



Valuation of livestock eco-agri-food systems: poultry, beef and dairy

W. Baltussen, T. Achterbosch, E. Arets, A. de Blaeij, N. Erlenborn, V. Fobelets, P. Galgani, A. De Groot Ruiz, R. Hardwicke, S.J. Hiemstra, P. van Horne, O. A. Karachalios, G. Kruseman, R. Lord, W. Ouweltjes, M. Tarin Robles, T. Vellinga, L. Verkooijen



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TEEB asked for the assessment of the impact of global livestock production systems on human systems and ecosystems. Poultry, beef and dairy production system have been analysed. The analysis shows that in many cases the negative externalities of livestock production are higher than the consumer price paid for the products.

TEEB heeft gevraagd naar een analyse van het effect van veehouderijsystemen in verschillende delen van de wereld op de maatschappij en ecologische systemen. Voor pluimvee, rundveehouderij en melkveehouderij zijn analyses uitgevoerd. De analyse laat zien dat de maatschappelijke kosten vaak hoger zijn dan de consumentenprijs van de veehouderijproducten.

Key words: Livestock, poultry, beef, dairy, true price

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P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30

E communications.ssg@wur.nl, <http://www.wur.eu/economic-research>

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Authors

W. Baltussen¹, T. Achterbosch¹, E. Arets², A. de Blaeij¹, N. Erlenborn⁴, V. Fobelets⁴,
P. Galgani⁴, A. De Groot Ruiz⁴, R. Hardwicke⁵, S.J. Hiemstra³, P. van Horne¹, O. A. Karachalios⁴,
G. Kruseman¹, R. Lord⁵, W. Ouweltjes³, M. Tarin Robles⁵, T. Vellinga³, L. Verkooijen⁴

¹ Wageningen Economic Research

² Wageningen Environmental Research

³ Wageningen Livestock Research

⁴ True Price

⁵ Trucost

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Executive summary

Executive Summary

Introduction

The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative that helps decision-makers recognize the wide range of values, including economic, provided by ecosystems and biodiversity, so once those values are recognized they can filter down into decision-making. TEEB has conducted an agriculture and food study (TEEBAgriFood study) to bring together economists, business leaders, agriculturalists and experts in biodiversity and ecosystems to provide a comprehensive economic evaluation of eco-agri-food systems, and demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of dependency on natural capital. Indeed, a 'double-whammy' of economic invisibility of impacts from both ecosystems and agricultural and food systems is a root cause of increased fragility and lower resilience to shocks in both ecological and human systems.

As input for the TEEBAgriFood study, TEEB asked for a series of studies on livestock, rice, palm oil, inland fisheries and agro-forestry. This report deals with livestock production and aims to improve decision-making in livestock production policies, to enhance its viability, not just economically but also socially and environmentally. Livestock sector is important because they have high externalities and

it is expected that livestock consumption will be 76% higher in 2050 compared to 2005 (Alexandratos and Bruisma, 2012) because of population growth, income growth, urbanization and preference shifts. This report aims to provide evidence that will help to identify policy options for the transition towards increased food security with sustainable livestock production systems, with particular emphasis on the role of smallholder farmers.

This study started with the following specific research objectives:

- Assess the visible and invisible values of biodiversity and ecosystems to the various types of agriculture systems (inputs) and evaluate the scale, range and degree of both positive and negative impacts of livestock production systems on ecosystems, health and livelihoods (outputs);
- Explicitly address the role of smallholder farming, and contrast it with an assessment of one large-scale system;
- Use a differentiated approach that looks at major segments of society, such as rural and urban populations, developed and developing countries, as well as gender;
- Include Tanzania as a study site for the purpose of evaluating a pastoralist system in order to complement the TEEB Tanzania country study.

Method

The aim of this study is to assess the positive and negative socio-economic and environmental effects of livestock production systems, from both global and national perspectives, using a methodology based on a framework developed by TEEB. The methodology is driven by the notion that the valuation of the costs and benefits derived from livestock can be approached in two ways: a top-down approach and a bottom-up approach (see [figure S.1](#)). The valuation of costs and benefits follows the principles of environmental economics,

implying that those aspects are quantified in economic terms.

