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FCRN foodsource

A free and evolving resource to empower informed discussion on sustainable food systems

Building Block

What is environmental efficiency? And is it sustainable?

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Contents

Why should you read this building block?

The concept of efficiency and its relation to food sustainability is defined and valued in different ways. Among those who argue that improved efficiency will lead to greater sustainability, there are different interpretations of what improved efficiency actually means. Others still, view the quest for efficiency itself to be problematic and its relationship with sustainability potentially oxymoronic.

This building block is based on the FCRN report Lean, green, mean, obscene...? What is efficiency? And is it sustainable? It introduces the concept of efficiency and explores its relation to food system sustainability.

1. Introduction

Efficiency, broadly construed, denotes the goal of achieving more, with less. The concept has a long history and has been around as a business and manufacturing principle since at least the industrial revolution[1].

Influenced by the development of environmental life-cycle assessment (LCA) (which itself has its origins in industrial engineering[2]), ideas about efficiency started to be applied to discussions about environmental sustainability in relation to the food system since the late 1990s[3,4]. The assumed starting point for many discussions about environmental efficiency is that we need to produce more food to meet the demands of a growing world population, but in ways that generate fewer environmental impacts per amount produced (this interpretation of efficiency is closely linked to a common perspective on Sustainable Intensification).

This understanding of environmental efficiency in the food system, however, is contested. There are different definitions of what efficiency is based on different understandings of what inputs to and outputs from the food system are to be valued; and more broadly on what the goals for the food system are and should be[3]. Some point out that efficiency does not inherently lead to sustainability while others emphasise the need for the food system to be '***resilient***' rather than 'efficient'.

This building block explores the concept of efficiency and the contestations around its use in discussions about food system sustainability.

2. What is efficiency?

2.1 A basic definition

In its most basic form, efficiency denotes a ratio between *inputs* and *outputs*. The Oxford English Dictionary provides the following definition:

> *[Efficiency is] the ratio of the useful work performed by a machine or in a process to the total energy expended or heat taken in*[5].

Applied to food, efficiency, here, can be understood as the ratio between inputs (such as seed, feed, fertiliser and labour) and food output. In debates on environmental sustainability in the food system, critics argue that this is too narrow a definition of efficiency because it externalises environmental impacts. Historically, they point out, a focus on this form of efficiency has contributed to high environmental impacts through the global spread of intensive agriculture and its reliance on chemical fertilisers, pesticides, and irrigation.

Fostered by concerns about the environmental impacts of food production and by the development of environmental LCA (see our chapter on LCA)[3], the efficiency concept has been broadened to include not only inputs and outputs, but also a third variable, environmental impacts. This expanded definition is often referred to as *environmental efficiency*[3].

2.2 Efficiency and environmental LCA

The use of environmental LCA has helped intensify a focus on environmental efficiency in the food system because it has enabled the environmental impacts of different food products and different production systems to be calculated and compared in a systematic way[4,6].

Environmental LCA calculates the amount of a given environmental impact (for example kg CO_2-eq emitted or litre water used) that is generated during the life cycle of a unit of useful output. Examples of impacts that are calculated using environmental LCA include climate impact, ***acidification***, ***eutrophication*** and the use of resources such as land, energy and water. Impacts can be generated at different stages of the ***life cycle*** and result from the use of inputs as well as from the production, use, or disposal of outputs[3]. A sub-set of environmental LCA is the carbon footprint assessment, which takes an LCA approach but only considers greenhouse gases[7].

In recent years, attempts have been made to include the social impacts of production systems in LCA. Referred to as social LCA, these assessments consider, for example, human rights violations or impacts upon ***livelihoods***[8].

The unit whose impacts an LCA calculates is called its '***functional unit***' – common examples in relation to food are 1 kg of beef, 100 calories of food, or 1 ha of land[3]. Importantly, the choice of functional unit and the environmental impacts that are being assessed affect an LCA's results, and ultimately influence views of what may be thought to be efficient[3,9]. For example, an LCA comparing ***GHG*** emissions associated with the production of 1 kg of beef and 1 kg of milk by weight, will differ from one that compares their emissions in terms of protein output, or that looks at, for example, the ***ecotoxicity*** or land use.

