42 Backcasting and Scenarios for Sustainable Technology Development

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Abstract

This chapter explores the relevance of scenarios and backcasting for sustainable technology development and sustainable innovation. It argues that backcasting, due to its normative nature and its focus on desirable futures, is very well equipped to be applied to sustainability, which is a strongly normative concept too. The chapter contains a brief overview of backcasting studies and a methodological framework is presented. The framework is illustrated by a backcasting case on meat alternatives and novel protein foods, which was conducted at the sustainable technology development (STD) program in the Netherlands. A backcasting methodology is presented that can be easily applied by engineers, which is also used in engineering education at Delft University of Technology.

1 Introduction

Sustainable technology development and sustainable innovation are essential for sustainable development. Technology and innovation should provide the means for substantially reducing the environmental burden of current ways of production and consumption. Obviously, social aspects, behavioral aspects, and equity issues as well as economic aspects of sustainable technologies are highly important too, as technology, ecological impacts, social effects, and economic implications are co-produced and strongly interrelated resulting in the co-evolutionary development of technology, society, and the environment. One clear example is the well-known rebound effect; users often use a new technology in an unforeseen way leading to unexpected impacts. For instance, energy efficiency gains are often lower than

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expected due to changing user behavior (Herring and Roy 2007). Another example is the hole in the ozone layer due to CFC emissions; the negative impact of technology use by mankind became only evident more than half a century after its market introduction in the early twentieth century. A third example is growing wealth in general; it comes along with an increased environmental burden, while decoupling economic growth from the increasing environmental burden has not been sufficiently successful until now (Jackson 2009).

Significant reduction of our current environmental burden is obviously required. Based on the well-known Ehrlich–Holdren equation (Ehrlich and Holdren 1971), environmental improvement with a factor 10 (Schmidt-Bleek 2008) or even a factor 20 (Weaver et al. 2000) has been proposed as required for sustainable development on the long term. These kinds of environmental improvement factors do not only require technological changes, but also cultural, organizational, structural, and institutional changes. This can neither be achieved by a new product or a product innovation, nor by the introduction of a specific sustainable technology alone. Instead, sets of systemic changes are needed at the level of societal systems in order to achieve significant environmental improvement with a factor 10 or a factor 20. For instance, most meat alternatives have a considerably lower environmental impact than meat, but they lead only to significant environmental gains if meat alternatives substitute meat at a large scale. So, it is not only about single product innovations or particular technologies, but also about systemic changes in our current consumption and production patterns and the related socio-technical systems. A shift to large-scale substitution of meat by meat alternatives also requires behavioral changes, raising public awareness and decreasing the current livestock and meat processing industries, as well as supporting policies and education.

Technologies are thus part of larger societal systems that comprise both technological and social elements and for which the term "socio-technical systems" is used in this chapter. The social part does not only include people, but also organizations as well as different kinds of rules and organizational structures. Together with the technologies, this makes up larger socio-technical systems and eventually society as a whole. Socio-technical systems can be industries, households, domains like transportation, mobility, or nutrition, and geographically bound systems like a city or a region. Within these socio-technical systems, long-term transitions occur, such as the transition from sailing vessels to steamships that took place between 1780 and 1870 (Geels 2005a), the transition of computers in society from the first operational computer in the mid-1940s and widespread personal use of PCs starting in the 1990, and the transition in public hygiene and water supply that took place in the Netherlands and many other industrializing countries between the mid-nineteenth and mid-twentieth centuries (Geels 2005b).

Aiming at large-scale change of such complex socio-technical systems in pursuit of sustainable development is often referred to as system innovations or transitions to sustainability (Elzen et al. 2004; Rotmans et al. 2001; Quist 2007; Loorbach 2007; Grin et al. 2010). Other terms can be found too, such as industrial transformation, industrial ecology, and shifts toward sustainable consumption and production systems. Nevertheless, these terms cover more or less similar concepts and share the idea that realizing considerable environmental improvement on the long term requires changes at the level of socio-technical systems (Quist 2007).

The focus of this chapter is on approaches that can be applied to explore long-term transitions and system innovations that contribute to sustainable development. The strong future orientation of sustainable development is exactly why future studies, scenarios, scenario assessments, and backcasting are highly relevant for system innovations and transitions to sustainability. Three types of scenarios and associated scenario methodologies can be distinguished (e.g., Vergragt and Quist 2011; Linstone 1999).

- The first type of scenarios is about likely futures and relates to the question what *will* happen. These scenarios are often based on trend extrapolations using quantitative methods, which result in surprise-free futures and Business-as-Usual (BAU) scenarios reflecting major trends.
- The second type of scenario approaches is about possible futures and relates to the question what *could* happen. This type of scenario methodologies generally results in a set of distinct alternative futures reflecting uncertainty and different perspectives on possible futures. Well-known examples are strategic context scenarios, as initially developed by the company Shell and the model-based scenarios, as for instance developed by the IPCC and earlier in "Limits to Growth," the first report to the Club of Rome.
- The third type of scenarios is about desirable futures; it relates to the normative questions what *should* happen, or what future we would like to have. This type of scenarios is also referred to as normative scenarios, or future visions. Backcasting and transition management are widely applied methodologies that generate desirable futures and explore the related system innovations and transitions to sustainability.

