Engineering and Ecosystems: Seeking Synergies Towards a Nature-Positive World
Ed. Bhavik R. Bakshi
Published November 2023. Springer Nature Switzerland AG
Available from https://link.springer.com/book/10.1007/978-3-031-35692-6

The following chapter content is provided for marketing purposes.

Chapter 23:
Preventing Unintended Harm from Socio-Ecological Interactions

Richard M. Gunton
Department of Digital Technologies, University of Winchester, Sparkford Road, Winchester, SO22 4NR, U.K.

23.1 Introduction

23.1.1 Ecosystems are always included in engineering

Engineering, like all human activities, takes place within a context that is not only physical and biotic but filled with human culture. The modern concept of 'nature' all too often implies a separation of humans and our culture from the rest of reality, when in fact we are inextricably linked. From breathing to eating and from building to travelling, humans have no option but to interact synergistically with the rest of nature. Ecosystems are bound up in the life of a society: as humans we not only relate to our environment ecologically but experience and appreciate it culturally. Enhancing socio-ecological interactions is therefore an important goal for sustainable development, and this vision features prominently, for example, in the United Nations Sustainable Development Goals (UN Sustainable Development Platform 2015). Accounting for the rich complexities of the relationships on which these interactions depend calls for frameworks relating abiotic, biotic and diverse cultural considerations (United Nations 1992). In our global village, projects must respect a diverse range of stakeholders' perspectives on all manner of ecological interactions if they are to be deemed successful in the broadest possible perspective.

The term 'ecosystem' might evoke images of pristine forests, lakes or traditional meadows, but in the broad sense of the term, ecosystems are everywhere. Within each person's gut, a microbiome of bacteria thrives as part of a healthy digestive system, constituting a human–bacterial ecosystem that influences our behaviour (Enders 2015). All kinds of buildings support diverse kinds of ecosystems in the bacteria, fungi, lichens and mosses that colonise exposed surfaces, not to mention unwanted invertebrate inhabitants or the flora and fauna of water conduits. If we also consider that the composition of the atmosphere is shaped by the combined effects of all the living organisms on Earth, providing its oxidizing potential and its ongoing uptake of carbon dioxide, then it becomes clear that ecology is never really alien to engineering. This inevitable inclusion means that the question for engineering is not whether to consider ecosystem processes or not, but how best to account for – or indeed integrate – them within the design of projects. Direct negative effects are necessarily considered as a matter of course; this book is primarily about adapting projects to exploit positive synergies. But this must be set in the context of an evaluation of the overall benefit of any adaptations, not just in financial terms but with regard to society at large. This chapter looks at how to reach a balanced integrative assessment of the benefits and harms that may accrue from a proposed engineering solution.

23.1.2 Outline of the Chapter

We begin by outlining some dangers in using the ecosystem services framework as a reference point in engineering, in Sect. 23.2. Sect. 23.3 then outlines a pluralistic evaluation framework for incorporating natural ecological processes into project design, management and evaluation. Section 23.4 then looks at how such a framework can make a difference in the specific areas of hydrology and atmospheric interactions, and agriculture. In Sect. 23.5 we sketch a protocol for implementing a pluralistic evaluation and look more closely at the challenge of overcoming the nature/engineering dualism. This is an ambitious vision, but our present global challenges and crises call for nothing less. The final section argues that the social and cultural challenges of our time may best be addressed when development projects are designed and evaluated in the broadest possible socio-ecological framework, with transparency and explicit recognition of ethical considerations.

23.2 From Services to Harmonious Synergy

Previous chapters have made clear the advantages of seeking ecosystem services to enhance engineering projects. However, when a project is modified so as to derive additional services from ecosystem functions, a balanced assessment must consider negative as well as positive effects of the proposed modification. This section indicates some potential dangers of focusing narrowly on measurable 'services' and ends by pointing to the need for a broader framework.

23.2.1 Ecosystem services: real benefits?

The concept of ecosystem services arises from an analogy with the human services economy. Just as customers may avail themselves of commercial services upon payment of an appropriate price, humans may be said to benefit from a range of services provided by ecosystems (Daily 1997) and perhaps ought to pay something for them, or at least to account for the potential cost of losing them. The term 'services' is essentially a metaphor. Authors disagree as to whether ecosystem 'functions', 'outputs' or 'benefits' is the best concept to define ecosystem services more precisely (Danley and Widmark 2016), and the microeconomics background of the term suggests that it is bound up with the concept of opportunity costs. For the purposes of engineering project design, it is reasonable to focus on the net benefits that a project's builders, owners, lessors or users may derive from ecological processes that would otherwise have been more costly to obtain by other means. Such benefits, as earlier chapters have shown, may be of many kinds, and will generally be measured in terms of financial net benefits to one or more of the above-mentioned parties. But responsible engineering calls for a wider societal view on ecosystems, landscapes, wild places and haunts. Real benefits must be assessed not only in terms of services but through a balanced audit that involves a wide range of stakeholders.