The top-down approach is a high-level analysis that identifies key geographical hotspots and material natural capital impacts. The top-down analysis is a valuation for the production of each commodity at a country level, with no differentiation between farming systems. This type of analysis makes it possible to determine the impact of livestock sectors worldwide. In this sense, a top-down

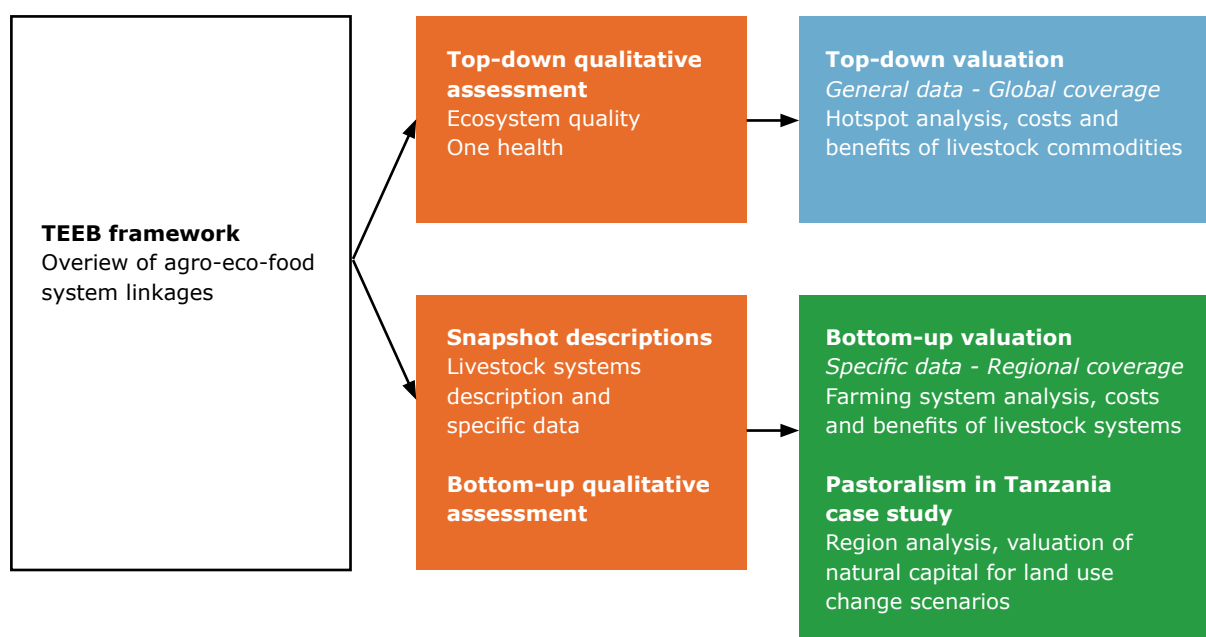


Figure S.1 Overview of methodologies used to assess the impact of livestock production systems on socio-economic systems and ecosystems.

approach can be informative for decision-making with a large geographical scope.

The bottom-up approach goes into more detail and complements than the top-down approach. The bottom-up approach assess the impacts upstream till farming gate and excludes the impacts from processing and consumption. Therefore, the authors have selected a set of livestock production systems for poultry, beef and dairy called 'snapshots'. Data are collected and used in the analysis to monetize the economic, social and environmental values and impacts of the different livestock production systems.

A bottom-up approach can act as the foundation for decision-making within a specific geographical scope. This report also uses an in-depth case study to look at natural capital-human systems linkages for one of the selected livestock production systems (pastoralism in Tanzania) in a holistic manner. This analysis quantifies many dependencies on ecosystem services simultaneously and looks at local externalities using a time-explicit model. The in-depth case study is an example of how a detailed bottom-up valuation can show the invisible value of natural capital to the human economy in a given region.

Findings

The findings are divided and presented by method, beginning with the findings from the top-down approach, and followed by the ones from the bottom-up approach. Finally, the case study is provided.

Findings from the top-down approach

Natural capital costs

- Natural capital costs express in monetary terms the impacts on natural capital that are produced by livestock systems, as a result of resource use and pollutant emissions (units in US\$). Natural

capital costs include the impact of supply chain (upstream) and operational (farming) activities on six natural capital impact categories: GHG emissions, air pollutants, water consumption, water pollutants (from fertilizers application), soil pollutants (from pesticides application) and land-use change.

- The total natural capital cost of beef, dairy milk and poultry meat have been calculated by considering all producing countries, and thus represent the impacts of those sectors at a

global scale. Beef production is the sector with the greatest impact on natural capital worldwide. The annual total natural capital cost of beef production (which is 1.5US\$ trillion) is three times higher than that of dairy milk production (0.5US\$ trillion) and approximately six times higher than that of poultry meat production (almost 0.26US\$ trillion).