Approaches like backcasting (Quist and Vergragt 2006; Quist 2007) and transition management (Rotmans et al. 2001; Loorbach 2007) are thus normative, long term oriented, system oriented, take a broad view on sustainability and are often participatory. These approaches combine (Quist and Vergragt 2006: 1028):

1. The involvement of a broad range of stakeholders and actors from different societal groups including government, companies, public interest groups, and knowledge bodies, not only when defining the problem but also when searching for solutions and developing shared visions.
2. Incorporating not only the environmental component of sustainability, but also its economic and social components.
3. Taking into account the demand side and the supply chain as well as related production and consumption systems. Backcasting literally means looking back from the future. A more comprehensive definition is "generating a desirable future, and then looking backwards from that future to the present in order to strategize and to plan how it could be achieved" (Vergragt and Quist 2011, see also Fig. 42.1) or "envisaging a desirable future first, before looking back to how that future may be achieved, and defining what steps need to be taken to bring about the envisaged future" (Quist and Vergragt 2006; Quist 2007).

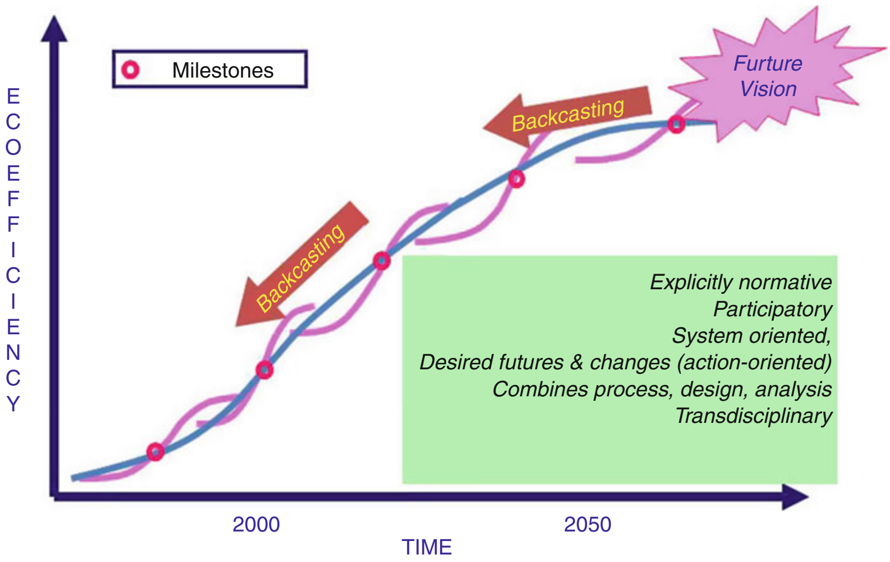

Fig. 42.1 Backcasting: principle and key characteristics

By developing future visions or desirable normative scenarios, engineers can develop ideas on sustainable technologies and sustainable innovations, while backcasting can also be used to develop R&D agendas and pathways toward realizing sustainable future visions as well as for defining next steps and short-term activities in line with the developed sustainable future vision. In addition, backcasting also allows for involving stakeholders and for getting a better understanding about the possible gains and side effects of a future vision.

The relevance of backcasting and scenarios for sustainable engineering is the starting point and focus of this chapter. It builds on backcasting in the Netherlands at the program for sustainable technology development (Weaver et al. 2000) and on backcasting research at Delft University of Technology (Quist et al. 2006; Quist and Vergragt 2006; Quist 2007; Geurs and van Wee 2000). The chapter is organized as follows. Section 2 gives a brief overview of backcasting and presents a methodological framework. Section 3 presents a backcasting case study: a backcasting project on meat alternatives and so-called novel protein foods, which was conducted in the mid-1990s in the Netherlands as part of the sustainable technology development Program. It resulted in significant impact and spin-off 10 years later. Section 4 elaborates the backcasting framework into a methodology that can assist engineers in their work. At Delft University of Technology, this methodology is taught to engineering students as part of the Technology in Sustainable Development (TiSD) specialization. Finally, conclusions are drawn and discussed in Sect. 5.

2 Backcasting for Sustainable Development: Overview and a Methodological Framework

Over the last decades, backcasting has evolved into a major approach to explore system innovations toward sustainability using normative or desirable futures (e.g., Weaver et al. 2000; Quist and Vergragt 2006; Quist 2007; Vergragt and Quist 2011). As argued by Dreborg (1996) backcasting is particularly useful in case of complex societal problems, when there is a need for major change, when dominant trends are part of the problem, when there are side effects or externalities that cannot be satisfactorily solved in markets, and when longtime horizons allow for future alternatives that need several decades to develop. Most sustainability problems are obvious examples of such complex problems.

Backcasting was developed in the 1970s and early 1980s by, for instance, Amory Lovins in the USA (Lovins 1977), John Robinson in Canada (Robinson 1982), and Peter Steen in Sweden (Johansson and Steen 1980) in response to the then dominant practices of energy forecasting that emphasized large-scale electricity production and nuclear power, and assumed a strong growth of the energy demand. Whereas Lovins used the term "backwards-looking analysis" (Lovins 1977), it was Robinson who coined the term "backcasting" (Robinson 1982, 1990). Driven by the then emerging environmental awareness, frontrunners like Lovins, Robinson, and others proposed soft energy paths toward alternative futures that emphasized energy conservation and decentralized renewable energy technologies. They also assessed these pathways on their feasibility and compared them to regular trend extrapolating Business-As-Usual (BAU) scenarios; their conclusion was that soft energy paths were feasible when energy policies would be changed.