3. What are inputs, outputs and impacts?

Those working on the environmental dimensions of food system issues sometimes argue that the challenge we face can be expressed as the need to increase the quantity of food produced (the *output*) both relative to the *inputs* to the production process (such as land or fertilisers) and to the generation of environmental *impacts* (such as GHG emissions). However, reflecting their goals and values, stakeholders classify different things as inputs, outputs and impacts, and prioritise differently among trade-offs. For example, for some the use of synthetic fertiliser may be an unacceptable violation of ecological principles, whereas for others this is a legitimate agricultural input that could potentially greatly increase yield levels and therefore reduce land use pressures. Others argue that the entire premise of efficiency is misguided and that we do not need to be producing more food per se: what we need is a resilient food system that provides multiple outputs, including adequate nutritious food, ***biodiversity conservation***, and sustainable rural economies that, amongst others, provide a livelihood for smallholder farmers. They may also argue that the drive for efficiency perpetuates existing problems such as nutrient pollution or soil erosion, and engenders new ones as in the case of antimicrobial existence linked to the use of antibiotics in livestock systems (read this Foodsource chapter on the connection between infectious diseases in humans and livestock).

Many contestations about environmental efficiency in the food system originate from different views on inputs, outputs and impacts. Some further examples are as follows:

Inputs: Many things may be classed as inputs in the food system. Typical examples of inputs include seeds, farm animals, fertiliser (mineral or organic), animal feed, land, labour, fuel and irrigation water. Other things, such as rainfall, sunshine, or traditional knowledge, are often not classified as inputs because they are generally taken for granted, not costed, and not exhaustible. In other cases, the legitimacy of certain inputs may be contested (e.g. bonemeal as an animal feed input, pesticides, or GM seeds).

Outputs: Even if their primary purpose is to produce food (or the nutrients people need for a healthy diet), agricultural production systems produce many other outputs too. Examples include livelihoods, animal welfare, ***ecosystem services*** (e.g. flood protection, ***carbon sequestration***, or clean drinking water), the conservation of endemic species, landscape value, and so forth. Some argue that these are often ignored, or at least not valued explicitly in formal efficiency evaluations such as LCAs. If such outputs are to be recognised, a method of valuing them needs to be agreed. Some suggest natural capital valuation tools such as payments for ecosystem services[10]. Others point out that many of these outputs are difficult to measure or sometimes even immeasurable[11,12].

Impacts: An impact may be positive or negative, but the word is often used to refer to an undesirable output of a system. GHG emissions, biodiversity loss, deforestation, water pollution, and soil degradation are commonly classified as impacts. However, the list of impacts that are valued by different stakeholders is much longer and may include non-environmental impacts such as harm done to animals and the loss of traditional knowledge, livelihoods and cultures.

Impact or output? Some things that are often classified as impacts are sometimes considered to be outputs. For example, although it is generally viewed as an 'impact of' a given agricultural system, environmental quality can also be considered an 'output from' the food system – that is, a goal to achieve in its own right. For example, some consider agriculture to be efficient when high food output is produced at the lowest possible environmental cost. Others, however, argue that agriculture is ultimately inefficient when it produces high food outputs but does not contribute positively to such things as biodiversity conservation or soil regeneration – things they may regard as equally important outputs from a sustainable food system. Similarly, animal welfare may be framed as an impact (i.e. harm to animals is a potentially necessary price to be paid for the production of food) or as a desired output in its own right (a sustainable food system has to provide both food and a 'good' life for animals).

4. Three perspectives on efficiency and sustainable food

Stakeholders differ in how they classify and prioritise inputs, outputs and impacts and this leads to different understandings of what environmental efficiency actually is. Beyond this, differences also reflect different overall visions of what a more sustainable food system looks like and whether a focus on efficiency is helpful to its realisation.

The following describes three common (albeit overlapping) views on efficiency in relation to environmental sustainability in the food system[6,13]. Expressing different understandings of what challenges the food system faces and how these should be overcome, these views formulate different answers to three questions:

- What are we being efficient *with*? Stakeholders consider and value different outputs, inputs and impacts.
- What are we being efficient *for*? Stakeholders have different views of what a sustainable food system looks like and what outputs it provides (or should provide).
- Is efficiency *effective*? Stakeholders disagree about the relationship between efficiency and sustainability. Critics refer to the need to keep production and consumption within limits and argue that an efficient food system may lack resilience.