- For all producing countries, the share of the operational impact to the total natural capital cost is approximately 78% for beef, 65% for dairy milk and 29% for poultry meat. Thus for beef production the natural capital impact is mainly associated with the direct operations, while for poultry it is mainly associated with the upstream supply chain. This can be attributed to the lack of enteric fermentation, the low land requirements for poultry production associated with its direct operations, and the higher use of feed cultivated off farm and thus acquired as part of supply chain activities. Compared to beef, for dairy milk production the higher impacts occur in the supply chain as dairy systems rely more on purchased feed than beef systems, which have a greater impact on the supply chain.
- The share of the total global natural capital cost for the top-five contributing countries is 50% for beef (Brazil, United States, China, Argentina and Mexico); 39% for dairy milk (United States, India, Brazil, China, Russian Federation); and 43% for poultry (United States, Brazil, China, Indonesia, Russian Federation). EU28 contributes 8%, 19% and 11% of the total natural capital cost of beef, dairy milk and poultry production respectively. This estimate is only for upstream and production and does not include consumption.
- Variation in natural capital costs between countries can be explained by:
 - The total number of animals under production;
 - Efficiency of livestock production systems (resource use or emissions per tonne of production);
 - Natural capital valuation coefficients (for example, the value of the ecosystems present in the country).

Natural capital intensities

- Natural capital intensities express the natural capital cost per protein content (units in US\$/kg protein). This metric makes it possible to identify the commodity that provides the greatest amount of protein with the lowest impact on natural capital.

- When determining the average natural capital intensity (considering all producing countries), beef has a higher natural capital intensity than poultry. This result is caused by higher GHG emissions and land-use change associated with beef production.
- The average natural capital intensity of EU countries is lower than the global average. This is partly due to a more efficient production system.

Types of natural capital impacts

- For beef and dairy milk, land-use change is the most important natural capital impact (contributing 72% and 62% of the natural capital intensity, respectively) followed by greenhouse gas emissions (20% and 22%, respectively) when considering all producing countries. In the case of poultry meat, GHG emissions (39%) and land-use change (36%) represent the largest natural capital impact.
- The contribution of water pollution, water consumption and soil pollutants is on average small compared to the other impacts, in total less than 5% of the total natural capital costs for all species.

Benefits

- The provision of food represents one of the most significant benefits to society provided by livestock. Furthermore, livestock systems can enhance a wide range of regulating, supporting and cultural services, for example soil carbon sequestration (regulating service), the connection of habitats for plant species through seed dispersal in seasonal grazing systems (supporting service) and the enrichment of cultural identity through the role of livestock in social and spiritual activities (cultural service).

Biodiversity impacts and dependencies of livestock production

- Livestock production affects biodiversity in many different ways, the impact of which differs in type and magnitude depending on local conditions. The impact is predominantly negative, although some positive externalities exist as well, especially in extensive livestock grazing systems, such as pastoralism. Yet local management practices can be used to alleviate the negative impacts or restore biodiversity.

One health: animal and human health

- Livestock production systems have a huge direct and indirect impact on human health. This

impact can be a positive or negative externality. Animal protein is an important part of the human diet. Zoonoses (animal diseases) can endanger human health, as can the use of antibiotics in animal production systems.

- Good indicators to quantify the relation between animal diseases and human health are currently lacking. This is partly due to a lack of knowledge and data in both the developed and developing world. However, sufficient information is available to underpin the above statements.
- The relation between animal health and human health can differ among species which can influence the hidden costs per species.

Findings from the bottom-up approach

Following are the key findings of the bottom-up analysis of ten livestock production systems in four countries:

Overall findings

- The environmental externalities of animal protein production are a large invisible cost. The comparison of carbon externalities with the retail price of livestock products shows that these can account for 1%-143% for beef, 19%-161% for milk and 19%-37% for poultry. Water pollution costs go from less than 1% to up to 25% of the product prices and show a high variability due to local environmental conditions. This implies that diversity is high but society as a whole nevertheless pays a significantly larger price for animal protein consumption than the retail price paid.
- Beef farming has much larger natural capital costs per kg of protein compared to poultry farming; mixed dairy farming, which also produces beef, has lower external costs than pure beef farming. This holds for all the environmental impacts considered, namely greenhouse gases (GHG), land occupation and water pollution.
- Chicken meat production requires the smallest amount of land per unit of animal protein produced because of its favourable feed conversion rate and absence of grazing. Mixed systems in dairy farming also occupy relatively smaller amounts of land, especially where productivity

is high or reliance on grazing and imported feed is low. Extensive cattle systems result in the highest land occupancy as their primary source of feed is pasture grazing. Indeed, some of these areas, used by extensive cattle systems, support no other agricultural activity. However, land occupancy can be better understood if viewed alongside the impacts on biodiversity and local communities that each production system has within its specific region.

