculture, the framework used in this study is modified to include social, economic and natural capital. It classifies provisioning services as production benefits or outputs, for example production of milk, grains and meat. Regulating and supporting services are grouped into environmental benefits, whereas cultural services provide social benefits. Similarly, ecosystem disservices are grouped under an environmental and social impacts category and they result in environmental costs (see Appendix A for details on definitions and examples).

Although ecosystem services are critical to the productivity and health of agricultural production systems, they are often invisible in the economic choices we make (UNEP, 2015). Market prices paid for farm produce cover the cost of inputs such as seeds, fertilisers, and pesticides, but not the value of bees pollinating crops, or micro-organisms cycling nutrients into the soil, the lack of which can cause crops to fail. Likewise, agricultural producers are typically neither fined for causing negative externalities, such as pesticide run-off or soil erosion, nor rewarded for positive ones, such as ensuring groundwater recharge through farm vegetation or preserving scenic rural landscapes. These invisible costs and benefits are missing as key inputs into the economic system in which farmers and policy makers operate, creating a skewed and incomplete picture. The framework developed in this study recognises and captures the economic value of these invisible benefits and costs.

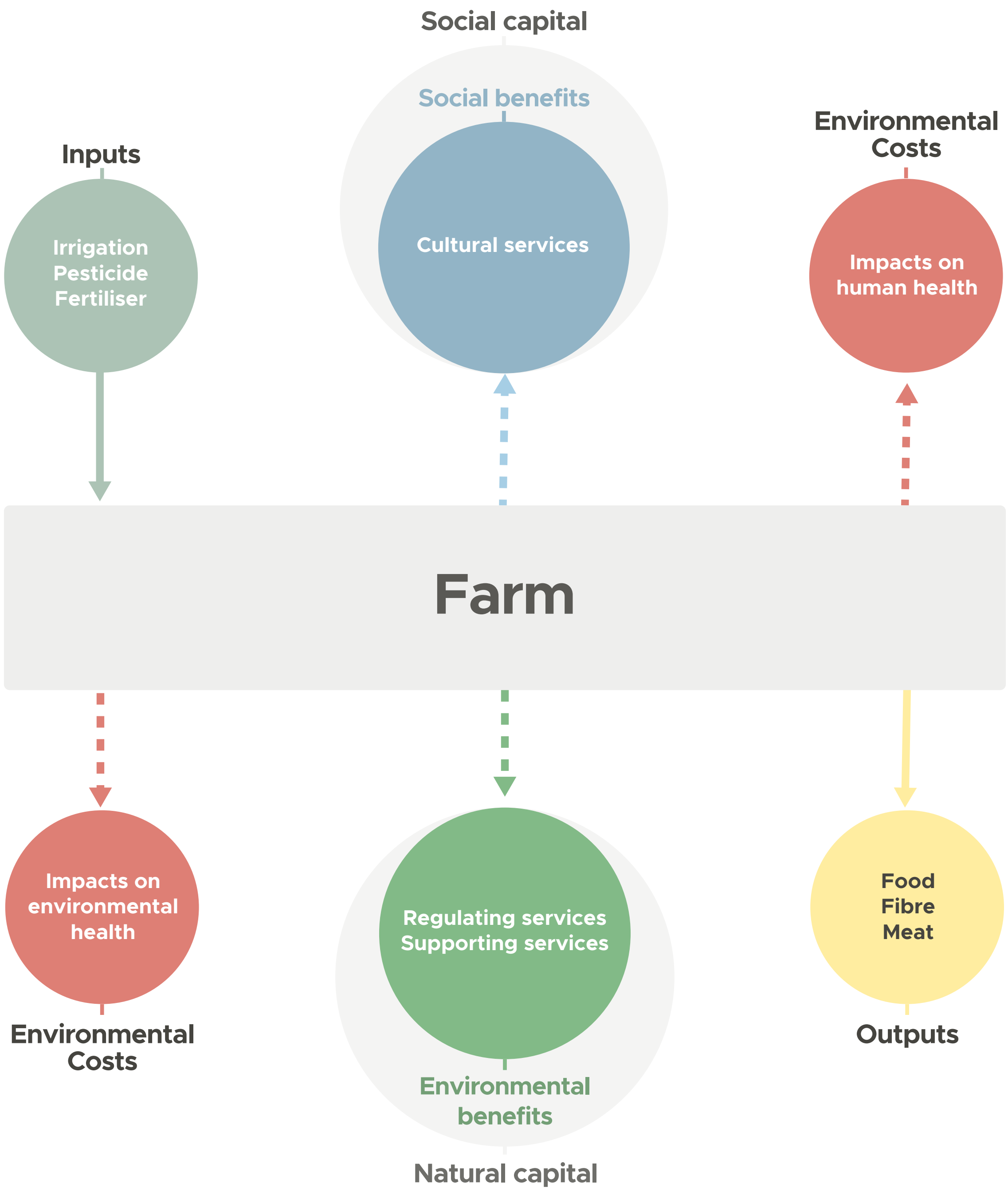

Figure 1
Conceptual framework to assess externalities at farm level. Environmental and social benefits are the benefits generated on the farm and they contribute to natural and social capital, respectively. Environmental benefits comprise regulating and supporting ecosystem services, whereas social benefits include cultural ecosystem services. Environmental costs comprise damage to environment and human health. Arrows indicate the flow of inputs and outputs (production benefits) from the farm. Broken arrows indicate those 'invisible' benefits and costs that are not accounted for in current agriculture.

3. Ecological and Economic Methods

This study focuses on monetising externalities which are divided into four categories – production benefits and their market value, environmental benefits, social benefits and environmental costs. Four farms are selected to carry out the assessment – a conventional corn and soybean farm, an organic dairy farm cluster (comprised of four individual dairy farms), a diversified livestock farm (Polyface Farm) and organic rice farms.