23.2.2 Service-users, Stakeholders and Lovers

Whereas a commercial service is generally delivered by a business directly to a paying client – perhaps an engineering firm – with limited impact on other parties, ecosystems have broad effects that may be appreciated by some parties and suffered by others. This raises important issues of justice: suppose a service to one person or project is the blight of another? It is not straightforward to identify and measure an ecosystem's 'services' in the abstract: a tree whose roots stabilize the slope on which a building sits may also deprive its occupants of natural light, or the beauty of a flowering meadow may be accompanied by hayfever for local residents. Multiple sets of people may be 'served' by any particular ecosystem patch, over a range of timeframes: developers may reduce construction costs by clearing or 'improving' vegetation that subsequent users of a facility might have appreciated if it had been left intact, for example. Another important contrast with commercial services arises in relation to **fungibility**[1]: whereas commercial services are largely treated as commodities, people may engage most strongly with the uniqueness of natural places. Indeed, the generic term 'ecosystem' leaves little space for the love that people may have ***de re*** for specific places, trees, meadows, ponds, etc. (O'Neill 2017). If a valley is flooded for a hydroelectric power scheme, there is no way to substitute for that particular valley with its contours, history, ecological communities and inhabitants – even if some of the valley's hydrological, atmospheric, agricultural and aesthetic functions may be substituted by services from elsewhere by **offsetting**. Thus ecosystem services accounting can only be a partial accounting for the full range of ways in which humans and societies may appreciate natural places, and even within the sphere of fungible goods, it cannot yield a single analysis valid for all stakeholders (Gunton et al. 2017).

23.2.3 An Objective Assessment?

In a free market, the price of a service can be modelled as the intersection between a demand curve (how much consumers overall would buy at a range of given prices) and a service-providers' supply curve (how much providers would collectively provide at different prices). In the case of ecosystems there are no supply curves, and demand curves can only be modelled for certain market-oriented 'seminatural' human enterprises such as farming (which is considered below). Therefore other ways must be sought for evaluating ecosystem services in order to maintain the plausibility of the metaphor. For engineering, the most relevant consideration is the alternative cost of non-ecological ways of achieving a function that ecosystems can provide: the opportunity cost of losing the ecosystem function. The relative costs of alternative ways of interacting with ecosystem functions should be an important part of designing cost-effective projects, and innovative interfaces with natural processes can certainly enhance an economy-wide financial evaluation of projects, at least where there is appropriate regulatory protection of common-pool resources. Previous chapters have shown how innovative approaches can improve the long-term profitability of projects while reducing negative externalities.

There is a risk, however, that monetary valuation of ecosystem functioning will obscure the diverse kinds of ethics that people hold, and confuse the divergent interests of diverse stakeholders. The commodification of ecosystems into units of services inevitably means discounting much of what people really value about natural landscapes. If we commodify ecosystem services in monetary terms, there is *prima facie* a risk that the wealthy will eventually gain at the expense of the poor, especially if and when trading and financial speculation are introduced (O'Neill 2017). The type of instrumental value that can be priced and traded is a rather tightly bounded subset of 'value' in the general sense (Spangenberg and Settele 2016). There are many reasons for resisting marketisation – especially since alternative frameworks are available that can help avoid the problems of a 'services' mentality.

For engineering, then, it is important to have a realistic approach to understanding how decisions in project design are likely to affect ecosystems and other processes alongside the prospects of the project itself. This should then be combined with an integrative approach to evaluating the positive and negative impacts of a project in the perspective of a wide range of stakeholders. A general evaluative framework is needed for combining these, and we now turn to sketch what this might look like.

---

[1] Terms in bold are explained in the Glossary at the end of the chapter.

22.3 A Pluralistic Evaluation Framework

If projects must be designed and evaluated with respect to multiple criteria and stakeholders simultaneously, a pluralistic framework is called for. To achieve this in a way that connects with the specifications and objectives of a project, we must combine objective evaluation of system functioning with subjective evaluation by stakeholders, and on each side a plurality of evaluation criteria should be considered.

The pluralistic evaluation framework (PEF) proposed by Gunton et al. (2022) has three pillars, concerning recognition of stakeholders, systems and values (Fig. 1). Each pillar provides a suite of categories that provide a pluralistic perspective, and combining all three results in a template that can be used to guide the design of a project or structure and its post-hoc evaluation. The suite of categories, known as **aspects**, is derived from the Reformational philosophy framework pioneered by Herman Dooyeweerd (Dooyeweerd 1953a) and Dirk Vollenhoven (Vollenhoven 2005). These aspects arguably reflect the structure of the world as recognized in academic discourse, although the list is of course open to refinement.

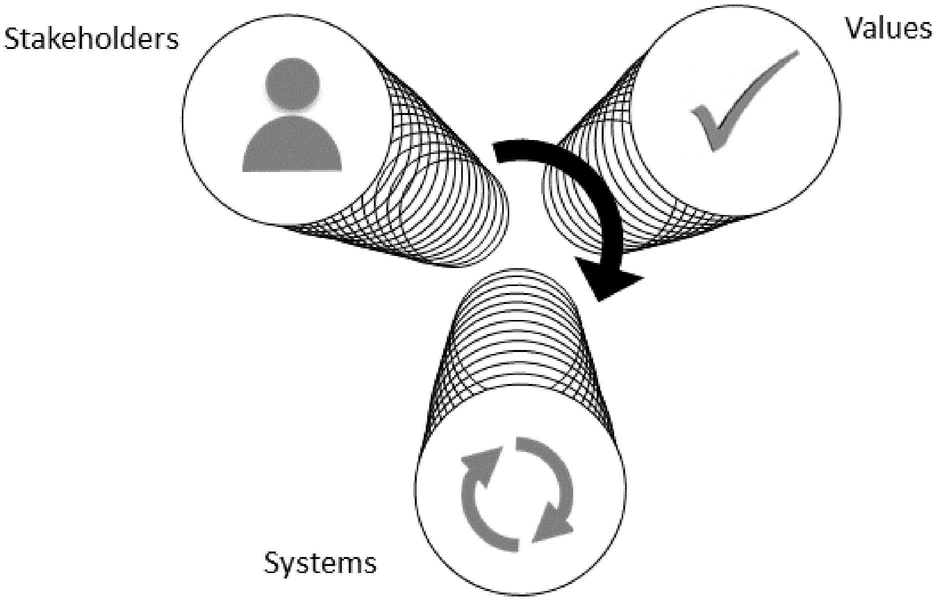

Fig. 23.1 Symbolic representation of the three pillars of the pluralistic evaluation framework. Functional groups of stakeholders are identified according to a suite of aspects (represented by layers in the 'Stakeholders' column); then systems and processes created or modified by a project are identified according to a similar suite of aspects; then a corresponding suite of modes of valuing is examined for each stakeholder–system relationship.