In the late 1980s, the emphasis in backcasting shifted toward exploring sustainable futures, for instance, in Canada (Robinson 1990, 2003), Sweden (Dreborg 1996; Höjer and Mattsson 2000), and the Netherlands (Vergragt and Jansen 1993; Weaver et al. 2000; Vergragt 2005). Since the early 1990s, a shift to stakeholder involvement in backcasting has also taken place (Vergragt and Jansen 1993; Dreborg 1996; Holmberg 1998; Holmberg and Robèrt 2000; Weaver et al. 2000; Quist et al. 2001; Van de Kerkhof et al. 2002; Robinson 2003; Quist and Vergragt 2006).

Up till now backcasting for sustainability has been applied to a wide range of different topics like river basins (Robinson 2003), transportation and mobility (Höjer and Mattsson 2000; Geurs and van Wee 2000; Banister et al. 2000), transforming companies into sustainable ones (Holmberg 1998; Holmberg and Robèrt 2000), sustainable technologies and sustainable system innovations (Vergragt and Jansen 1993; Weaver et al. 2000), sustainable households (Quist et al. 2001; Green and Vergragt 2002), climate policy options (Van de Kerkhof et al. 2002), industrial ecology (Giurco et al. 2011), and urban and rural land-use futures (Carlsson-Kanyama et al. 2008; Kok et al. 2006; De Graaf et al. 2009; Höjer et al. 2011). Interestingly, energy backcasting has made a revival too (Anderson et al. 2008; Gomi et al. 2011). For a recent overview of developments and applications in backcasting, see Quist and Vergragt (2006) or Quist (2007).

The examples show that there is a considerable variety of topics dealt with in backcasting projects (see also Quist 2007; Vergragt and Quist 2011). There is variety in whether and how stakeholder participation has been organized, in the number of steps in which the methodology has been split, in the methods that are used, in the nature and scale of the systems addressed (e.g., local, regional, national, consumption systems, or societal domains), in the number of visions developed and how the visions have been developed, and if the focus is on developing and analyzing future vision, on learning and raising awareness among stakeholders, or on realizing follow-up and implementation. Visions can be target-fulfilling images developed and analyzed by researchers, as well as more general visions developed and endorsed by a range of stakeholders. In addition, other approaches like transition management (Rotmans et al. 2001; Loorbach 2007), road mapping also use normative future visions and pathways on how to get there, though sometimes without explicitly referring to the term “backcasting”; this makes the variety even larger.

The extent to which impact and spin-off of backcasting has occurred varies too. For instance, the impact of backcasting experiments in the Netherlands on meat alternatives, multiple land use, and sustainable household food consumption has been evaluated (Quist 2007; Quist et al. 2011). Ten years after the projects, it was found that there were considerable differences in the degree to which follow-up and spin-off had occurred. The study showed that participatory backcasting may, but does not automatically, lead to substantial follow-up and spin-off at the level of niches in the research-, business-, government-, and public domains (Quist 2007; Quist et al. 2011).

To deal with the variety in backcasting, four different backcasting approaches have been analyzed and compared (Quist 2007: 24–30):

- The backcasting approach of Robinson (1990)
- The Natural Step backcasting methodology, as reported by Holmberg and Robèrt (Holmberg 1998; Holmberg and Robèrt 2000),
- The backcasting methodology applied at the Dutch STD program (Weaver et al. 2000; Vergragt 2005) and
- The backcasting methodology applied in the international Sustainable Households project (Quist et al. 2001; Green and Vergragt 2002; Vergragt 2005),

Based on this analysis, a more comprehensive methodological framework for participatory backcasting has been developed (Quist 2007), which is depicted in Fig. 42.2.

This framework is based on three key elements of participatory backcasting that also emerged from an earlier literature review (Quist and Vergragt 2006; Quist 2007):

1. The construction and use of desirable future visions or normative scenarios
2. Broad stakeholder participation and stakeholder learning (at the level of paradigms and values); usually stakeholders from different societal domains like business, research, government, and society are involved, with the latter including both the wider public and public interest groups

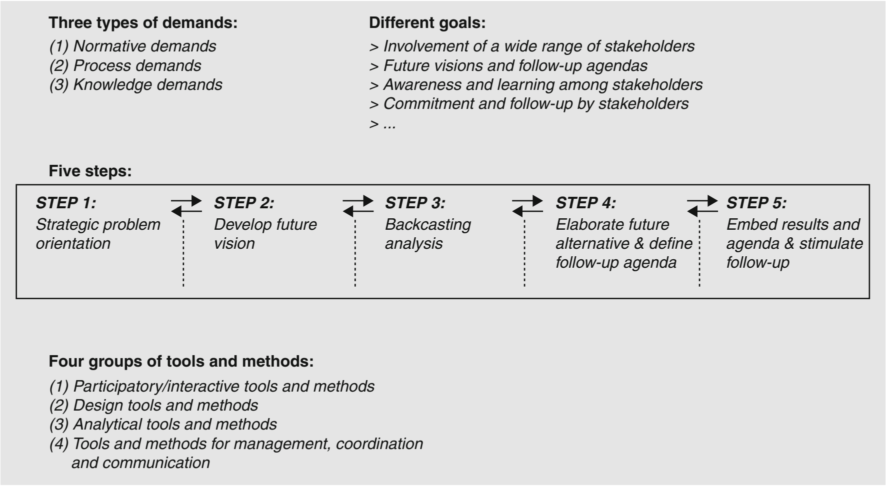

Fig. 42.2 A methodological framework for participatory backcasting (Quist 2007: 232)