Snapshot findings

- The production of beef as a 'side' product of intensive dairy farming with a high animal replacement rate is an alternative comparable to poultry in terms of the low impact on natural capital. This system, explored in its Dutch variation, appears to have land occupation and GHG emissions comparable to poultry, due to the system's high efficiency. There are two important caveats to this conclusion: the first is that the quality of meat produced in this system may not be comparable to that of pure beef-focused extensive systems, and it is more suitable for ground meat products. The second conclusion is that due to the high animal density, and import of nutrients, the Dutch system has a high water pollution cost and a very high nutrient leaching per hectare, the largest of all snapshots. A low water pollution cost per unit of output still translates into a very high nutrient load per hectare.
- The study of alternative beef systems in Brazil shows that improved pasture management and finishing in feedlots can reduce GHG natural capital costs by up to 20% and land use by 37%. An analysis of water pollution externalities reveals that while improved pasture management reduces water pollution, finishing in feedlots increases it compared to pure grazing systems. The net result is still positive for finishing in feedlots.
- Backyard chicken rearing is found to have an environmental profile similar to that of more developed poultry systems, in terms of GHG emissions and water pollution, while it provides animal proteins at a lower cost in terms of land occupation and blue water use*.

* Water use is often split into green water, blue water and grey water. The blue water footprint refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (see [Mekonnen and Hoekstra, 2010](#))

- Pastoralist systems generally have lower natural capital efficiency than other cattle systems, and land requirements are especially high. However, as opposed to feed-based or pasture-based systems, pastoralism can reap benefits from semi-natural ecosystems without seriously negatively affecting biodiversity and natural capital, as highlighted by the in-depth case study on pastoralism and landscape preservation in Tanzania.

Biodiversity impacts and dependencies of livestock production

- Livestock has both a direct and indirect impact on biodiversity. The direct impact through trampling and grazing and defecation appears to be smaller than the indirect impact through land-use change (deforestation) and intensification of the land use creating homogeneous pastures for grazing and croplands for feed production, and climate change resulting from emissions of methane and other greenhouse gases.
- In poultry, and more intensive industrial-scale livestock production systems, the relation between land use and its impact is more obscure. Although these systems are sometimes called 'land-less' production systems, this is a misleading term. These systems still rely on (distant) cropland for production of the concentrated feed they import, spatially disconnecting the livestock and an important part of its impacts.
- Intensification of livestock production is an important trend resulting from the increasing demand for animal protein. Intensification involves a further concentration of resources (financial, labour and nutrient inputs) to produce more livestock on the same unit of land. As a result, intensification can influence livestock's impact on biodiversity and natural capital in different ways. Locally the impact of more intensive production will increase; at the same time demand for feed will increase, leading to a higher distant impact. If, however, this increase in intensity is accompanied by better production efficiency, i.e. more kilograms of protein (or meat, milk or eggs) per unit of input, then the overall biodiversity impacts per unit of protein product may decrease. Because it is not always possible to increase efficiency, as it depends on factors like local growing conditions, this does not mean that intensification is a solution under all circumstances.

Animal and human health

- There is variation in the use of antibiotics within and between species. In general, intensification of livestock production goes hand in hand with an increase in the use of antibiotics, and in poultry antibiotics are used more frequently than in cattle production per kg of protein produced. However, there are mitigation strategies that enable a mix of intensive production and low input of antibiotics.
- Zoonoses exists in all regions and animal production systems. The impact of food-borne diseases and non-alimentary zoonoses (like Q-fever in the Netherlands) is more or less unknown.