23.3.1 Stakeholders

The first pillar of the PEF is a checklist for identifying a comprehensive set of stakeholders who may be affected by a project. Fifteen aspects of human functions or interests are outlined in Table 23.1, along with examples of stakeholder types whose interests may be characterised by each function. This classification is about the *roles* or functions of people, groups and organisations; particular individuals will tend to fit into more than one category. The three basal aspects (numeric, spatial and kinetic) evoke the basic dichotomies of individuals vs. groups, local vs. distant stakeholders and resident vs. mobile stakeholders (e.g. tourists and commuters). The subsequent 12 aspects then point to typical interests and concerns that may identify particular groups of stakeholders, as illustrated in Table 23.1. We return to stakeholders when considering the third pillar below.

Aspect	Examples of stakeholder functional groups	Examples of system processes	Examples of positive (negative) values attributed
Ultimate	Religious/cultural groups	Ideology	Inspiring, Sacred (Unreliable)
Moral	Volunteer groups; NGOs	Public morality	Endearing, Loved (Despised)
Jural	Government; Campaigners	Legislation	Just, Equitable (Inappropriate)
Aesthetic	Arts groups; Tourists	Fashion	Harmonious, Enjoyable (Ugly)
Economic	Businesses	Economy	Efficient, Sustainable (Wasted)
Social	Communities	Social dynamics	Sociable, Welcoming (Inhospitable)
Symbolic	Journalists	Discourses	Informative, Significant (Misleading)
Formative	Historians; Educators	Historical change	Developed, Innovative (Degraded)
Analytic	Scientists	Information systems	Distinctive, Diverse (Mixed-up)
Sensory	Mental healthcare providers	Emotional life	Stimulating, Comfortable (Unpleasant)
Biotic	Farmers	Ecosystems	Health-giving (Toxic)
Physical	Resource managers	Hydrology; Climate	n/a
Kinetic	Residents /Commuters	n/a	n/a
Spatial	Local /Dispersed	n/a	n/a
Numerical	Individuals /Groups	n/a	n/a

Table 23.1. List of categories used in the pluralistic evaluation framework, with examples of their application to each of the three pillars.

23.3.2 Systems

The second pillar calls for consideration of types of engineered system. Engineering challenges can readily be classified by the kinds of system they primarily interact with, and the corresponding range of sciences they employ. Many conventional engineered artefacts are primarily physical systems, understood in terms of the physical sciences – from buildings and bridges to chemical plants and electrical devices. Some engineered systems are intrinsically biotic – from bioreactors to agricultural systems – and thus understood biologically as well as with physical sciences. Software and information systems, while dependent on physical hardware, are based on principles of logic and information science, along with elements of psychology. Within software engineering, language processing systems are informed by linguistic science as well as all the foregoing sciences. We may also recognize social engineering, economic engineering, and so on; or more commonly it is in multi-disciplinary vocations such as architecture, business administration and management consultancy that designers seek to manipulate higher-level systems. Each kind of engineering, in this broad sense, focuses on a range of systems, depending on the apparent laws of those systems – for example, gravity, electrical laws and the properties of materials in many cases, but biotic, sensory, lingual, social and economic processes in many cases too). A full suite of 12 aspects for considering kinds of systems that projects may create, modify or interact with is outlined in the centre of Table 23.1. Not all of these are prominent or necessarily important at present, but the philosophical framework behind the PEF suggests that each of them has potential and ought to be considered. In any case, multidisciplinary engagement across diverse sciences can go a long way to helping enhance the effectiveness of engineering projects and minimising unintended side-effects.

Within the systems perspective outlined here, there is a degree of natural ordering. Physical processes (e.g. erosion) determine the functioning of biotic ones (e.g. ecological succession), and biotic systems (e.g. vegetation) in turn feed back into the functioning of physical ones (e.g. watersheds). The biotic and psychological functioning of humans determine the possibilities for information systems, and information systems in turn shape the biotic and mental life of humans (increasingly so in the age of mobile devices), while interactions between information systems and physical systems will tend to be less direct. Information systems are part of historical development, the evolution of discourse and especially social systems and dynamics (not least through social media), whilst all these domains of change feed back into the design of viable information systems. The ordering of these and the later aspects is more fluid, and again, less-direct connections can be made between systems that are further apart in the sequence (see Brandon and Lombardi 2010 for more about this approach). In general, each category of system has its own intrinsic dynamics and also its interactions with neighbouring kinds of system. But systems analysis is only a foundation for a pluralistic evaluation framework.

23.3.3 Valuing

The third pillar of the PEF concerns the ways in which different stakeholders appreciate systems, and indeed the world in general. The latter 11 of the aspects suggest modes of appreciation, or kinds of value that stakeholders may attribute to the functioning of any of the systems identified in the second pillar of the PEF. Stakeholders may make negative as well as positive judgements in each of these modes of appreciation, as indicated in the final column of Table 23.1. A given scenario may elicit positive judgements in some aspects and negative ones in others; sometimes stakeholders have a clear overall view of whether they are in favour of a scenario or against it, and in other cases thoughtful deliberation is necessary. There is an important social factor in how stakeholders appreciate situations, ranging from the general influence of social contexts during individuals' life-histories to intentional processes of consultation and group decision-making. The modes of valuing outlined here may be useful as a checklist within such deliberation procedures, including outward-facing stakeholder consultations and the workings of internal committees. It should be pointed out that the social aspect, mid-way through the 11 aspects of valuing, should be considered independently of social deliberation processes. Individuals and social groups alike may consider the social benefits or detriments of a given scenario, not forgetting that even a degree of solitude can be a social good.