3. Combining process, participation, analysis, and design, using a wide range of methods within an overall backcasting framework. Other characteristics of backcasting include problem orientation, system orientation, and turning visions into actions that can be started right away (see also Fig. 42.1)

The developed framework consists of five steps and the outline of a toolkit containing four groups of methods and tools. The backcasting approach reflected by the framework is not only interdisciplinary (by combining and integrating tools, methods, and results from different disciplines), but also transdisciplinary in the sense that it involves stakeholders, stakeholder knowledge, and stakeholder values. The following five steps have been defined:

STEP 1 *Strategic problem orientation*
STEP 2 *Develop future visions*
STEP 3 *Backcasting analysis*
STEP 4 *Elaborate future alternative and define follow-up agenda*
STEP 5 *Embed results and agenda and stimulate follow-up and implementation*

It must be noted that though the approach is depicted stepwise and seems to be linear, it definitely is not. Iteration cycles are likely to occur, while there is also a mutual influence between steps following one to another. In addition, the first step includes defining and bounding the system and includes defining time horizon, the number of visions to be developed, and developing the transdisciplinary or multidisciplinary research design.

Furthermore, four groups of tools and methods are distinguished. In each step of participatory backcasting, methods and tools can be applied from each group. The four groups of tools and methods that make up a toolbox for backcasting are (Quist and Vergragt 2006):

- *Participatory tools and methods.* This group comprises all tools and methods that are useful for involving stakeholders and generating and guiding interaction and dialogue among stakeholders. It includes specific workshop tools, creativity tools, discussion tools, and tools supporting stakeholders to conduct backcasting and participatory envisioning.
- *Design tools and methods.* This group consists not only of tools and methods for scenario construction, but also for elaboration and detailing future systems, as well as for the design of the stakeholder involvement process.
- *Analytical tools and methods.* This group of tools and methods is meant for assessing scenarios and designs and includes consumer acceptance methods, environmental assessments, and economic analyses. It also includes methods for evaluation of stakeholder interaction and stakeholder analysis.
- *Tools and methods for management, coordination and communication.* This group consists of methods and tools that are relevant for managing the project and the stakeholder involvement process. It includes the methods, which can be applied for shaping and maintaining stakeholder networks, communication, and coordination and is sometimes also referred to as organizational tools.

The framework also distinguishes three types of demands: (1) normative demands; (2) process demands; and (3) knowledge demands. Normative demands reflect the goal-related requirements for the future vision, as well as how sustainability is defined in the case under study and how sustainability is turned into principles or criteria that future visions should meet. Process demands are requirements with regard to stakeholder involvement and their level of influence in the way issues, problems, and potential solutions are framed and resolved in the backcasting study. Knowledge demands can be set to distinguish between the scientific and contextual knowledge strived for and how these are valued. Stakeholder knowledge and interdisciplinary knowledge in general does not meet regular disciplinary academic standards, but is crucial for the process. Most demands need to be specified in the beginning of a backcasting study. This can be done by the organizers, but it may also be the outcome of early stakeholder involvement. It is also possible that demands are partly set by the organizers and are partly based on stakeholder discussions.

In addition, various goals can be distinguished in backcasting studies, which can refer to process-related variables, to content-related variables, or to a range of other variables like knowledge or methodology development. In general, multiple goals are set in participatory backcasting, though they are not necessarily all equally important. Possible goals for backcasting studies include:

- Generation of normative options for the future and analyzing these on their environmental improvement, opportunities, and other consequences
- Putting attractive future visions or normative scenarios on the agenda of relevant societal and political arenas
- A follow-up agenda containing activities for different groups of stakeholders contributing to bringing about the desirable future
- Stakeholder awareness and learning with respect to the options, the consequences, and the opinions of other stakeholders

- Stakeholder support and commitment with respect to vision, designs, analysis, and commitment to the follow-up agenda

The framework presented here is intended as an overall methodological framework for participatory backcasting that covers a large part of backcasting methodologies available in the literature. It can be used to categorize backcasting methodologies in a systematic way. The presented methodological framework is also useful for researchers and practitioners who want to apply participatory backcasting. They can use the framework when elaborating an operational backcasting methodology for a specific study.

3 The STD Program and the Novel Protein Foods Case

Backcasting was introduced in the Netherlands in the early 1990s at the government funded sustainable technology development (STD) program as an approach for long-term thinking on sustainable technology development (Vergragt and Jansen 1993; Weaver et al. 2000). The STD program ran from early 1993 until 2002. Taking the factor 20 as a challenge for technology development and applying an interactive and stakeholder-oriented backcasting approach, major societal needs like nutrition, water, mobility, and housing were explored, searching for future sustainable alternatives for fulfilling these societal needs. This was done by developing future visions using the expertise of stakeholders from government, companies, research organizations, and public interest groups, which was followed by further elaboration and assessment of technological options with the potential to meet the factor 20 challenge (Weaver et al. 2000). A major rationale was to turn visions into actions by the stakeholders involved after a backcasting study had been completed.