Findings from the case study

Following are the findings from the case study on pastoralism and landscape preservation. They add an additional layer to the bottom-up valuation of the snapshot regarding the pastoralist beef system in Tanzania. An analysis of the internal value of natural capital takes a regional approach to provide a closer look at what other benefits pastoral rangeland ecosystems provide to human populations in the Maasai Steppe, beyond meat and milk production. The expansion of farmland brings income to settlers, both traditionally nomadic local populations and migrants from other regions, but it has a negative impact on pastoralists and wildlife. Cropland encroaches upon migratory routes and the most fertile grazing areas are claimed by agriculture. Furthermore, as land in the Maasai Steppe is generally arid and not particularly suited for farming or keeping concentrated livestock, agriculture is characterized by low productivity and declining soil fertility.

- The discounted internal natural capital value (discount rate = 3%) of the Maasai Steppe, valued looking at final ecosystem services to the Tanzanian population, is estimated to be US\$2.7 billion if the conversion from pastoral rangeland to mixed crop and cattle farming occurs at high speed, US\$3.3 billion if it occurs at medium speed, and US\$4 billion if it occurs at low speed.
- Livestock production provides the largest share of benefits from ecosystems for the local population in the Maasai Steppe. Pastoralism and sedentary farming both contribute equally to this value creation, mainly through food production, although skins and hides are also marketable products.
- Two other large components of natural capital value in the region today are contributions to crop farming and tourism. A literature study

reveals that these two activities are in competition, as expansion of farmland threatens wildlife migration corridors, negatively affecting animal populations, which in turn have significant touristic value.

- Other forms of direct value creation from ecosystems and biodiversity are raw materials, wild food such as vegetables and roots, medicinal herbs, drinking water, and forest products such as timber, charcoal, firewood, tree gum, honey and beeswax. These goods have a lower market value but can still constitute an important means of subsistence for the local population.
- A comparison of three scenarios of land conversion from rangeland to mixed crop and cattle farming at different speeds reveals that a faster conversion from pastoralism to agriculture leads

to less ecosystem value in the long run, although farming has the highest value in the short term. This result is attributable to the negative effect of mixed crop and cattle farming on pastoralist access to grazing lands and on wildlife populations in national parks, together with the unsustainability of current mixed arable livestock systems in the region.

- Additionally, carbon emissions due to land-use changes are also an important externality of conversion of rangeland to agriculture, estimated to range from US\$15 billion in a low speed scenario to US\$24 billion in the high speed scenario. Expanding the analysis to carbon stocks confirms that the interests of the global communities are aligned with the local community, as global communities will also benefit from a slower rate of conversion.

Conclusions

The livestock sector is a major contributor to the global ecological footprint. The global demand for animal products will grow further in the next decades due to expanding human populations and the average increase of meat consumption per person. Existing scenarios estimate global demand in 2050 to be 150% to 200% of what it was in 2010.

The question is whether this growth will further deplete natural capital worldwide, or whether we will be able to enhance the production of animal protein and simultaneously reduce the loss of natural capital. This study – the first of its kind to apply natural capital valuation on a large scale to livestock production worldwide – analyses cattle and poultry production at a global level but also in different countries for specific production systems, climatic zones and under different levels of intensification. The impact of livestock systems on social, economic and environmental issues has been quantified where possible. When there is no reliable data, the authors provide a qualitative assessment based on scientific literature.

The big picture is clear: animal products are under-priced. Climate change, the loss of ecosystems, water pollution, and the impact of water shortages are only some examples of the costs derived from livestock production that were calculated in this study and are ultimately borne by society. We estimated these costs for cattle and

poultry to be 2.28×10^{12} US\$ per year (2.28US\$ trillion) worldwide, most of it due to beef production.

In order to understand the implications of this growth we have to analyse specific livestock systems in more detail. The implications for natural capital of high-input, specialized livestock systems on the medium and large scale are reasonably well documented and understood. These systems reach high productivity levels and rely largely on external inputs, such as purchased feed, capital and medicines. These highly specialized systems could potentially feed large urban populations as they can be easily scaled up.

It is well known that the production of chicken and milk proteins have a much lower natural capital impact than the production of beef per kg of animal protein, so it is likely that internalizing external natural capital costs would shift diets towards poultry and dairy. At the same time, there is room for livestock systems to reduce the natural capital costs per kilogram of protein, especially for smallholder livestock systems, which are a major contributor to the world's food supply. The more intensive dairy systems are more efficient at this moment but also more closer to maximum efficiency and the potential for improvement are therefore less.