4.1 The production-side efficiency perspective

From this mainstream perspective – commonly advanced by policy makers, the food industry, and academics from the agricultural sciences – there is a need for more food output (in particular more animal products) in order to meet the *demands and preferences* of a growing world population[14,15]. The focus is on the agricultural sector rather than on the food system more broadly. Emphasis is placed on improving production-side efficiency (e.g. through improved breeding, ***precision farming*** techniques, or better land management), with efficiency here defined as achieving higher yields with the use of no more, or fewer resources such as seed, fertiliser, feed, and energy. In this approach, achieving fewer GHG emissions (or other environmental impacts) per unit of food output is the goal. Focusing on improving the ratio of outputs relative to inputs and impacts, this perspective pays little attention to the need to cap overall consumption and production levels in order to remain within ***planetary boundaries***. It generally classifies food as the sole or most important output which will have (often negative) impacts on things such as environmental quality and animal welfare – impacts that need to be managed using primarily improvements on the production side.

4.2 The demand restraint perspective

Many animal welfare advocates and a growing number of academics argue that production-side measures alone are insufficient. They point out that while the agricultural sector produces enough food to feed the entire global population, a large portion of this is used inefficiently in that it is being fed to animals in intensive livestock systems. They may additionally point out that environmental impact reductions arising from production-side efficiency gains can be outweighed by consumption increases (Jevon's paradox). For example, greater efficiencies in the livestock sector may cause meat and dairy prices to drop and subsequent demand for these products to rise. For these stakeholders the focus is on food and nutrition rather than, more narrowly, agriculture, and the challenge is understood as one of shifting towards diets that are mostly plant-based. This shift would enable the provision of sufficient nutrition for all at a lower environmental cost than the current meat-heavy status quo in affluent parts of the world and would also alleviate animal suffering (see box 1).

An efficient food system, from this perspective, is one that meets the nutritional needs (not necessarily the *demands* or *preferences*) of a growing world population while remaining within planetary boundaries. It is assumed that current dietary patterns and trends should and can change. Proponents of this perspective consider both animal welfare, human nutrition and other social dimensions to be important outputs of the food system in their own right. They may also highlight some of the limitations of efficiency as a guiding principle: since efficiency is a ratio (the relationship of one thing to another) it is open ended – there is no 'highest number'. As such it prescribes no limits on human environmental impact and of itself cannot guarantee that we operate within planetary boundaries. (Note that this critique of efficiency has parallels with criticisms of the 'green growth' agenda, with its assumption that '***decoupling***' economic growth from environmental impact is possible and sufficient as a response to the environmental challenges we face).

4.3 The system transformation perspective

Drawn from the alternative agriculture movement and from some within the international development community, proponents of a third perspective argue that efficiency and sustainability are by no means synonymous[11]. They point out that the metrics used to determine environmental efficiency – for example kg CO_2-eq/kg meat or protein – tend to be overly simplistic; they do not capture the multifaceted complexity of the food system and omit important aspects that are difficult to measure or even immeasurable. Social and environmental problems in the food system, they argue, are interconnected and ultimately originate from structural inequalities, inequalities that generate problems both of excess and of insufficiency[16]. In contrast with the other two perspectives, people, institutions and the power relations among them are central to this narrative.

Achieving sustainability, from this perspective, requires an integrated approach that explicitly addresses the needs of the poor and the marginalised and that seeks to achieve multiple objectives simultaneously. These objectives may include access to nutritious food, clean drinking water, ***food sovereignty*** and smallholder farmers' livelihoods, biodiversity conservation, animal welfare, and climate change mitigation and adaptation[11,16,17]. This perspective considers that our definition of valued inputs to the food system should go beyond things such as seeds, manure, labour and energy, to include, for example, traditional knowledge and farming techniques (which can, it is argued, be at risk of being displaced by robots and automatisation). This perspective may also reject the use of GMOs, pesticides and high-tech solutions not only on environmental grounds, but also because it is argued that they risk undermining food sovereignty – for example when technologies are unaffordable to smallholder farmers.

Proponents of this perspective may dislike the way the term 'efficiency' has become a proxy for environmental sustainability, and they often emphasise other qualities, such as *resilience*, rather than *efficiency*. The difference is understood to be as follows: a so-defined *efficient* system geared at optimising the production of a small number of outputs and minimising the use of inputs and generation of impacts, risks being vulnerable to shocks – for example an intensive monocultural system may be brought down by a pest or a drop in food prices. A *resilient* system, instead, is seen as one that spreads risks by aiming at many outputs and accepting a degree of redundancy – this enables the system to 'bounce back' against shocks[18]. Note that the concept of resilience is itself a contested one and will be explored in a future piece.