A farm survey has been designed to collect information on various aspects of each case study farm. Typically, it comprises information on the location, size and type of farm and includes all inputs and outputs. The data is used to develop a profile of each case study farm.

This data is then used to estimate the value of production benefits, environmental benefits, social benefits and environmental costs for each farm types (Equation 1; see Appendix C for details).

$$TC=(P_v+E_b+S_b)-E_c \qquad \text{Equation 1}$$

TC=True cost \$ per acre
P_v=Production value \$ per acre
E_b=Environmental benefits \$ per acre
S_b=Social benefits \$ per acre
E_c=Environmental cost \$ per acre

Production value
Each farm produces a particular commodity which is recorded from the farm data for the production year 2015 (quantity P_q and value P_v, \$ per acre). Its market value at farm gate (price that farmer gets at the farm gate) is obtained from the farm records in US dollars (year 2015).

$$P_q=\sum(P_{q1}+P_{q2}\ldots\ldots\ldots\ P_{qn}) \qquad \text{Equation 2}$$

$$P_v=\sum(P_{v1}+P_{v2}\ldots\ldots\ldots\ P_{vn}) \qquad \text{Equation 3}$$

Environmental benefits
These include ecological processes that are generated by agriculture production system. In this study, following benefits were assessed and

valued (see Appendix C for details).

$$E_b=\sum(E_{b1} + E_{b2} \dots \dots \dots \quad E_{bn}) \qquad \text{Equation 4}$$

1. Water regulation: Crop and livestock consumes water in form of evapotranspiration by the crops and pastures (Equation 2). Deep drainage (water stored in soil profile) = Total Water input (rainfall and irrigation) – (Wateruse by crops and pastures + Runoff) Water recharged into soil profile is estimated using above equation and valued from the market price of irrigated water at each site ($0.006 per gallon).

2. Carbon sequestration by soil and vegetation: Both above ground and below ground vegetation captures carbon in the field. This is estimated from amount of soil carbon sequestered annually under different crops and pastures and value obtained from the carbon price in market ($15 per metric tonne).

3. Nitrogen fixation: It differs under different cropping systems, is estimated by the amount of nitrogen fixed, and is valued at the market price of nitrogen ($0.30 per kg).

4. Nutrient cycling: Nutrient cycling differs under different management practices. Its value is obtained from the amount of nutrients made available after breakdown of organic matter and is valued at the price of nutrients in market (nitrogen, $0.30 per kg; phosphorus $0.16 per kg; potassium $0.24 per kg).

5. Soil erosion control: Permanent pastures prevents soil erosion (as compared to bare soil) which is compared with crop cover. Soil replacement cost is estimated from the market price of topsoil ($50.3 per acre).

6. Biological control of pests/diseases: Different management practices use natural pest control of pests and disease and thus avoid cost of pesticides. Biological control of animal disease ($14.37 per acre) is attributed to those systems that enhance biological control.

Environmental costs

It includes damage to human health and environment. There are various practices used in pastures and cropping systems that are detrimental to the environment. Following categories are assessed and valued in each of four farm types (see Appendix C for details).

$$E_c = \sum (E_{c1} + E_{c2} \ldots\ldots\ldots E_{cn}) \qquad \text{Equation 5}$$

1. Green house gas emissions: Various inputs such as agrochemicals, tillage practices, use of animal feed, fossil fuel for transportation, enteric fermentation in animals, etc. generate large amount of greenhouse gases. These are assessed as carbon di-oxide equivalents for each farm. There is social cost of carbon that takes into account economic damages associated with a small increase in carbon di-oxide emissions ($42.3 per metric tonne; EPA, 2015). This cost is used to estimate environmental costs associated with each farm.

2. External costs of pesticides and fertiliser used in US agriculture is used to estimate various impacts on human health and environment (Tegtmeier and Duffy, 2004). These are estimated from the annual cost in each category at national level. There is an annual external cost of fertiliser use ($0.41 per kg) and pesticides use at $46.03 per kg of active ingredient used. These costs are then calculated for each category as a cost per acre and considered in each of the four case study sites depending upon crops or livestock operations. These include following categories:

   - Damage to water resources: It includes facility infrastructure needs for nitrate and pesticide treatment.

   - Damage to soil resources: This includes soil sediments accumulated in water ways and cost to water industry, cost to replace lost capacity of reservoirs, water conveyance cost, flood damages, damages to recreational activities, cost to navigation due to shipping damages, dredging, in stream impacts to commercial fisheries, and off stream impacts such as industrial users, steam power plants.

   - Damage to air resources: Cost of green house gas emissions from cropland and livestock.

   - Damage to ecosystems and biodiversity: It includes honey bee and pollination losses, loss of beneficial predators by pesticides application, fish kills due to pesticides, bird kills due to pesticides and pesticides poisoning.

   - Damage to human health: It includes pathogens and pesticides that cause human health issues.

In addition to the categories above, the annual budgets of the government agencies responsible for their management are also included in the calculation of the external costs of US agriculture for crops and livestock. These are US EPA budget for the non-point source programme, US EPA budget for reduce public and ecosystem, USDA budget for natural resources, USDA budget for farm advisory, USDA budget for food safety, USDA plant safety, USDA microbiological data, EPA safe food programme, USEPA programme to reduce public and ecosystem risks, and USDA pesticides data programme.

Social benefits

Social benefits are the contribution to society and each of the four farm types is assessed and benefits are estimated from below categories (see Appendix C for details).