We found substantial diversity in the regions we studied in terms of productivity, impact on climate, water quality and biodiversity, as well as a high potential for improvement. This potential can be realized by understanding the options available based on local conditions, measuring the impacts and developing and disseminating best practices. Local conditions that should be taken into account include access to markets, inputs and knowledge, but also local climate, local ecosystems and availability of crop residues. Especially in ruminant systems, there is a double benefit, because intensifying systems will increase production and reduce the GHG emissions per unit of product. Thus, food security and mitigation can go hand in hand with livestock intensification in many smallholder systems the output can be strongly increased by small increase in inputs (like knowledge, feed or antibiotics). This is especially the case for smallholder systems in Asia and Africa.

This study also looked at several subsistence systems. Pastoral cattle and backyard poultry do not require much input, but have a low output level per animal and low efficiency per kilogram of protein. However, not only do subsistence systems supply food to the most vulnerable populations, they are also well adapted to local constraints, have many side benefits for local poor communities, and usually have a very low or even positive biodiversity impact. Though these aspects of subsistence livestock production are not yet well understood, they are important. For example, a case study of the Maasai Steppe in Tanzania showed that pastoralism can conserve measurable ecosystem services and natural capital value, especially if the alternative is farming that will

eventually lead to land degradation. The pastoralist systems are under pressure, especially in rural areas in developing countries. The importance of subsistence systems for the poor should be made visible in more contexts and basic improvements in terms of food security and productivity should be pursued.

The message is clear: the growth of the livestock sector presents many risks for natural capital, but there is much that can be done to tackle these risks. It is possible to produce animal products for the world population without losing this form of wealth, if the right path is followed. First, natural capital has to be fully measured, as its visibility is a requirement for its conservation. Second, a single livestock production system alone cannot supply animal products to the whole world. The entire range of livestock systems would need to contribute to feed the future world population with animal proteins. Therefore, the right improvements need to be identified and pursued for each context, using a suitable, location-specific approach. The links between livestock, ecosystems and society needs to be valued and understood at the regional level. Finally, livestock systems are key components of agro-ecosystems and under specific management practices can enhance the provision of ecosystem services. Therefore, mechanisms have to be developed to internalize external costs and encourage good agricultural practices, without affecting food security for the poor. Internalization will help market forces to steer the food sector down a more sustainable path, where natural capital wealth is leveraged to create wealth for the current as well as future generations.

Policy recommendations

Based on these findings, we have identified the following policy recommendations:

Pay the full price without affecting food security

- Negative externalities should be internalized in the price of animal products, without affecting food security. This can be done, for example, via voluntary commitments, environmental taxation or environmental regulation. However, these measures should not increase food prices for vulnerable shares of the population. Internalization of negative externalities will help to steer the livestock sector down a path that

minimizes the loss of natural capital.

- The positive externalities of livestock production – from managing landscapes to supplying organic fertilizer, from animal traction to fulfilling cultural functions – should be rewarded. These rewards should at least consist of fully recognizing any type of social cost-benefit analysis, and at best offer payment for ecosystem services schemes. If positive externalities remain invisible and co-benefits are not encouraged, desired improvements of agricultural systems may lead to unwanted side effects. If invisible but important positive externalities disappear, as a result of agricultural develop-

ment, the economic losses for the beneficiaries of these co-benefits could be larger than the benefits due to these innovations.

Consolidate valuation of natural capital

- An important requirement for internalization is that natural capital be consistently measured. Governments should encourage dialogue between different stakeholders, such as international organizations, NGOs, companies and investors, in order to create a standardized valuation framework that would make it possible to monetize different costs and benefits that affect human well-being as well as the ecosystem and biodiversity. This framework will make it possible in the future to simultaneously capture the hidden costs and benefits of livestock systems and the visible costs and benefits, and that, in turn, has given decision-makers the opportunity to start embracing sustainable livestock production practices. The Livestock Environmental Performance and Assessment (LEAP) project aims to build consensus between different stakeholders (governments, the private sector, NGOs and CSOs) on how to measure the environmental impact of livestock. Furthermore, the Natural Capital Coalition and The Sustainability Consortium (TSC) are great examples of progress in this regard, which can be applied to different industry sectors, not only livestock.