Within the context of human valuing, the natural ordering of the aspects is once again important. Modes of value at the lower (biotic) end of the spectrum tend to be compelling and non-negotiable, in that they concern health and safety, even life and death. Towards the higher (ultimate) end of the spectrum, modes of valuing tend to be more variable among individual people and cultures, reflecting religious and ideological traditions. Ultimate value-commitments also tend to colour the ways in which people value situations in earlier aspects, insofar as a vision of the ultimate meaning of life can shape what is perceived as good or bad.

These three pillars of stakeholders (with 15 categories), systems (12 categories) and stakeholders' values (11 categories) may be used, in the first place, as a checklist for assessing possible impacts of any plan, decision or scenario. In Sect. 23.5 below, we look at how the PEF as a whole can be used as a decision-support tool.

23.4 Pluralistic Evaluation in Practice

This section looks at two cases of natural systems covered in earlier chapters of this book. Each subsection below briefly considers a group of natural and human systems that may be affected by a certain kind of engineering projects, and then how a range of stakeholders may appreciate these with regard to particular benefits or losses that may be derived from them. Although space prohibits more detailed engagement with each topic, the aim here is to outline how a broad framework such as the pluralistic evaluation framework (PEF) may be useful when engineering projects are planned and evaluated. The focus, in line with that of this book as a whole, is on ecosystem processes – including both physical and biotic systems that function in the non-human natural world.

23.4.1 Hydrology and Atmospheric Dynamics

The cycles of water, carbon, nitrogen and other substances are fundamentally physical processes that are profoundly modified by higher-level biotic and human processes. We will focus here especially on water, since this is an essential physical component or resource in many industrial processes and its local availability and quality have direct impacts on humans. The physics of water capture, transport and loss are particularly important with regard to sustainability concerns, but the dynamics of water usage are not so much about physics: to understand these we must analyse biotic, social, economic and political systems. The study of biology, and especially the concept of the ecosystem, lies at this interface (Fig. 2).

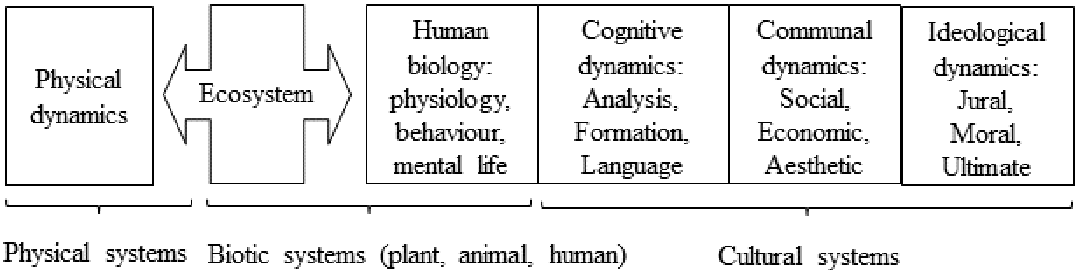

Fig. 23.2 How ecosystems sit at the interface between physical systems such as hydrology or climate and all kinds of human systems, conceived according to the second pillar of the pluralistic evaluation framework (Table 23.1).

The ecosystem interface with hydrology is of concern for sustainability in all parts of the world, and is the main focus of Chaps. 4, 9, 15 and 17 of this book. Projects that concern water treatment and provisioning for human uses can have either competitive or synergistic relationships with the functioning of ecosystems, as mentioned in Chap. 9. A set of questions must therefore be asked concerning system processes (the second pillar of the PEF): how do hydrological systems function with respect to other systems? Their interactions with other physical systems, such as the structural stability, thermodynamics and chemical reactions of an installation, are routinely considered in engineering design, but the interactions with ecosystems are the focus of this book, and subsequent interactions with all kinds of human biological, psychological and cultural dynamics are the particular concern of this chapter. Thus we can consider a range of ways in which engineering projects concerned with hydrology might impact human life, and also some ways in which human dynamics might feed back to affect hydrology.

For impacts on human life, it is routine to conduct risk assessments concerning human health and safety (largely concerning biotic processes), but a much wider kind of impact assessment is in view here. First, how will the project affect the sensations and behavior of culturally-significant animal populations – including those of conservation concern, those where animal welfare is of concern, and pest species? Then, how will the project's hydrological impacts affect the sensory life of local human populations – considering all five senses and integrated effects on mental health? Moving to cognitive dynamics, what impacts will there be on education or on scientific research opportunities? Some engineering projects achieve a historic cultural significance that attracts media attention and influences discourse, such as the construction of dams, which provide an important case study (Nia et al. 2019). It may be expedient to design public engagement facilities, such as visitors' centres at reservoirs that may become important for wildlife (see https://www.essexwt.org.uk/visit/centres for an interesting set of such facilities).

We may also consider how engineering projects may produce unintended feedbacks from plant, animal or human dynamics to hydrology. Ecological interactions are routinely considered – how algae, fish and birds may affect water treatment processes, for example, but we must also look at changes in the complex behaviors of humans. These may arise from diverse kinds of human dynamics: social activities, recreational possibilities (especially important with reservoir construction) or economic opportunities, for example. Large-scale changes in human behavior may affect the quality of water or even the movement – especially if agricultural or industrial activities are involved. To predict such feedback effects, an analysis of potential stakeholders is important (the first pillar of the PEF). In a sense, humans must be brought into the ecosystem as responsive agents.