$S_b = \sum(S_{b1} + E_{b2} \ldots \ldots \ldots E_{bn})$ Equation 6

Farm employment: This is considered as a social benefit of the production system. Data from farm survey is used to calculate annual employment generation per acre.

Recreation: Many farms provides opportunities for ecotourism and recreation by offering farm tour and hence provide recreational benefits to wider community. Data from farm visits and amount charged is used to estimate recreational benefits.

Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc. Data is collected on such activities at individual farm and is valued on per acre basis.

Above information is then used to calculate environmental and social benefits and environmental cost per unit of commodity ('i') using below equations 7, 8 and 9, respectively.

$E_b/unit_i = E_{b1}$ per acre/ P_{qi} per acre Equation 7

$S_b/unit_i = S_{b1}$ per acre/ P_{qi} per acre Equation 8

$E_c/unit_i = E_{c1}$ per acre/ P_{qi} per acre Equation 9

where,

$E_b/unit_i$ =Environmental benefit of commodity 'i'
$S_b/unit_i$=Social benefits of commodity 'i'
$E_c/unit_i$ =Environmental cost of commodity 'i'

4. Corn and Soyabean Farm

Farm description
The corn and soybean farm selected for this case study is located in Blue Earth City Township in Faribault County, Minnesota. This is a family owned farm comprising 795 acres with a cropping area of 766 acres and 29 acres of building sites. This farm produces corn and soybean in rotation using conventional farming practices with strip tillage. This is the tillage system that is used for both corn and soybean, with 30 inches between rows. Zones are made in the fall after harvest. Fertilisers are incorporated in the zone as per variable rate soil test maps, yield goal and soil type. In the spring, no-till plant directly into the zone strips. At planting, liquid starter fertiliser (mostly micro nutrients) are injected with the seed. After harvest, the zone strip is re-established in the middle of the previous year's crop rows.

Benefits and costs of corn and soybean production
Benefits and costs associated with this production system are summarised below (see Appendix B 1 for details).

Production value
This farm produces corn at the rate of 221 bushels/acre per year, which is valued at $4 per bushel. Whereas soybean yield is 69 bushels per acre valued at $10 per bushel.

Environmental benefits
Corn and soybean crops use 2500 and 3738 gallons of water respectively for consumptive use. Out of the total rainfall at the site (31.11 inches annually), ground water recharge is estimated to be 5600 and 4362 gallons respectively for corn and soybean. By using the tap water price in the market at $0.006 per gallon, water regulation benefits are estimated as $33 and $26 per acre respectively for corn and soybean. There is 29 acres under trees that captures carbon at the rate of 1.22 tonnes per acre annually. At the market price of carbon (used in the study) of $ 15 per metric tonne, the annual carbon sequestration is valued at $18 per acre. Soybean fixes nitrogen through a biological nitrogen fixation process, and this is estimated to be 40kg N per acre per year and is valued at the current price of nitrogen ($0.30 per kg N). Thus the value of nitrogen fixation is estimated as $12 per acre.

Social benefits
This farm employs two permanent and two part-time staff. On the

basis of the annual wages, it is estimated that it generates employment benefits worth $134 per acre per year.

Environmental costs

Environmental costs in this farm involves greenhouse gas emissions from the use of seed ($1.1 per acre), strip tillage ($2.6 per acre), fertilisers ($30.3 per acre), pesticides ($78.23 per acre), external costs associated with damage to human and environmental health ($101 per acre), transportation fuel ($4.1 per acre) and electricity ($1.4 per acre) used to dry corn. Summary of these values are provided in Table 1.

Table 1. Benefit and costs associated with corn and soybean.

	Benefits ($/acre/year)	Cost ($/acre/year)	Net ($/acre/year)
Production value – Corn	884		
Production value – Soybean	690		
Environmental benefits	89		
Social benefits	134		
Environmental cost		219	

True cost of corn and soybean: Value of production, environmental benefits, social benefits and environmental cost is calculated for each bushel of corn and soybean from the above data (using equations 7-9) and is provided in table 2.

Table 2. Summary of benefits and costs per bushel of corn and soybean.

	Corn ($/bushel)	Soybean ($/bushel)
Production value	4.00	10.00
Environmental benefits	0.40	1.29
Social benefits	0.60	1.90
Environmental cost	-1.00	-3.17
Net cost	**4.00**	**10.02**

5. Dairy Farm Cluster

Farm description
A cluster of four dairy farms has been selected for the analysis of the true cost of milk. These four farms produce certified organic milk and to supply the Straus Family Creamery based in Petaluma. California. The dairy farms are spread across Marin and Sonoma counties, California.

Benefits and costs of milk production
Benefits and costs associated with this production system are summarised below (see Appendix B 2 for details).

Production value
Milk production varies according to the size of herd (220 to 800) in each farm (area from 180 acres to 2500 acres) from 808 to 5416 gallons per acre per year (with mean of 2377 gallons). The mean farm gate price of the four farms is $0.40 per lb or $3.44 per gallon of milk.

Environmental benefits
These include carbon sequestration by soil and vegetation (pastures and biodiverse plantings), nutrient cycling due to manure additions and methane use in electricity generation. On an average pasture management provides carbon sequestration at the rate of 0.5 tonnes per acre annually ($15 per tonne of carbon). Forest or planted trees and shrubs on farms sequesters 1.22 tonnes of carbon annually. Liquid manure additions ranges from 1662 to 7368 gallons per acre per year and adds a large amount of nutrients to pasture. These nutrients are valued at $57 - $262 per acre (with a mean value of $138 per acre). One of the farms has also installed a methane digester that generates electricity and avoids greenhouse gas emissions associated with electricity from the grid. The methane digester provides benefits worth $156.43 per acre per year. These combined environmental benefits ranges from $65 - $270 per acre on the four farms (with a mean of $193).