Improve livestock production systems

- Scenario studies show that increased animal protein production is possible without increasing natural capital costs. Governmental environmental programmes and reduction initiatives should focus on material natural capital impacts identified in this study, such as GHG emissions, land use and water pollution. In this sense, developing and promoting good agricultural practice could contribute greatly to reducing the impact of livestock. For example, improving manure management or animal diet would decrease GHG emissions of livestock. On the other hand, avoiding the excessive fertilization of feed crops (for example through precision agriculture) as well as promoting appropriate manure management would decrease nutrient

run off and thus pollution of water bodies associated with livestock production.

- One of the most important options is increasing the production per unit of land and per animal, so more animal proteins can be produced with less input, such as water, minerals, antibiotics, land and energy. This would also decrease the natural capital costs per kilogram of animal protein. Sometimes, improving efficiency goes hand in hand with an increase in scale of farms and the risks of increasing negative impacts like the leaching of minerals, the misuse of antibiotics, or the outbreak of zoonotic diseases. For example it was highlighted that in the case of Brazilian grass-fed cattle, the introduction of a finishing period in feedlots can increase output and improve GHG and land intensity, but it would also have some costs related to additional water pollution. Good farming practices like improving pasture management, improving animal health or soil fertility management where feed is produced, should be put in place to increase the production without increasing the negative impacts. Improvement options for smallholders must be assessed and identified on a regional basis. In general, technical knowledge should be shared between countries with dedicated platforms, so that the good technology and good farming can be applied to decrease natural capital impacts. Special attention should also be given to the adaptability of those techniques to local conditions. This is particularly important as several BRIC and developing countries are becoming key worldwide livestock producers as a result of rising incomes. For example, Brazil and China are key global contributors to the total natural capital cost for the three livestock commodities analysed, partly due to high production quantities.

Healthy diet: our role as consumers

- Governments should start a dialogue on the links between consumer behaviour, change in diets and natural capital preservation. According to the results of this study, diets that would substitute beef with chicken consumption are beneficial from a natural capital point of view. This holds at the margin until the point where grassland has no alternative agricultural use.

Agenda for future research

This study has tried to help answer the question how we can sustainably feed the global population with animal proteins without increasing natural capital costs. Still, this question has many more dimensions than those addressed here. Future research should continue to look systematically at the positive and negative impacts on natural capital of livestock production value. This will require expanding the scope and including in the equation issues that have been left out until now. The extended TEEBAgFood framework can be used as a basis to guide an economic evaluation of the eco-agri-food system as a complex, highlighting economic distortions, hidden external costs and dependencies on natural systems. The framework overcomes the problems of seeing nature, agriculture and the food system as distinct from each other by mapping their interconnections in a comprehensive way.

Following are some important questions that need to be addressed in the future:

- This study has focused on livestock production systems worldwide. The next step is to systematically compare alternative livestock systems and potential improvements, because it will yield insights that can be directly used in decision-making. Substitutability happens when systems operate in the same geography or produce the same products for the same market and one can be scaled down and the other scaled up to some extent.
- This study has highlighted the fact that livestock production exists not only in complex interrelation with natural ecosystems, but also with nearby and faraway crop systems. Looking in more detail at mixed arable livestock systems as a whole can reveal the full benefits of integrating these two activities, which is common practice for smallholder farmers all over the world. This type of complex research faces methodological and data availability challenges, but offers a unique perspective in linking food production and natural capital regeneration from an economic, ecologic and agronomic perspective.
- Smallholder agriculture feeds a significant part of the world population, but whether and how this can be leveraged for natural capital conservation and enhancement is not always clear to policymakers. Research linking the economic and social development aspects of smallholder agriculture with environmental considerations is necessary in this regard. Monetary valuation is one of the key tools to understand and compare these interrelations. We recommend integrating economic, social, and environmental aspects in research on smallholder agriculture in the same way as it is often performed in family and large scale farming. This kind of research would be useful in understanding the costs and benefits of intensification and examining trade-offs between income and natural capital.
- Not only can livestock and agricultural systems provide food, but they can also manage landscapes to increase their value in multiple ways. The innovative land valuation framework applied to East African pastoralism can be applied to investigate the value of natural capital assets in other agricultural, natural and semi-natural ecosystems. Research that seeks to systematically identify and calculate the internal and external natural capital value of key food-producing regions in the world and the value of sustainable landscape management should be strengthened. This requires additional efforts to gather reliable regional data on the natural goods and services grown and used on a specific type of land (provisioning ecosystem services such as water supply and agricultural products) and of the sustainability over time of these benefits (related to deforestation, water stress and land degradation trends).

To explore
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Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

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The mission of Wageningen University and Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.