Once a set of stakeholders is identified, another set of questions to ask concerns valuing (the third pillar of the PEF): how do various stakeholders appreciate hydrological and atmospheric systems, and how can this inform the design and evaluation of projects? This question cannot be avoided because to do so leads to the adoption of unstated ethical assumptions about how such physical-ecological systems should function. In other words, we must ask what the assumed goodness of 'synergy' means in this case. Different stakeholders may consider engineered projects to work synergistically with ecosystems according to different criteria, some of which may sit in tension with each other. For example, do we seek to treat waste water in ways that maximise affected habitats' biodiversity – and if so, do we care about all biodiversity, from microbial species richness through weed diversity to the presence of rare animals? Or are the relevant stakeholders more concerned about net carbon sequestration? How far do we prioritise the protection of particular habitats and ecosystems that may have historic, symbolic and even religious value for certain stakeholders, and how far do we prioritise the sensory, economic or aesthetic value of ecosystems such that novel or restored habitats may be deemed as good as, or better than, original sites that might be changed beyond recognition?

Humans' valuing and appreciation of carbon contrast with those of water in many ways. With growing awareness of human-induced climate change, carbon dioxide and other greenhouse gases such as methane have led to atmospherically-available carbon being considered a public disutility in diverse ways. As greenhouse gases diffuse throughout the atmosphere, populations around the world suffer a range of aspects of climate change: altered seasonality of rains affecting food production and basic human biotic functions, flooding causing loss of life, property and economic livelihoods, and higher temperatures affecting human health both directly and through changing patterns of diseases. These impacts concern human valuing in various aspects. But whereas hydrological impacts of a project must be evaluated in multiple context-specific ways, the carbon footprint of engineering projects is relatively simple to calculate and to feed into standard national and international protocols for assessing its contribution to multi-aspectual costs incurred by various populations and sectors of global society. In this way the carbon budgets associated with engineering projects should ideally be connected to a full analysis of impacts on each aspect of the lives of global citizens (not just impacts on health and livelihoods, for example).

This PEF approach does not entail that all stakeholders' views are equally important for any given project. The provider of funding for the project (whether public or private) has a special authority over how it should be executed, and non-negotiable regulatory considerations will impinge at some points (issues to be considered in Sect. 23.5). But at the very least, an enlightened self-interest will prompt project designers to consider stakeholders' views in a nuanced way. One reason why this matters is because, as outlined above, the subsequent behavior of humans affected by a project can influence its success, either positively or negatively. More broadly, firms and authorities that commission and execute projects have an interest in their social reputation.

23.4.2 Agroecosystem Engineering

Farming is a form of ecological engineering that lends itself easily to the ecosystem services framework – if the farmed system itself is considered an ecosystem. The so-called agro-ecosystem is not so much the interface between humans and engineered systems (as in Fig. 23.2) but rather the engineered system itself as a provider of goods, in the form of agricultural foodstuffs. Farming systems may also provide other benefits and detriments to particular stakeholders, as outlined in Chap. 11, and the farming system itself may be designed to engage synergistically with a range of ecological processes, as outlined in Chap. 16.

If farming is the oldest form of engineering, it is also the archetypal form in which to seek synergies with natural processes. As mentioned in earlier chapters, agriculture has been developed in various ways to engage as closely as possible with natural ecological processes, from ancient forms of vegetable gardening to modern conceptions like **permaculture**, and from the 20th-century ideology of organic farming to contemporary concepts like **sustainable intensification**. The general term we will use in this chapter for adapting agricultural systems to make greater use of synergies with natural processes is 'ecological intensification'. Much of the material in this section is also applicable to forestry, and some of it to fisheries also.

The impacts of farming systems on stakeholders need unpacking carefully. Merely cataloguing potential agro-ecosystem services, or indeed disservices, is likely to overlook the diverse and differential ways in which various stakeholders may appreciate or suffer from aspects of farming systems, whether conventional or more ecologically synergistic. Beginning with biotic effects, it is important to consider firstly the quality of agricultural produce itself. Pressures for productivity may adversely impact the nutritional quality of crops and livestock. There are also health and safety concerns for farm workers and local residents that arise from chemical inputs and the operation of various kinds of machinery: for example, systems using less chemical inputs for weed control sometimes make greater use of energy-intensive techniques and machinery such as in thermal weed control. Sensory effects are also important both via the quality of agricultural produce (colour, taste, etc.) and by virtue of the farmed environment (considering either irritant chemicals or therapeutic experiences of workers, for example). Moving on to human cultural considerations, most forms of ecological intensification result in greater spatial and temporal diversity in the farmed landscape, which tend to enhance human cultural processes. For example, more diverse crop rotations, catch-crops, wildflower buffer strips and larger hedges all tend to produce landscapes that are more cognitively, socially and ideologically attractive for various stakeholders, and only rarely have significant disbenefits for any stakeholders. This is not to say that obtaining real agronomic benefits by ecological synergies is straightforward in itself. The vagaries of weather and associated insect population dynamics and movements tend to produce a large variance in expected payoffs from any move towards ecological intensification.

In such a culturally significant and socially embedded arena as farming, changes to production systems can have far-reaching effects on a wide range of stakeholders at various spatial scales and temporal horizons. Fig. 23.3 presents a framework for thinking about the objectives and possible impacts of moves towards ecological intensification, conceived here as a subset of interventions for sustainable intensification, and building on papers by Gunton et al. (2016) and Wigboldus et al. (2016).