Social benefits
These farms employ 3-16 staff. Some farms also attract visitors from schools and environmental organisations. This recreational benefit ranges from $0.72 to $2.20 per acre. Some farms also generate knowledge and help in its dissemination via conferences and workshops. This results in social benefits of $2.2 per acre. On the basis of the annual wages, it is estimated that it generates employment benefits worth $170 - $760 per acre per year (with mean of $490). The combined mean of the four farms for social benefits is $494 per acre.

Environmental cost
Environmental costs in this cluster of farms includes greenhouse gas emissions associated with milk production ($107 - $715 per acre), animal feed ($2 - $760), manure ($11 - £47) and fuel and electricity ($7-31 per acre), along with external costs associated with damage to human and environmental health ($13.29 per acre). Summary of these values are provided in Table 3.

Table 3. Benefit and costs associated with milk production.

	Benefits ($/acre/year)	Cost ($/acre/year)	Net ($/acre/year)
Production value	8178		
Environmental benefits	193		
Social benefits	494		
Environmental cost		599	
	8865		8266

True cost of milk: Value of production, environmental benefits, social benefits and environmental cost is calculated for each gallon of milk from the above data (using equations 7-9) and is provided in Table 4.

Table 4. Summary of benefits and costs per gallon of milk.

	Milk ($/gallon)
Production value	3.44
Environmental benefits	0.08
Social benefits	0.20
Environmental cost	-0.25
	3.47

6. Diversified Farm

Farm description
Polyface farm is located in the Shenandoah Valley in Virginia and is a unique pasture-based diversified farm that produces beef, pork, rabbit, poultry meat and eggs along with other products such as maple syrup and honey. As the name indicates, this farm produces multiple products.

Benefits and costs of livestock production
Benefits and costs associated with this production system are summarised below (see Appendix B 3 for details).

Production value
This farm is a diversified farm that produces multiple products – beef, pork, turkey and chicken broilers, eggs, rabbits, honey, maple syrup and timber. The combined value of these products is estimated from the farm data and is valued at $2015 per acre per year.

Environmental benefits
Diversified operations at this farm use 3.5 million gallons of water for consumptive use. Out of the total rainfall at the site (31 inches annually), ground water recharge is estimated to be 1826 gallons per acre per year. By using the tap water price in the market at $0.006 per gallon, water regulation benefits are estimated as $10.95. There are 500 acres under forest that captures carbon at the rate of 2 tonnes per acre annually.

At the market price of carbon (used in the study) of $ 15 per metric tonne, the annual carbon sequestration is valued at $30 per acre. Soil under pasture also sequesters carbon at the rate of 4 tons per acre and is valued at $60 per acre per year. Legumes in pasture fixes nitrogen through a biological nitrogen fixation process. This is estimated to be 22.7 kg N per acre per year and is valued at the current price of nitrogen ($0.30 per kg N). Thus the value of nitrogen fixation is estimated as $6.81 per acre. Continuous vegetation cover also offers soil erosion prevention which is valued at $ 50.3 per acre annually. Since animal diseases are managed naturally, the value of biological control of diseases is estimated at $14.37 per acre. The combined environmental benefits are valued at $172 per acre.

Social benefits
This farm employs 25 permanent and part-time staff. On the basis of the annual wages, it is estimated that it generates employment benefits worth $285 per acre per year. Apart from this, annual recreational benefits

produced on the farm are $80 per acre and value of knowledge generated comes to $285 per acre. The total value of social benefits is $650 per acre.

Environmental cost

Environmental costs on this farm include greenhouse gas emissions from livestock ($112 per acre), animal feed ($16 per acre), external costs associated with damage to human and environmental health ($13.29 per acre), transportation fuel ($4.2 per acre) and electricity ($7.6 per acre) used to process and store meat products. Summary of these values are provided in Table 5.

Table 5. Benefit and costs associated with diversified farm.

	Benefits ($/acre/year)	Cost ($/acre/year)	Net ($/acre/year)
Production value	2015		
Environmental benefits	172		
Social benefits	650		
Environmental cost		153	
	2837		2684

True cost of various products: Value of production, environmental benefits, social benefits and environmental cost is calculated for each pound of beef, pork meat, poultry meat and eggs from the above data and is provided in Table 6.

Table 6. Benefit and costs associated with pound of beef, pork, poultry meat and eggs production.

	Beef ($/pound)	Pork ($/pound)	Poultry ($/pound)	Eggs ($/dozens)
Production value	1.6	3.67	3.5	3.75
Environmental benefits	0.7	0.71	1.91	3.40
Social benefits	2.67	2.7	7.2	13.00
Environmental cost	-0.63	-0.63	-1.7	-3.06
Net cost	**4.34**	**6.45**	**10.91**	**17.09**

7. Organic Rice Farm

Farm description
A cluster of two rice farms is selected for the analysis of the true cost of rice. These two farms produce certified organic rice for the Lundberg Family Farms based in Richvale, California.

Benefits and costs of rice production
Benefits and costs associated with this production system are summarised below as an average of the two farms (see Appendix B for details).

Production value
Rice production is valued at $1632 per acre per year (6400 pounds/acre) with price of $0.25 per pound.

Environmental benefits
These include carbon sequestration in soil by incorporating rice straw and nutrient cycling from chicken manure addition. Rice straw annually adds about 1.7 tonnes of carbon ($15 per tonne of carbon). Chicken manure addition of 3.5 tonnes per acre adds large amount of nutrients worth $19 per year. Rice crops use 1.1 million gallons of water for consumptive use. Out of the total rainfall at the site, ground water recharge is estimated to be 2101 gallons per acre per year. By using the tap water price in the market at $0.006 per gallon, water regulation benefits are estimated as $12.60. Beans fix nitrogen through biological nitrogen fixation process, and this is estimated to be 40kg N per acre per year and is valued at the current price of nitrogen ($0.30 per kg N). Thus the value of nitrogen fixation is estimated as $12 per acre. These combined environmental benefits amount to $61 per acre.