These three perspectives underlie many disagreements on food system sustainability topics, for example the debate on livestock production and associated consumption (see box 1).

Box 1: Three perspectives on food sustainability in relation to livestock production

The three perspectives on efficiency in the food system approach the question of livestock and the consumption of animal-based products in different ways.

1. The demand restraint perspective

This perspective, which sits at the heart of much anti-meat advocacy, views all animal production as inherently inefficient because it relies on the consumption of plant-eating animals. It is argued that a whole trophic level could be omitted by eating plants directly[19]. From this perspective, improving the efficiency of animal production fails to tackle the ultimate driver of inefficient production: our demand for animal products.

Plant-based diets are seen as more 'efficient' in terms of the food energy value and protein per unit of environmental impact they deliver. Proponents point out that because the production of plant-based proteins requires a smaller agricultural footprint, land could be freed up for other uses such as biodiversity conservation or biofuel production. The omission of livestock, they argue, would also lead to a reduction in agriculture's overall GHG emissions as, for instance, methane emissions from ***ruminants*** are avoided. In addition, plant-based diets help achieve a more 'humane' food system, one that does not use animals as a means to an end. Finally, proponents may also argue that a shift to more plant-based diets will benefit our health[19,20].

2. The production-side efficiency perspective

A second perspective argues that growth in animal production and associated consumption is inevitable and may well be desirable. The challenge therefore is to develop and adopt more efficient forms of animal production[21,22]. This approach favours intensive production systems and ***monogastric*** over ruminant production. Chickens are seen as particularly efficient since, due to their metabolism, they require far less feed energy to produce a given amount of food (meat and eggs) – food that is rich in protein and micronutrients (see Table 1)[3]. Feathers, moreover, can be processed into a high-protein feed ingredient or burned to produce energy, and the concentrated piles of manure that intensive poultry farming generates can be used to produce energy or a nitrogen-rich fertiliser[23].

	Beef	Pig	Poultry	Dairy	Egg	Fish	Insects
Godfray *et al.* 2010[24] – feed required to produce 1 kg of meat, kg of cereal per animal	8	4	1				
Galloway *et al.* 2007[25] – total global feed to meat	20	3.8 (non-rum)	3.8 (non-rum)				
Galloway *et al.* 2007[25] – feed from arable land to meat	3	3.4 (non-rum)	3.4 (non-rum)				
Wilkinson, 2011[26] – kg feed (dry-matter) per kg meat	7.8-27.5	3.6	2.0	1.1	2.2		
Pelletier *et al.* 2009[27] – amount of feed used to raise 1 kg of salmon						1.1-1.5	
Van Huis *et al.* 2013[28]							0.9-1.7

Table 1: This table shows feed conversion ratios for various types of animals and animal products in livestock production systems and aquaculture as they were found in different studies[24-28]. The feed conversion ratio refers to the ratio between mass feed inputs and mass (or the food energy value of) food outputs such as meat, milk and eggs. Adapted from Garnet *et al.* 2015[3].

3. The system transformation perspective

A third perspective challenges the second on the basis that intensive pig and poultry systems rely heavily on the use of feed grains that could be used for human consumption[29,30]. While pigs and poultry are monogastrics and require high quality feed, ruminants such as sheep and cattle are able to live on fibrous agricultural by-products and human-inedible grass. In so doing, they can create 'something' from 'nothing' – i.e. they are able to produce meat and dairy from rough grassland that could not otherwise be used for the production of food or biomass. Proponents of this perspective also point out that while meat and dairy are nutritionally valuable products, ruminants also provide leather, wool, glues, manure and bonemeal (a source of phosphorus).

Rather than reinforcing an existing economy in which large companies and corporate greed are thought to drive the use of economies of scale and the production of food at the lowest possible cost, this perspective seeks a system transformation to achieve multiple objectives. It sees a role for extensive ruminant farming as a means of sustaining the livelihood of poor, marginalised smallholder farmers; in maintaining landscapes and a species diversity that we value; and in supporting good animal welfare (as compared to confined indoor systems which are seen to undermine welfare). Some proponents also argue that despite ruminants' production of methane, their net contribution to climate change can be close to, or even below, zero as grazing on rough pasture land could potentially foster carbon sequestration (see our Grazed and Confused report for a fuller discussion).