Examples of factor 20 backcasting studies at the STD program are shown in Table 42.1 (Jansen 2003; Weaver et al. 2000). They include topics like fuel cells for boats, urban underground freight transport, novel protein foods as vegetarian meat substitutes, sustainable multiple land use in which function integration and reduction of the environmental burden in rural areas were combined, sustainable urban renewal in the city of Rotterdam, biomass-based (C1) chemistry, and sustainable municipal water systems. The STD program has been considered successful in identifying alternative solutions with the potential for achieving a considerable environmental reduction factor and developing follow-up agendas and strategic research programs, though the program did not succeed in establishing significant follow-up in all backcasting studies.

One of the more successful topics was meat alternatives and novel protein foods (NPFs), which emerged early during the STD program as a sustainable alternative for meat consumption and production. A backcasting study was initiated to elaborate this option, which was cofinanced by major Dutch food companies, and ran from 1993 till 1996. Results and stakeholder dynamics of the NPF backcasting study are dealt with and subsequently structured by the steps of the backcasting framework presented in Sect. 2.

Table 42.1 Backcasting projects at the STD program (Weaver et al. 2000; Jansen 2003)

Sub-program	Backcasting projects
Food/Nutrition	Novel protein foods Multiple sustainable land use Zero-emission and closed system greenhouse horticulture Whole crop utilization
Mobility/Transport	Urban underground freight transportation Demand-responsive public transport Hydrogen fuel cells for mobile applications
Buildings/Urban districts	Sustainable district renewal Sustainable office buildings
Water/Washing	Integrated sustainable water supply systems Sustainable washing
Chemistry	Conversion of hydrocarbons (C_1-chemistry) New (organic) cells for photovoltaic solar energy Whole crop utilization Fine chemistry process technology Natural fiber-reinforced composite materials

3.1 Step 1: Strategic Problem Orientation

What were major issues and developments in the meat consumption and production system in the Netherlands in the early 1990s? At that time, meat production and consumption was increasingly considered a major sustainability problem in the Netherlands. The country had (and still has) a large intensive livestock breeding sector, which has huge environmental effects due to emissions especially from manure, the inefficient conversion of vegetable protein to meat protein, a huge use of energy, and large land use for growing fodder crops abroad. Effects of livestock breeding include contributions to acidification, climate change, eco-toxicity, and nutrification or eutrophication of soils and surface waters, while growing fodder crops also prohibits using land and crops (biomass) for other applications such as biofuels or supplying raw materials to the chemical industry. In addition, intensive livestock breeding was raising serious animal welfare issues and vegetarianism was gradually increasing, though still limited.

Nevertheless, livestock breeding and meat processing was (and still is) an important economic sector in the Netherlands. Meat is an important source of proteins in people's diet and fulfills a range of non-nutritional requirements among consumers, such as taste, habit, custom, and status; these are strongly entrenched in the national culture and not easily changed. Stakeholders in the meat business have defended their interests by forming powerful alliances that had a strong influence on government policies and research agendas. In the Netherlands, all this had made the environmental problems associated with meat production and consumption extremely complex and persistent. Nevertheless, during the 1990s, some policies were initiated to mitigate the environmental burden of livestock production, targeting cattle farmers, for instance, by limiting and regulating when and how manure could be put on agricultural land.

Meat alternatives were not at all on the food innovation and research agenda in the Netherlands in the early 1990s, partly due to the large influence of both vested meat-related interests and incumbent players. Attempts to put soy-based texturized vegetable protein (TVP) foods on the market by a major Dutch food multinational in the late 1960s had failed (Aiking et al. 2006: 8, 29; Quist 2007), which had negatively influenced the interest in this topic in the Dutch food industry. However, in the early 1990s, several SMEs were producing meat alternatives, as a small niche market was gradually growing, which was served with foods based on TVP and single cell protein (SCP) in addition to soy-based tofu. A major breakthrough was the launch of quorn, a meat alternative based on proteins from a mold. The range of available meat alternatives was gradually increasing and vegetarian foods had become available in supermarkets. To a certain extent, this development was driven by growing animal welfare concerns and livestock epidemics, rather than by environmental concerns. For instance, environmentalists advocated to eat organic meat or sometimes (considerably) less meat, rather than encouraging the consumption of meat alternatives.

Against this background, the idea initiated at the STD program was called meat-like products, which was inspired by the possibility of meat-in-vitro from tissue breeding (Quist 2007). The essence of this idea was that if new meat alternatives could be developed with a low environmental burden but with similar characteristics and performance as high-quality meat products, consumers would be willing to buy and consume these foods instead of meat at a substantial level. This would result in considerable environmental improvement. As fierce resistance from the Dutch livestock and meat sector was expected, only a small group of carefully selected stakeholders from business and research was initially consulted by the chair of the STD program and a senior staff member of the Netherlands Council for Agricultural Research (NCAR).