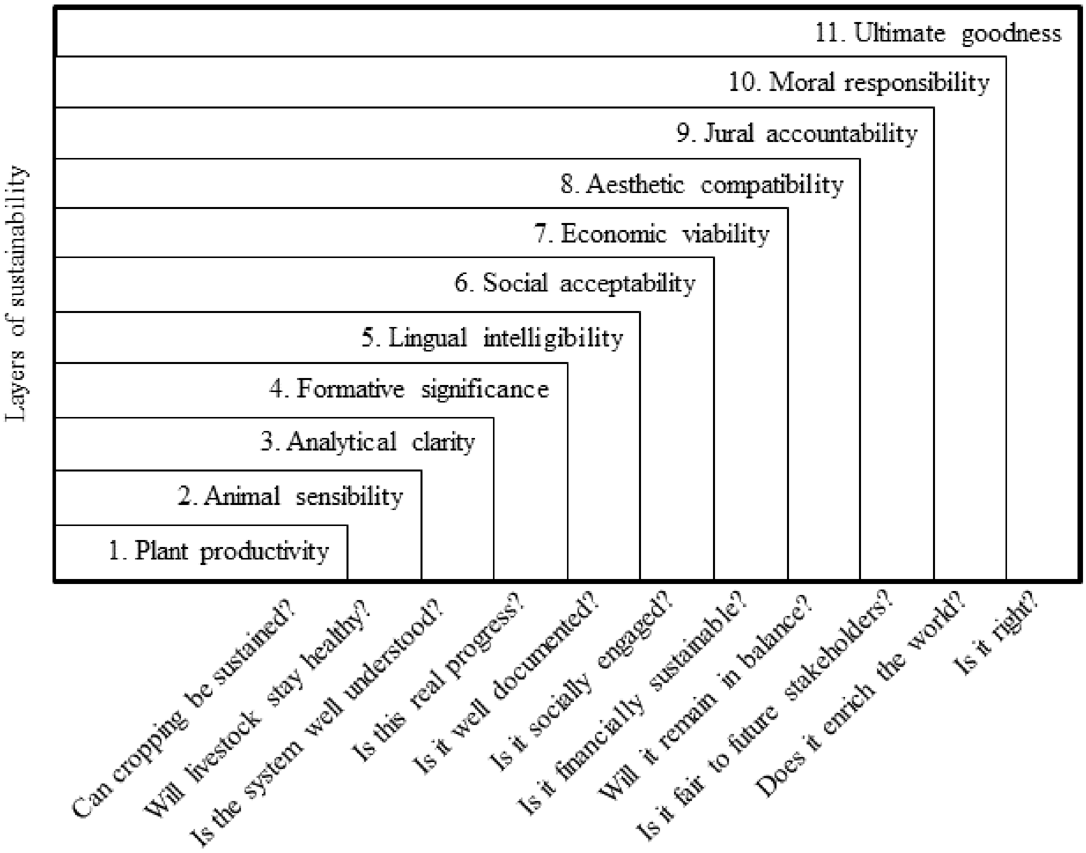

Fig. 23.3 The scope of sustainable intensification. Moving from the bottom left of the diagram towards the top right corresponds to opening up a land management system to additional layers of interest and thereby broadening the scope of its sustainability. Starting with a basic focus on plant productivity (1), as in gardening, additional considerations can qualify a project as, for example, innovative (4), socially embedded (6) and business-oriented (7). This far is sufficient for a farming system, but a more enlightened vision may entail aesthetic harmony (8), concern for others' rights (9, 10) and ultimately a commitment to the good (11).

The vision for sustainability illustrated in Fig. 23.3 subsumes ecological intensification mostly within its first layer: that of plant productivity. Strategies for improving soil fertility, ecological weed and pest control and enhanced pollination, for example, can all fall within a farmer's orb of self-interest, although they may be tempered by business considerations as the system is opened up as far as a regular farm business (the seventh layer in Fig. 23.3). This is especially important with a long-term horizon in view (e.g. that of family landowners rather than tenant farmers or opportunistic profiteers). Moreover, actual farmers, like all humans, will have some conception of ultimate good – perhaps the common good in an ideological view – and this will shape their overall vision of good farming: their personal and communal ethics.

23.5 Pluralistic Evaluation for Sustainable Engineering

23.5.1 Completing the Transition to Natural Engineering

We began this chapter by critiquing the traditional distinction between nature and humanity, and between ecosystems and engineering. Nevertheless, we find the concepts of non-human ecological systems and processes extremely important. How can we maintain appropriate distinctions between human and non-human systems to carry out analyses like these and properly consider human impacts on so-called 'natural' habitats like ecosystems where humans have minimal direct impact?

The philosophical concept that undergirds the structures recognized by the PEF, as outlined above, is that of enkaptic relationships. We can avoid creating a natural-plus-artificial dualism by saying that 'lower' or 'earlier' kinds of systems in the sequence of aspects outlined in Table 23.1 are caught up and transformed by higher ones. **Enkapsis**, a term derived from philosophy of biology and developed by the philosopher Herman Dooyeweerd (Dooyeweerd 1953b, Klapwijk 2008), means the wrapping up of one kind of system inside another one that transforms its meaning. Enkapsis therefore evokes the way in which the foundational functions of a system are given additional meaning by those of a later (higher) aspect (see Table 23.1 and Fig. 23.3) (Ouweneel 2014). Thus we can look at the ways in which ecosystems are transformed for better or worse by changing the degree of human engagement with them. The value judgement of 'better' or 'worse' should, of course, be informed by a range of stakeholders' attitudes.

If we are to maintain that human engineering projects and technical innovation can be 'goods' at all, we need such a view of the world. Considering non-human nature as an ultimate, unqualified good – as in the perspective of Deep Ecology (Curry 2011), tends to entrench conflicts between the human and the non-human. In that view, the ideal is to minimise the impact of humans on certain regions of our planet, such as those where the illusion of pristine, virgin wildness can be maintained – while sacrificing other regions to human despoliation. If we avoid subscribing to such perspectives yet lack an ethical framework for seeing different aspects of the world as built upon each other and developed within each other for better or worse, we risk falling prey to unspoken ethics about how the ecological aspects of the world should function.