Source: The three perspectives on efficiency and livestock production in this box are based upon the FCRN report Lean, green, mean, obscene...? What is efficiency? And is it sustainable? and several earlier publications by Tara Garnett[4,12].

5. Is efficiency sustainable?

Debate about efficiency reflects some of the larger discussions about where we are and where we want to go with the food system. Interpretations of efficiency and views on the desirability of pursuing it as a goal are shaped by assumptions and visions that underpin people's views of food system sustainability. These include, among others, the following:

- assumptions about the malleability of food demand and food preferences;
- perspectives on the potential of markets to decouple production from environmental impacts;
- ideas about animal harm and what constitutes 'good' animal welfare;
- perceptions of risk regarding the use of technologies such as GM, pesticides and robotics; and
- attitudes to humanity's place in the natural environment.

While there may be no definitive answer to the question of efficiency, it is important to pay attention to the different usages of the word, as its use speaks volumes about what people desire for and from the food system.

Glossary

Acidification. Acidification refers to changes to the chemistry of a body of water that make it more acidic over time (i.e. increased hydrogen ion availability). This change in acidity can then affect many other reactions that take place in water, including those important for ecosystem functioning.

Biodiversity conservation: all human activity aimed at the preservation of both the variety and variability of living organisms in a particular area of concern, or on earth in general. People value different aspects of biodiversity in different ways, and can have different priorities in biodiversity conservation e.g. to protect an endemic species or a species that supports an ecological process important to human wellbeing such as pollination.

Carbon sequestration. Carbon sequestration is any process by which carbon dioxide is removed from the atmosphere and stored elsewhere, whether by biological or technological means. There are two main types of carbon sequestration, terrestrial (carbon plants and soils), and geologic (carbon stored in rock formations) . One classic example of carbon sequestration is reforestation.

Decoupling (or eco-economic decoupling). This concept is used to refer to the idea of disconnecting the growth of gross domestic product (GDP) from increases in environmental impacts – climate change in particular. The term is sometimes used more broadly in relation to overall human well-being rather than GDP. The idea of decoupling is based on the understanding that economic growth often goes hand in hand with increases in environmental impacts. Advocates of decoupling think that advances in technology will provide ways of fostering economic growth without increasing the use of resources or the generation of environmental impacts, and without requiring radical shifts in aspirations as to what constitutes a 'good' standard of living. Decoupling can be used both in a relative sense (e.g. a lower ratio of environmental impacts versus GDP) and in an absolute sense (i.e. the overall amount of environmental impacts is reduced). Relative decoupling is sometimes criticised for being open ended and thereby failing to speak to the need of keeping production and consumption levels within environmental limits. In general, critics question whether decoupling (both relative and absolute) is feasible for diverse reasons: because of the possibility of rebound effects; because it is unlikely to be possible to separate the production of goods and services from resource use (and the impacts of this resource use) to the degree that is necessary; and because the growth-based economic paradigm on which faith in decoupling is based fails to challenge the potential insatiability of human demand – an insatiability which (it is argued) lies at the root of our environmental crisis.

Ecosystem services: the tangible and intangible benefits that are provided by ecosystems to humans, which both enable human life and that contribute to its quality. Ecosystem services include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

Ecotoxicity. Ecotoxicity refers to the toxicology of pollutants in the environment. The study of ecotoxicology includes consideration of the interaction of pollutants both with abiotic aspects of the environment - soil, air and water; and how they interact with living systems, at the level of cell, organ, and organism to communities and ecosystems.

Eutrophication. Eutrophication refers to the buildup of nutrients in a body of water (e.g. nitrogen and phosphorus) to a level in excess of what would occur naturally and to which aquatic ecosystems are adapted. This can result in detrimental impacts on many aquatic plants and animals, as well as the rapid overgrowth of some plants and algae.

Food sovereignty. Food sovereignty is a political movement that emphasises the rights of food producers, distributors and consumers to have control over the food system, as opposed to coorporations and market institutions. It has been defined as the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems.

Functional unit. This term refers to the product, service or system whose impacts a life-cycle assessment (LCA) calculates. Common examples of food-related functional units are 1 kg of beef, 100 calories of food, or 1 ha of land. The choice of functional unit influences an LCA's results and care is needed when comparing the results of LCAs with different functional units. The functional unit is defined in the first phase of a life-cycle assessment study – that of goal and scope definition. GHGs. GHGs is an abbreviation for greenhouse gases. These include gases such as carbon dioxide, methane, and nitrous oxide, which are released as a result of human activity, and which trap heat within the earth's atmosphere, leading to global warming.