Stakeholder consultation led to further development of the idea and early stakeholder support. As a next step, a feasibility study was commissioned to a consulting firm. The consultants proposed the term novel protein foods (NPFs) and studied the technological, cultural, environmental, and consumer-related aspects through desk research and expert interviews. Twenty potential NPF categories were identified, each consisting of a combination of a protein source from nonanimal origin and the technologies that were needed to extract the proteins and to process them into protein foods. The protein sources ranged from existing single cell proteins (SCP) and texturized vegetable proteins (TVP) to proteins from molds, algae, tissue breeding, and de novo protein synthesis in the laboratory.

Nearly all categories showed huge potential for environmental improvement, though they varied substantially in terms of technological maturity, as well as in terms of estimated development time and costs.

3.2 Step 2: Develop Future Vision

After the feasibility study, a larger backcasting project was initiated for further development and assessment of the vision. It included further research into technological and non-technological aspects. The follow-up study was multidisciplinary and included research into consumer-related and social aspects, food technology research, environmental life-cycle analysis, economic input–output analysis, and production costs calculations. A major issue was how to relate and integrate the results from different disciplines, for which knowledge demands and a research design were defined.

Normative demands were defined as terms of reference and included (1) developing alternative protein foods with a factor 20 environmental improvement compared to the environmental impact of pork meat at that time, (2) developing alternative protein foods that are attractive to both consumers and producers.

Different ways of stakeholder participation were part of the study, which relates to process demands though these were not always articulated and sometimes implicit. First of all, the multidisciplinary research was conducted by seven research groups from different universities and research institutes in the Netherlands. Involving these research groups was not only done, because of their expertise, but also because these research groups and their research organizations were major players in the food innovation system. It was expected that their involvement would result in support for the outcomes and could also facilitate follow-up research. A different type of involvement was achieved through funding by several companies and ministries. The funding organizations were also represented in the advisory board of the project, which was extended with key persons from research and public interest groups. Furthermore, a societal panel was established by applying a dialogue method from the field of constructive technology assessment entitled "Future Visions for Consumers"; a broad group of stakeholders from business, research, government, and public interest groups gathered in three meetings of 1 day and a half for discussing intermediate results, social aspects, opportunities, and dilemmas. Finally, the project was led by a retired research director from a major food multinational. He was supported by a project team at the STD program office and was also responsible for involvement of stakeholders.

During the backcasting project, a more detailed future vision was developed. The early vision comprised the idea of protein foods from nonanimal sources having a 20 times lower environmental burden than (pork) meat. The key of the more elaborated future vision was that novel protein foods – meeting the factor 20 requirement – could replace 40% of Dutch meat consumption in 2035, while 5% substitution would be obtained in 2005. The market share of 40% was based on the expectations that the market share of processed meat products would increase to 75% and that consumers would perceive NPFs as of similar quality as regular meat. Then NPF products would be capable of conquering half of the processed meat market. It was also expected that protein food consumption would stabilize at 117 gram per person per day, similar to the amount of consumed meat in 1995. An important change in the vision was the focus is on NPFs as a separate food category. Another change was the shift from meat alternatives toward NPFs as food ingredients; it was assumed that NPFs would be particularly attractive when applied as an ingredient in assembled and processed foods. Processed foods are, for instance, burgers, sausages, and minced meat. Assembled dishes and foods include pizzas, ready-made meals, soup, etc.

3.3 Step 3: Backcasting Analysis

The backcasting analysis, in which is looked backward from the desired future situation, evolves around the questions "WHAT changes are needed to bring about the vision?," "HOW can the changes be brought about?," and "WHO could or should contribute to realizing the vision and what activities should they do?" The WHO question can be extended by asking "who would oppose the required changes and how can this opposition be dealt with?" It is also possible to add a question on drivers and barriers for the proposed changes.

Looking from a backcasting perspective, WHAT are the needed changes? At the STD program a distinction was made between (1) technological changes, (2) cultural and behavioral changes, and (3) structural changes, which included changes in institutions, rules, and the organization of the socio-technical system under study.

With regard to *technological* changes, the future vision implied that food technology had to be improved considerably enabling to produce vegetarian protein foods similar or superior in taste and structure to meat, while also having a similar nutritional value as meat. The vision also implied *cultural* changes, not only related to the role and status of meat and meat consumption, but also related to the role and status of protein foods from other sources than animals. Obviously, a major cultural and behavioral shift would also be that consumers would (on average) purchase and consume significant volumes of vegetarian protein foods as part of their diet. Backcasting analysis also shed light on *structural* changes, as the meat sector would considerably decrease, and new protein food chains and a significant vegetarian food industry would emerge.

The HOW question refers to the overall strategy or mechanism, which could drive innovation leading to the envisaged 40% meat substitution by 2035. The strategy developed in the backcasting assumed that producers would take the lead and would serve a growing market demand. Producers were expected to develop new, more attractive products and to introduce them into the market in a way that they would seduce consumers to purchase and consume higher volumes of these vegetarian protein foods. This would be supported by more fundamental academic knowledge development and research, as well as by increasing awareness by consumers. These developments would also be supported by government policies mitigating

Table 42.2 The seven selected NPF options

Ingredients	Protein source
Protex: An ingredient resembling minced meat in structure that can be made from bacteria, yeasts, and plants	(1) *Spirulina* (cyanobacterium) (2) Pea (3) Genetically modified pea (4) Lucerne
Fibrex: A fibrous ingredient made by continuous fermentation of fungi	(5) *Fusarium* (fungus)
Fungopy: An ingredient produced by fermenting plants with fungi	(6) Pea with the fungus *Rhizopus* (7) Genetically modified lupine with the fungus *Rhizopus*

the socioeconomic effects of the decreasing livestock breeding and meat industry as well as by policies facilitating the rise of vegetarian foods. Though other strategies are possible too, such as levying meat, but these were not considered in the backcasting study.