23.5.2 Decision-Making

At first glance, the list of values considered within the PEF is highly aspirational. Engineering projects are conducted primarily within financial and regulatory constraints, and when these dominate, there may appear to be little room for considering diverse stakeholders' ethical concerns that go beyond those required by relevant legislation. However, there are at least three reasons why project designers, managers and evaluators may want to avoid such a narrow approach. First, as considered above, there are dynamic interactions among a wide range of cultural processes, and these affect the ways in which economic and regulatory criteria may be applied. Regulators, for example, in seeking the public interest, may pay special attention to firms that exploit loopholes in legislation and apply penalties or adjust the legislation in ways that benefit more public-spirited parties. This leads to a second consideration, that the economic and regulatory criteria are themselves evolving in ways that cannot fully be foreseen. Economic realities may shift to favour firms and projects that have been designed with a more holistic or broader range of objectives in view, while regulatory criteria tend to be developed so as to seek greater realization of the public good. Third, humans invariably do have some notion of the good, and strict adherence to one or two overly narrow criteria may be personally unbearable or dehumanizing.

By this point it is clear that the nature of an evaluation, especially concerning potential societal and ideological impacts, will be coloured by the worldviews and ideologies of the individuals and authorities that perform it. The normative practices approach (De Vries 2015, de Vries and Jochemsen 2019) is a framework that recognizes this, based on the same set of aspects as outlined in Table 23.1 and used in the PEF. The central insight of this approach is that in professional practices such as engineering, it is useful to separate the profession's own 'constitutive norms', such as those of health and safety, teamwork and economic efficiency, from the ethical 'regulating context' within which engineers think and work. Being a good engineer primarily means working safely, productively, cooperatively, efficiently, etc, but, depending on the individual and the context, it may also mean being responsible, loyal, compassionate, etc. In short, good engineering is the practice of a range of virtues.

For planning and evaluating an engineering project in synergy with ecological systems, then, there is much to commend a multi-aspectual framework that is broad and transparent, not just ecologically but in terms of the whole of human life. The pluralistic evaluation framework sketched here offers at the very least a checklist for aspects of human life and culture that might be neglected, or thought to be of low priority, in the design of projects. It can also, however, be used as more than a checklist by recognizing the interdependencies among aspects of reality. The following procedure is suggested for an impact assessment of a project at the planning stage, with flexibility for adaptation according to the kinds of data available.

1. Identify relevant types of stakeholder along with system processes likely to be of concern to them that may be affected by the project. This step may need to be iterated with consultation of stakeholders to help identify additional system processes that the project might affect, which in turn might elicit additional stakeholders.
2. Consider the modes of valuing that might be relevant to each system process, for one stakeholder group at a time. Different kinds of stakeholder may be able to provide different levels of detail and possibly quantification in their evaluations within different aspects.
3. Identify scenarios to compare (e.g. under different kinds of proposed ecological synergy) and, where possible, describe these through modelling.
4. Elicit value assessments for each scenario or case from the stakeholders identified, for each relevant system process and aspect of value. The type of evaluation required, and availability of resources, will determine how much direct consultation of stakeholders is possible and how much must be imputed based on existing data and previous experience.
5. Complete the assessment, if appropriate, using multi-criterion optimisation methods (Wątróbski et al. 2019) to explore the relative goodness of the scenarios. Each system process may be considered in turn to assess its overall improvement in the eyes of the relevant stakeholders, or each stakeholder may be considered in turn to assess their appreciation of the processes affected.

Such a procedure has similarities with participatory **systems mapping** (Lopes and Videira 2017), in which the causal relationships among systems and indicator variables are investigated through discussions among diverse stakeholders. The PEF adds structure to this and a value-explicit dimension. The use of this kind of structure with stakeholders has been described by Basden (2019), who offers further suggestions for operationalising the use of Dooyeweerd's aspects. The pluralistic evaluation framework and its categories are described in more detail by Gunton et al. (2022).

23.6 Conclusion

We have sketched a view of ecosystems as not just omnipresent but enkaptically taken up into human affairs. This enkapsis is evident in the increasing concern for 'ecological' ways of living at all levels of culture – a remarkable trend in view of the low awareness that most Western people have of natural ecosystems in daily life, the small amounts of time that modern city dwellers may spend in green spaces, and the low funding for ecology among the biological sciences. What we are seeing in contemporary culture is a growing awareness of the complex – we might say enkaptic – inter-relationships between human lifestyles and ecosystems around the globe, epitomized by the transformation of environmental discourse to focus on the worldwide dispersion and impacts of CO_2 and other greenhouse gases. Engineering is rightly caught up in these ecological concerns, and it is appropriate that engineered projects of all kinds should be assessed on a broad range of criteria. These must include ecological criteria in the strict sense but also 'environmental' criteria more broadly, and indeed cultural criteria in the broadest possible sense. Our world of inter-connected systems, from the physical and ecological through the societal and economic to the dynamics of ideology, demands nothing less than fully integrated design and evaluation of each innovation and project. We have pointed out here that the nature of evaluation, especially concerning potential societal and ideological impacts, will be colored by the worldviews and ideologies of the individuals and authorities that perform it. This makes it all the more important for evaluations to be transparent and clearly structured – which is the central benefit of the pluralistic evaluation framework outlined here.