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Life cycle. In life-cycle assessment and carbon footprint analysis, the concept of life cycle refers to the entirety of phases a product or system passes through from its development, through to its use and, eventually, how it is managed as waste. A life cycle is generally understood to start at the growing and harvesting or mining of raw materials and to end when a product is disposed of as waste. While waste management is thought to be a part of a product's life cycle, potential recycling is generally considered to be part of the life cycles of other, new products. For example, the life cycle of a loaf of bread may be thought to consist of the following phases: the growing and harvesting of corn and other ingredients (including pre-production of inputs such as fertilisers), their transport to a bakery, bread production, transport and retail, consumption and waste.

Livelihood. A livelihood is a person's, household's, or group of people's means of making a living. It encompasses people's capabilities, assets, income, and activities that are required for securing the necessities of life, such as food, water, medicine, shelter and clothing.

Monogastric: is a mammal with a single-compartmented stomach. Examples of monogastrics include humans, poultry, pigs, horses, rabbits, dogs and cats. Most monogastrics are generally unable to digest much cellulose food materials such as grasses. Herbivores with a monogastric digestion system (e.g. horses and rabbits) are able to digest cellulose in their diets through microbes in their gut, but they extract less energy from these foods than do ruminants. A major proportion of the feed given to monogastrics reared in intensive systems comprises human edible grains and soybeans.

Planetary boundaries concept. The planetary boundaries concept refers to the idea that humans are substantially altering natural systems, and that beyond a certain level of change this may become irreversible and self sustaining. The potential result is a planet with environmental conditions that differ substantially from those in which human civilisation developed and to which many species and ecosystems are adapted. Planetary boundaries have so far been proposed for climate change, biodiversity loss, biogeochemical cycles, ocean acidification, land use, freshwater, and ozone depletion.

Precision farming: is an agricultural management practice that aims to supply plants or animals with precisely the amounts of agricultural inputs (e.g. water, pesticides, and fertilisers) they need at a specific location and moment in time, thereby increasing efficiency by reducing the total inputs needed for agricultural production, and reducing environmental impacts. Precision farming uses different types of technologies to measure, observe, and act upon factors that are relevant to the growth of crops and livestock. These can range from big data, GPS, robotics, sensors, and drones, to low-tech measures such as using bottle caps for applying the right amounts of fertilisers to individual plants. Aiming to optimize crop or livestock production, precision techniques include measuring, modelling, and responding to (site-specific) data, including weather forecasts, soil properties, soil water content, pests, and weeds.

Resilience. In the context of food system sustainability, the concept of resilience refers to the ability of the food system to cope with and recover from socio-economic or environmental shocks and pressures. A resilient system has a certain degree of toughness and is able to bounce back against or adapt to disturbances. A resilient food system, for example, is able to keep providing food or other outputs such as livelihoods for farmers, drinking water, and biodiversity conservation under conditions of drought, a drop in food prices, war, climate change, the spread of virus in plants or animals, and so on. Resilience can be thought of at different scale levels. For example, what may be considered as resilient on a national level may not be understood to be resilient at a farm level. While some see resilience as synchronous with sustainability, others point out that a resilient system may also be one that resists needed transformation; an unsustainable status quo may in fact be resilient to change.

Ruminant: is a mammal with a four-compartmented stomach which enables it to acquire nutrients from plant-based food such as grasses, husks and stalks. Examples of ruminants include cattle, sheep, goats, deer, giraffes and camels. After swallowing, microbes in the ruminant's rumen (its first stomach compartment) begin fermenting the food. This process generates fatty acids (nutrients which the ruminant absorbs through its rumen walls) and methane, which the ruminant eructs or burps. Through this process, ruminants are able to digest coarse cellulosic material which monogastrics and people cannot. Methane emissions from ruminants are a significant source of greenhouse gasses from ruminant-based livestock systems.

Recommended resources

- The FCRN report Lean, green, mean, obscene…? What is efficiency? And is it sustainable? by Garnett *et al*. 2015
- Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? by Garnett, 2014
- Foodsource chapter 2: The environmental impacts of food: An introduction to LCA by Garnett and Röös, 2016

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