Social benefits
These farms employ an average 18 staff and provide employment benefits of $368 per acre. There is some recreation and educational tours conducted on the farm that attract visitors from schools and environmental organisations. However, this information is not monetised due to lack of any monetary data.

Environmental cost
Environmental costs on this farm include greenhouse gas emissions associated with rice production from diesel use ($8.5 per acre), electricity ($9.22 per acre) and also tillage ($4.30 per acre). The combined environmental cost is $22 per acre.

Table 7. Benefit and costs associated with rice production.

	Benefits ($/acre/year)	Cost ($/acre/year)	Net ($/acre/year)
Production value	1632		
Environmental benefits	61		
Social benefits	368		
Environmental cost		22	
	2061		2039

True cost of rice: Value of production, environmental benefits, social benefits and environmental cost is calculated for each pound of rice from the above data and is provided in Table 8.

Table 8. Summary of benefits and costs per pound of rice.

	Rice ($/pound)
Production value	0.25
Environmental benefits	0.01
Social benefits	0.06
Environmental cost	-0.003
	0.31

8. Conclusions and Recommendations

These four case studies revealed the true cost of eight commodities which are associated with four different types of farming systems. The combined environmental and social benefits are proportionately higher in the diversified farm followed by the dairy farm cluster, rice farms and the corn/soybean farm. The diversified farm also generated very high social benefits as compared to the other four farming systems. The associated environmental benefits, social benefits and environmental costs are specific to the type of farming operation and should not be generalised from these four case studies.

The four farming systems investigated in this study are delivering more positive externalities than the negative ones due to the sustainable practices already in place at these farms. Therefore, in order to reflect the true cost of conventional production systems, there is need to include a greater number of farms and also include those farms that are using high amount of inputs and use intensive production systems such as confined animal feed operations, confined dairy systems, conventional tillage and high input farming systems.

Although data on all externalities is included in the current assessment, there is limited information on the public health impacts apart from the social cost of carbon, pesticide poisoning and some data on food safety. Therefore, the environmental and social costs category needs more attention, and further research is required to include monetary values on the impacts of pesticides, agrochemicals, antibiotic resistance, and the risks of human and animal diseases.

There are several gaps in the research literature on the greenhouse gas emissions of various management practices that need to be filled, in order to refine the methods used in this study. There is need to establish a bench mark by conducting a number of studies in each type of production system, such as organic, conventional, integrated systems under cropping and livestock production.

The results of this study can be used to influence sustainable farming practices and policies and also to raise awareness among consumers of the benefits and costs of various types of food and agriculture production systems. Some of the key recommendations are:

1. Farmers and practitioners can utilise this information to adopt technologies that have less detrimental impacts on the human health and the environment.

2. Consumers can make informed decisions to choose products that have higher environmental and social benefits and less environmental costs.

3. This study develops new farm sustainability assessment methods that reveal environmental benefits, social benefits and environment costs associated with different production systems. However, the research here should be developed further by conducting more studies to standardise and refine methodology in order to develop a uniform metric system that can be used by the food and agriculture industry as a label or a standard. These methods can supplement global assessments such as TEEB AgFood's project to investigate the benefits and costs of different farming systems worldwide.

4. Assessment and quantification of all externalities in production systems is needed and would help the policy community to understand the costs and benefits of various farming systems. This could help to shift support mechanisms towards sustainable production systems. This information could then can be used to develop long term sustainable food and agriculture production systems that could supply nutritious food in required quantities without impacting the environment and human health.

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Appendix

Appendix A

Ecosystem services categories assessed in this study are summarised in the table with brief description, examples and method for economic valuation used in each category.

	Types	Ecosystem services and disservices	Examples	Description	Method used for valuation
1	Production benefits	Crop, livestock, milk etc.	corn, soybean, milk, meat, eggs, timber, honey, maple syrup etc.	Provisioning services: These include food and services for human consumption, ranging from raw materials and fuel wood to the conservation of species and genetic material	Market value
2	Environmental benefits	Water regulation: Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, particularly in terms of the water storage potential	Permanent groundcover and permeable soil facilitates aquifer recharge; retaining water can decrease flooding during runoff peaks	Regulating services: Ecosystems regulate essential ecological processes and life-support systems through bio-geochemical cycles and other biospheric processes	Avoided cost
		Local climate regulation by carbon sequestration: Regulation of atmospheric chemical composition	Carbon sequestration by soil due to tillage practices, permanent pastures and by vegetation on farm.		Avoided cost
		Soil erosion control: Role vegetative cover plays in soil retention	Permanent pastures prevent soil erosion		Avoided cost
	Environmental costs	Greenhouse gas emissions	Carbon di-oxide equivalent emissions from inputs, tillage, fuel use, livestock on farm		Direct cost
		Damage to water resources	Infrastructure to treat pesticide and nitrate in water sources		Direct cost
		Damage to soil resources	Soil losses due to management practices		Replacement cost
		Damage to ecosystems and biodiversity	Loss of biodiversity and impacts on other species		Replacement cost
		Damage to human health	Pathogens and agrochemical that can enter food chain		Replacement cost