Acknowledgments I would like to thank Yoseph Araya and Maarten Verkerk for helpful comments on drafts of this chapter. The development of the PEF benefitted from funding and support from the Centre for the Evaluation of Complexity Across the Nexus (www.cecan.ac.uk).

Glossary

Aspect (in Reformational philosophy) An irreducible mode of functioning and meaning. Each aspect is an end-point in the process of abstraction, such that its meaning can be evoked but not defined. 15 aspects are classically posited (see Table 23.1), and any object or phenomenon functions in all of them, albeit only passively in some cases.

de re (in analytical philosophy) Literally 'about the thing': used by O'Neill (2017) to evoke the way in which a thing (e.g. a person) may be valued as a unique individual that cannot be replaced. This is contrasted with *de dicto* ('about what is said), in which something is valued according to its fitting a certain description, such that a substitute could be found (see **fungible**).

Enkapsis (in Reformational philosophy) The involvement of one entity or system in another entity or system that transforms its functioning or meaning. In contrast to a part–whole relationship, an enkaptic relationship is one that links different **aspects**.

Fungible (in economics) Interchangeable with respect to value; substitutable

Offsetting A practice of compensating ecological loss at one site by creating substitute habitat of equivalent quality at another site. Biodiversity offsetting (where species richness and the presence of notable species are expected to be replicated or enhanced) is now enshrined for certain situations in the planning policies of some jurisdictions including the USA and Australia and appears to be an aspiration in others, including the UK.

Permaculture A paradigm of producing food and other natural products by designing a seminatural ecosystem in which humans participate with minimal disturbance

Shadow price A monetary value that is attributed in cases where no market price exists

Sustainable intensification Changes to a farming system that will maintain or enhance specified kinds of agricultural provisioning while enhancing the delivery of a specified range of other ecosystem services measured over a specified area and specified time frame (Gunton et al. 2016).

Systems mapping A process of analyzing a complex system to describe its components and boundary, and to elucidate causal relationships among the components, often with respect to measurable variables

References

Basden, A. 2019. Foundations and Practice of Research: Adventures With Dooyeweerd's Philosophy. Routledge, Oxford.

Brandon, P. S., and P. L. Lombardi. 2010. Evaluating Sustainable Development in the Built Environment. Wiley-Blackwell, Chichester.

Curry, P. 2011. Dark Green or Deep (Ecocentric) Ethics. Pages 92–126 Ecological ethics; an introduction. Polity Press.

Daily, G. C. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press.

Danley, B., and C. Widmark. 2016. Evaluating conceptual definitions of ecosystem services and their implications. Ecological Economics 126:132–138.

Dooyeweerd, H. 1953a. A New Critique of Theoretical Thought (4 Vols). Amsterdam.

Dooyeweerd, H. 1953b. A New Critique of Theoretical Thought (3): The Structures of Individuality of Temporal Reality. H.J. Paris.

Enders, G. 2015. Gut: The Inside Story of Our Body's Most Underrated Organ. Greystone Books, Vancouver.

Gunton, R. M., E. N. van Asperen, A. Basden, D. Bookless, Y. Araya, D. R. Hanson, M. A. Goddard, G. Otieno, and G. O. Jones. 2017. Beyond ecosystem services: valuing the invaluable. Trends in Ecology and Evolution 32:249–257.

Gunton, R. M., L. G. Firbank, A. Inman, and D. M. Winter. 2016. How scalable is sustainable intensification? Nature Plants 2:16065.

Gunton, R. M., A. P. Hejnowicz, A. Basden, E. N. van Asperen, I. Christie, D. R. Hanson, and S. E. Hartley. 2022. Valuing beyond economics: A pluralistic evaluation framework for participatory policymaking. Ecological Economics 196:107420.

Klapwijk, J. 2008. Purpose in the Living World? Creation and Emergent Evolution. Page (H. T. Cook, Ed.). Cambridge University Press, Cambridge.

Lopes, R., and N. Videira. 2017. Modelling feedback processes underpinning management of ecosystem services: The role of participatory systems mapping. Ecosystem Services 28:28–42.

Nia, M. G., M. F. Harandi, and M. J. de Vries. 2019. Technology Development as a Normative Practice: A Meaning-Based Approach to Learning About Values in Engineering—Damming as a Case Study. Science and Engineering Ethics 25:55–82.

O'Neill, J. 2017. Life beyond capital. Centre for the Understanding of Sustainable Prosperity, Guildford, U.K.

Ouweneel, W. 2014. Wisdom for Thinkers: An Introduction to Christian Philosophy. Paideia Press / Reformational Pub Project.

Spangenberg, J. H., and J. Settele. 2016. Value pluralism and economic valuation - defendable if well done. Ecosystem Services 18:100–109.

UN Sustainable Development Platform. 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. United Nations.

United Nations. 1992. Convention on Biological Diversity. United Nations, Rio De Janeiro.

Vollenhoven, D. H. T. 2005. Introduction to Philosophy. Dordt College Press, Sioux Center, Iowa.

De Vries, M. J. 2015. Engineering as normative practice: Ethical reflections on tasks and responsibilities. Pages 12–21 Contemporary Ethical Issues in Engineering. Delft University of Technology, Netherlands.

de Vries, M. J., and H. Jochemsen, editors. 2019. The Normative Nature of Social Practices and Ethics in Professional Environments. IGI Global.

Wątróbski, J., J. Jankowski, P. Ziemba, A. Karczmarczyk, and M. Zioło. 2019. Generalised framework for multi-criteria method selection. Omega (United Kingdom) 86:107–124.

Wigboldus, S., L. Klerkx, C. Leeuwis, M. Schut, S. Muilerman, and H. Jochemsen. 2016. Systemic perspectives on scaling agricultural innovations. A review. Agronomy for Sustainable Development 36:46.