The answer to the WHO question provided a range of stakeholders needed for the envisaged system innovation, which were already involved as stakeholders in the backcasting study. This list included food regulators, supermarkets and other retailers, institutional food catering companies, and public interest organizations. The latter includes consumer organizations, the environmental movement, and vegetarian and animal welfare groups. The activities that should be conducted by the different kinds of stakeholders are included in the follow-up agenda described in step 4.

3.4 Step 4: Elaborate Future Alternatives and Define Follow-Up Agenda

The production of NPF ingredients begins with crop growing. Following harvesting, crops are processed. The vegetable-based NPF options are produced using extraction, mixing, stirring, and texturing techniques. Vegetable-based material can also be used as the basis for a fermented product or for the cultivation of microbial biomass to arrive at the microbial NPF options. In principle, hundreds of potential NPFs are possible, which were clustered in around 20 clusters of a protein source and the technologies needed to turn them into a protein food ingredient.

Through a step-by-step selection process, a set of seven high-potential NPF options was generated, using criteria like technological feasibility, environmental reduction potential, attractiveness to consumers and firms, and structural economic effects. The seven NPF options are shown in Table 42.2 and are based on different vegetable and microbial sources like peas, lucerne, lupine, the fungus *Fusarium*, and the cyanobacterium *Spirulina* in combination with different technologies like fermentation, extraction, extrusion, and others. The seven NPF options were clustered in three types of ingredients. The first one resembled minced meat in structure and was called Protex. The second type was fibrous and was called Fibrex. The third one was a fermented ingredient, resembling tempeh and was called Fungopy.

Table 42.3 Possible end products with NPFs

Meal category	End product possibilities
Meal component	Burgers, nuggets, fingers, cordon bleu, soufflés, schnitzels, cocktail sausages
Meal ingredient	Stir-fry, slices, chunks
Ready-made meals	Soups, vegetable platters, rice/pasta dishes
Savoury snacks	Bread rolls, hot dogs
Sandwich filling	Pâtés, spreads, pastes, slices
Cocktail snacks	Balls, sticks, croquettes

While most of the technologies needed for producing NPF options were already incorporated in regular production techniques, technological research showed that it was not yet possible to provide the consumer with products that are sufficiently attractive to ensure a significant reduction in meat consumption. By translating consumer demands into product quality standards, a view could be derived of the areas in which fundamental knowledge was still lacking, namely, sensory and molecular sciences, nutritional value, scaling-up of production processes of NPFs, and also further improvement of the environmental impact of NPFs.

Consumer research emphasized that especially taste and convenience will determine whether consumers will be buying and consuming NPFs in 2035. Due to growing wealth and ongoing individualization, convenience will become more important and lead to a considerable growth of processed meat products, and assembled foods and meals. Health, global equity, and environmental concerns will become more important to consumers. The combination of growing health concerns, also driven by aging of the population, and convenience thus points in particular to processed products and assembled meals; some examples are given in Table 42.3.

Environmental research used LCA (life-cycle analysis) to compare the environmental impact of the selected NPF options with pork. It showed that the environmental impact of the options was 5–30 times lower than the environmental impact of meat (as shown in Table 42.4), when produced in 1995 using regular ways of crop growing. Nutrification, eco-toxicity, acidification, and global warming made up the main environmental impacts. In addition, it was found that the environmental impact of the seven NPF options could be considerably improved, when pesticides, manure, and transportation would be significantly reduced (see Fig. 42.3).

After the analysis, a pathway was elaborated that described a possible trajectory in which the future vision would be realized. It is summarized in Table 42.5 and shows the projected shares of meat and NPF foods in the Netherlands. It also shows the area of land needed to grow the NPF crops and how the environmental burden of total protein food consumption including the consumption of meat may evolve. It makes also clear that environmental efficiency improvements of meat may also make a significant contribution.

Also, seven clusters of follow-up activities were identified (see Table 42.6). The listed clusters of activities can be seen as a policy and action agenda for sustainable technological development around the option of novel protein foods.

Table 42.4 Environmental impact of pork meat and the NPF options in 1995

	Aquatic eco-toxicity	Nutrification	Acidification	Other themes	Total
Pork meat	67.1	11.1	10.3	11.5	**100**
(1) Protex from *Spirulina*	0.7	0.3	0.4	1.7	3.1
(2/3) Protex from peas	10.6	2.9	0.5	1.4	15.4
(4) Protex from lucerne	9.0	1.8	0.5	1.1	12.4
(5) Fibrex from *Fusarium*	3.2	0.9	0.6	2.0	6.7
(6) Fungopie from pea	10.4	2.9	0.4	1.9	15.6
(7) Fungopie from modified lupine	12.9	6.1	0.5	1.9	21.4