3	Environmental benefits	Nitrogen fixation	Biological nitrogen fixation by legumes in crops and pastures	Supporting services: These are the services that are required to support the production of other ecosystem goods and services	Avoided cost
		Nutrient cycling	Organic matter breakdown to release stored nutrients for crop use		Avoided cost
		Biological control of pests/diseases	Predators and parasites that control insect pests and diseases		Avoided cost
4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community	Farm workers, families	Cultural services: Cultural services contribute to the maintenance of human health and well-being by providing recreation, aesthetics and education	Market value
		Recreation: Recreational pleasure in agriculture	Farm tours, visits		Market value
		Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc	Knowledge generation and dissemination		Market value

Appendix B

1. Corn and soybean farm

	Types	Ecosystem services and disservices		Production quantity	Market price	Total value ($ per acre)
1	Production benefits		Corn	221 bushels/acre	$4 per bushel	884.0
			Soybean	69 bushels/acre	$10 per bushel	690.0
2	Environmental benefits	Water regulation	Corn	5600 gallons/acre water saved in deep drainage	$0.006 per gallon of water	33
			Soybean	4362 gallons/acre water saved in deep drainage	$0.006 per gallon	26
		Local climate regulation by carbon sequestration	By trees	1.22 tonnes/acre CO_2e sequestered annually	$15 per tonne of CO_2e	18.0

		Soil erosion control	-	-	-	-
	Environmental costs	Greenhouse gas emissions				
			MAP (32 kg/acre)	114 kg/ac CO_2e emission	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	4.83
			N,K2o,S Blend (77 kg/acre)	15 kg/ac CO_2e emission	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	0.63
			Potassium chloride (47.5 kg/acre)	27 kg/ac CO_2e emission	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	1.14
			In-row liquid starter fertiliser blend (14.3 kg/acre)	111 kg/ac CO_2e emission	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	4.7
			Pre-emerge broadcast application (76 kg/acre)	459 kg/ac CO_2e emission	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	19
			External cost of fertiliser use – see Appendix 3 for details on this category	1kg nutrient has external cost of $0.41 per kg	Total fertiliser use 246 kg per acre	101
			External cost Corn herbicide	1 kg a.i. has external cost of $46.03	1.2 kg ai /ac @ $46.03 per kg	55.23
			External cost Soy herbicide	1 kg a.i. has external cost of $46.03	0.5kg ai /ac @ $46.03 per kg	23
			Strip tillage	61 Kg CO_2e emissions per ac	$ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	2.6
			Gasoline use	7.8 litres/acre	21.06 kg CO_2e @ 2.7 kg CO2 e per litre of gas. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	0.9
			Diesel use	29.8 litres/acre	80.46 kg CO_2e per ac per yr 2.7 kg CO2 e per litre of diesel. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	3.4
			Electricity use	73 Kwh/acre	33 kg CO_2e per/ac. At 0.454 kg per kwh. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	1.4

			Corn	80,000 kernals = 43 pounds or 19.5 kg/acre	19.5 kg CO_2e emissions 1.05 kg C per kg of seed = 20.5 kgCO2/acre $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	0.86
			Soy	140,000 seeds=50 pounds or 22.7 kg/acre	22.7 kg seed CO_2e emissions 0.25kg C per kg of seed = 5.7 kgCo2/ac $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	0.24
3	Environmental benefits	Nitrogen fixation	By soybean	40kg N/acre	@ $0.30 kg N	12
		Nutrient cycling	-	-	-	-
		Biological control of pests/ diseases	-	-	-	-
4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community	Four employees over 790 acres	Average wage $26650 per workerW	Average worker manages 199	134
		Recreation: Recreational pleasure in agriculture	-	-	-	-
		Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc	-	-	-	-

2. Dairy farm cluster

Data is obtained from four dairy farms.

	Types	Ecosystem services and dis-services		Production quantity	Market price	Total value ($ per acre)
1	Production benefits		Milk	Average of four farm is 2377 (808 to 5416) gallons per acre)	$3.44 per gallon	8177
2	Environmental benefits	Water regulation	-	-	-	-
		Local climate regulation by carbon sequestration Methane capture	By trees By pasture By methane digester	1 tonne per acre 0.5 tonne per acre 575000 kwh electricity produced per year. 1266 MT per year CO_2e avoided CH4 emissions. 3.05 Mt per acre	$15 per tonnes of carbon 625 kg CO_2e per acre are avoided by producing electricity from methane use. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	15 7.5 26.43 130
		Soil erosion control	-	-	-	-
	Environmental costs	Greenhouse gas emissions				
			Milk production	9282 kg milk per acre per year	7425 kg CO_2e per acre per year @ 0.8 kg CO_2e per kg of milk produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	314
			Animal feed	26 ton per acre	5434 kg CO_2e per acre @ 209 kg CO_2e per tonnes of animal feed used. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	230
			Propane gas	38.75 litres per acre. With CO_2e of 2.3 kg per litre	89.7 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	3.75

			Diesel use	44 litres per acre. CO_2e of 2.7 kg per litre	118 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	5
			Electricity use	400kwh per acre. CO_2e of 0.45 kg per kwh	180.4 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	7.66
			Manure addition	15 cubic metre manure addition per acre	40kg CO_2e per cubic metre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	25
			External cost associated with manure	Treatment of surface water for microbial pathognes, manure spills, Cost of illness due to common food-borne pathogens, Cost to indutry to comply with HACCP	$1.85 per acre per year	1.85
			External cost associated with infrastructure management by various agencies	USEPA budget for non point source programme, USDA budegt for natural resources	$ 11.45 per acre per year	11.45
3	Environmental benefits	Nitrogen fixation	-	-	-	-
		Nutrient cycling	15.2 tonnes of liquid manure per acre	10% nutrients are utilised by pasture. Manure NPK (0.26 % N, 0.03% P, 0.03% K)	$0.30 kg N, $0.16 kg P, $0.24 kg K	138
		Biological control of pests/ diseases	-	-	-	-
4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community	Average acres per worker 25-166.	86 acres generates employment for one worker	Average wages 19000 to 54000 per worker per year.	490
		Recreation: Recreational pleasure in agriculture	About 11 farm tours organised per year	Attended by 214 people	Cost of travel $0.50 per mile distance travelled	0.90

		Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc	Speaking engagements	5 talks per year by one farm- Total $8.90 per acre	Average four farms	2.3

3. Diversified farm

	Types	Ecosystem services and dis-services		Production quantity	Market price	Total value ($ per acre)
1	Production benefits	Meat	Beef	243 lbs/acre	$1.60 per pound	389
		Meat	Pork	240 lbs/acre	$3.67 per pound	878
		Meat	Turkey	36 lbs/acre	$3.25 per pound	117
		Meat	Broilers	90 lbs/acre	$3.50 per pound	315
		Eggs	Eggs	50 doz/acre	$3.75 per doz	188
		Meat	Rabbits	0.8 head/acre	$28.5 per head	23
		Crop	Hay	0.32 tonnes / acre		32
		Syrup	Maple syrup	0.01 gallons/ acre	$116 per gallon	1.3
		Honey	Honey	0.042 gallons / acre	$100 per gallon	4.3
		Wood	Timber	70 board foot/ acre		67
2	Environmental benefits	Water regulation	Permanent pasture	1826 gallons/ acre water saved in deep drainage	$0.006 per gallon water price	10.95
		Local climate regulation by carbon sequestration	By forest By pasture By methane digester	2 tonnes per acre 4 tonnes per acre	$15 per tonnes of carbon	30 40
		Soil erosion control	Permanent pasture	Prevent soil from erosion	$50.3	50.3

	Environmental costs	Greenhouse gas emissions				
			Beef	110 kg per acre	13.44 kg CO_2e per kg of beef produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	63
			Pork	109 kg per acre	6.1 kg CO_2e per kg of beef produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	28
			Turkey meat	16.34 kg per acre	6.1 kg CO_2e per kg of beef produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	4
			Poultry meat	41 kg per acre	5.4 kg CO_2e per kg of beef produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	9
			Eggs	50 dozens per acre	3.7 kg CO_2e per kg of beef produced. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	8
			Animal feed	580 tonnes per year (Corn 1kg per kg	1kg CO_2e per kg of corn used, 0.25 1kg CO_2e per kg of sotbean used, 0.25 kg CO_2e per kg of oats used (social cost $ 42.3 per tonne of CO_2e)	16
			Diesel use	37 litres per acre. CO_2e of 2.7 kg per litre	100 kg CO_2e, Social cost $ 0.0423 per kg of CO_2e emissions	4.2

			Electricity use	200 kwh per acre. CO_2e of 0.9 kg per kwh	180 kg CO_2e, Social cost $ 0.0423 per kg of CO_2e emissions	7.6
			External cost associated with manure	Treatment of surface water for microbial pathognes, manure spills, Cost of illness due to common foodborne pathogens, Cost to indutry to comply with HACCP	$1.85 per acre per year	1.85
			External cost associated with infrastructure management by various agencies	USEPA budget for non point source programme, USDA budegt for natural resources	$ 11.45 per acre per year	11.45
3	Environmental benefits	Nitrogen fixation	Nitrogen fixed by legumes in pasture @30%	22.7 kg N fixed per acre	$0.30 per kg N	6.81
		Nutrient cycling	-	-	-	-
		Biological control of pests/ diseases	Animal disease suppression			14.37
4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community	1753 acres managed by 25 workers	Average wage $20,000 per worker	Each worker manages 70 acres	285
		Recreation: Recreational pleasure in agriculture	Visitors on farm, 16 per acre	16 per acre	Each visitor pays farm tour fees $5	80
		Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc	Knowledge generated on farming practices is disseminated through books, talks etc.	Information dissemination through books and talks.	Knowledge @ $171 per acre Scientific information @ $114 per acre	285

4. Rice farm

Data is obtained from two rice farms.

	Types	Ecosystem services and disservices		Production quantity	Market price	Total value ($ per acre)
1	Production benefits		Rice	Average of two farms is 6400 pounds per acre	$0.25 per pound ($0.33 and $0.18)	1632
2	Environmental benefits	Water regulation	Rice	1723 gallons water recharge per acre	$0.006 per gallon water price	10.33
		Local climate regulation by carbon sequestration Methane capture	Rice straw	1.7 tonne per acre	$15 per tonnes of carbon	25.50
	Environmental costs	Greenhouse gas emissions				
			Diesel use	74 litres per acre. CO_2e of 2.7 kg per litre	200 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	8.50
			Electricity use	242 kwh per acre. CO_2e of 0.45 kg per kwh	218 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	9.22
			Tillage		102 kg CO_2e per acre. $ 0.0423 per kg of CO_2e emissions (social cost $ 42.3 per tonne of CO_2e)	4.30
3	Environmental benefits	Nitrogen fixation	Beans	20kg N/ac/yr	$0.30 kgN	6
		Nutrient cycling	3.5 tonnes chicken manure	10.5 kg N, 4.5 kg P, 4.2 kg K	$0.30 kg N, $0.16 kg P, $0.24 kg K	19.20

4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community	Average acres per worker 74-140.	107 acres generates employment for one worker	Average wages 35700 per worker per year.	368
		Recreation: Recreational pleasure in agriculture	2000 to 5000 visitors per year			
		Education: Knowledge generated on farm can be disseminated to wider community through books, presentations at conferences etc	About 100 students visit to farm each year. Over 170 donations to charity, food organisations per year.			

Appendix C

External costs and benefits (quantity and values) used in calculations.

		Ecosystem services and dis-services		Quantity and/or Value	Reference
1	Production benefits	Grains, meat or milk produced per acre			Farm records and own calculations
2	Environmental benefits	Water regulation	Freshwater value per gallon	\$0.006 per gallon of water	Agricultural Resources and Environmental Indicators 2006 report
		Local climate regulation by carbon sequestration	Carbon sequestration	\$15 per tonne of CO_2e 1.22 tonnes/acre CO_2e sequestered annually in planted forest 4 tonnes per acre in natural forest	http://calcarbondash.org/ http://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references http://www.nrcs.usda.gov/wps/portal/nrcs/detail//?cid=nrcs143_014209
		Soil erosion control	Prevention of soil erosion by maintain pasture cover	\$50.3 per acre	Costanza et al. 1997, 2014
	Environmental cost	Greenhouse gas emissions	Social cost of CO_2e emissions	\$ 42.3 per tonne of CO_2e	http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html
		Fertilisers	MAP	3.55 kg CO_2e emission per kg	IPCC, 2006. Guidelines for National Greenhouse Gas Inventories 2006. Volume 3 Industrial Processes and Product Use, Chapter 3: Chemical Industry Emissions. Kool et al., 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization. Blonk Consultants. The Netherlands.
			N,K2o,S Blend	0.19 kg CO_2e emission per kg	IPCC, 2006. Guidelines for National Greenhouse Gas Inventories 2006. Volume 3 Industrial Processes and Product Use, Chapter 3: Chemical Industry Emissions.

			Potassium chloride	0.56 kg CO_2e emission per kg	IPCC, 2006. Guidelines for National Greenhouse Gas Inventories 2006. Volume 3 Industrial Processes and Product Use, Chapter 3: Chemical Industry Emissions.
			In-row liquid starter fertiliser blend	6.04 kg CO_2e emission per kg	IPCC, 2006. Guidelines for National Greenhouse Gas Inventories 2006. Volume 3 Industrial Processes and Product Use, Chapter 3: Chemical Industry Emissions.
			External cost of fertiliser use	1kg nutrient has external cost of $0.41 per kg	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20.
		Pesticide	Herbicide	1 kg a.i. has external cost of $46.03	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20.
		Tillage	Strip tillage	61 Kg CO_2e emissions per acre	West and Marland2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystems and Environment 91, 217–232
		Fuel	Gasoline use	2.7 kg CO_2e emissions per litre of gas	http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=9
			Diesel use	2.7 kg CO_2e emissions per litre of gas.	http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=9
		Energy	Electricity use	0.9 kg CO_2e emissions per kwh if 100% coal electricity. 0.454 kg CO_2e emissions per kwh if 50% is green electricity.	https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11
		Seed	Corn	1.05 kg CO_2e emissions per kg of seed	West and Marland2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystems and Environment 91, 217–232

			Soy	0.25 kg CO_2e emissions per kg of seed	West and Marland2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystems and Environment 91, 217–232
		Feed	Animal feed	209 kg CO_2e per tonnes of animal feed	FAO 2010. Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment. Rome.
			Milk production	0.8 kg CO_2e per kg of milk produced	FAO 2010. Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment. Rome.
		Manure	Mnure addition	40kg CO_2e emissions per cubic metre	FAO 2010. Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment. Rome.
			External cost associated with manure	$1.85 per acre per year	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			External cost associated with infrastructure management by various agencies	$11.45 per acre per year	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
		External cost associated with pesticide and fertilser use ($46 per acre per year)	Facility infrastructure needs for nitrate treeatment	$0.61 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Facility infratstructure needs for pesticide treeatment	$0.36 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations

			Cost to water industry	$1.79 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Cost to replace lost capacity of reservioirs	$10.15 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Water conveyance cost	$1.71 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Flood damages	$1.19 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Damages to receational activities	$6.01 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Cost to navigation: shipping damages, dredging	$1.04 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations

			Instream impacts: commercial fisheries, preservation,	$2.33 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Off stream impacts: industrial users, steam power plants	$1.03 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Cost of green house gas emissions from cropland	$0.92 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Honey bee and polination losses	$1.32 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Loss of beneficial predators by pesticides application	$2.15 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Fish kills due to pesticides	$0.12 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations

			Bird kills due to pesticides	$0.11 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			Pesticides poisioning	$3.26 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USEPA budget for non point source programme	$0.49 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USEPA budget for reduce public and ecosystem	$0.07 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USDA budegt for natural resources	$4.07 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USDA budget for farm advisory	$6.36 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations

			USDA budget for food safet y	$0.07 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USDa plant safety	$0.46 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USDA microbiological data	$0.01 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			EP safe food programme	$0.28 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USEPA reduce public and ecosystem risks	$0.09 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations
			USDA pesticides data programme	$0.05 per acre	http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx Tegtmeier E.M, Duffy M.D 2004 External costs of agricultural production in the United States. Int. J. Agr. Sustain. 2, 1–20. Own calculations

3	Environmental benefits	Nitrogen fixation	By soybean	40kg N/acre @ $0.30 kg N	Herridge et al. 2008. Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil (2008) 311:1–18 Own calculations
		Nutrient cycling	NPK (0.26 % N, 0.03% P, 0.03% K),	@ $0.30 kg N, $0.16 kg P, $0.24 kg K	FAO 2010. Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment. Rome.
		Biological control of pests/ diseases	Avoided cost of pesticide use	$20 per acre per year in animal diseases	Farm records and own calculations
4	Social benefits	Employment: Employment generated on farm leads to benefits to wider community			Farm records and own calculations
		Recreation: Recreational pleasure in agriculture			Farm records and own calculations
		Education: Opportunities for non-commercial uses			Farm records and own calculations

Further information

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