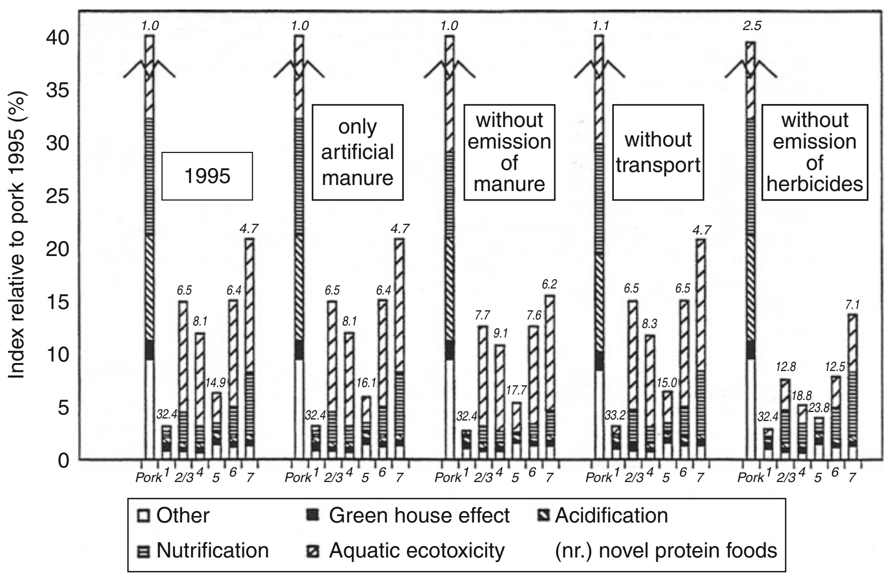

Fig. 42.3 The environmental impact of NPF options and pork meat expressed as an environmental index relative to pork meat. Results for several improvement options are also shown

3.5 Step 5: Embed Results and Stimulate Follow-Up

Although stakeholder communication and consultation took place throughout the backcasting activities, it was extended in the last phase and shortly after the project. This led to a range of research and development proposals and other initiatives.

Table 42.5 The total environmental strain per kg of product consumed

Year	Share of NPF (%)	Env factor NPF	Area of land needed for NPF crops (* 1,000 ha)	Meat share (%)	Env factor for meat	Total env reduction of NPF + meat (%)
1995	0	5	–	100	1.0	0
2005	5	5	41	95	1.2	20
2015	20	5	151	80	1.3	35
2025	35	10	240	65	1.3	47
2035	40	20	270	60	1.4	55

Table 42.6 Action agenda for Novel Protein Foods (Quist 2007: 97)

1. Communication with the general public and supply of adequate information
2. Professional education and transfer of generated knowledge
3. Consumer research and development of marketing instruments
4. Fundamental research and chain organization
5. Novel protein foods product development (both as foods and as ingredients)
6. Improvement of environmental impact of crop growing and LCA instruments for foods
7. Supporting regulation and social measures (facilitating the growth of a novel protein food sector and the reduction of the meat sector).

Ten years after the completion of the NPF backcasting study in 1996, its follow-up and spin-off was investigated (Quist 2007; Quist et al. 2011). Briefly, in terms of impact and spin-off, the backcasting study had been quite successful and various clusters of follow-up and spin-off activities and related networks of actors could be identified.

To start with, a large multidisciplinary research program entitled Profetas was initiated; involving research groups from different disciplines as well as several large food companies (see also Aiking et al. 2006). A second cluster of activities involved new R&D collaborations on meat alternatives, NPFs, and related supply chain management between firms and research institutes. It included the introduction of a new meat alternative made from dairy proteins by a major dairy firm in the Netherlands. A third cluster consisted of new activities by SMEs operating in the area of vegetarian protein foods and meat alternatives. These firms not only extended their regular activities and market share. They also started new activities, which were significantly stimulated by the NPF backcasting experiment and its spin-off.

A fourth cluster of activities was found in the government domain, where, as a spin-off of the NPF backcasting experiment, meat alternatives and vegetarian protein foods became a topic of policy making on sustainable consumption at the Ministry of the Environment and on sustainable supply chains at the Ministry of Agriculture.

A fifth cluster was identified in the public domain. Encouraged by the Ministry of the Environment, environmental organizations became more positive about meat alternatives and extended their activities on this topic. Vegetarian organizations used the NPF activities as a bandwagon for pursuing their own agenda and activities.

4 Backcasting for Sustainable Engineering

Five steps can be distinguished in participatory backcasting. This subsection deals with each step and presents methods that can be applied within a specific step.

4.1 Step 1: Strategic Problem Orientation

This step includes setting normative assumptions and targets, which can also be done through stakeholder participation. This step aims at exploring the problem from a systemic viewpoint, possible problem definitions, main unsustainabilities, opportunities, and possible solutions, identifying and involving relevant stakeholders. In addition, it should be analyzed how the problem is perceived by different stakeholders, how it relates to need and function fulfillment on an appropriate level – which is often a societal level or the level of socio-technical systems, how other stakeholders evaluate and judge the different problem formulations according to their own mind set, values, and interests, and how supply chain and demand side are interdependent and influence each other. It is important to take an integral viewpoint, while taking into account related consumption and production systems and present trends and developments for the whole system. Involving stakeholders is also important because they are experts in the field or system under study.

4.2 Step 2: Develop Sustainable Future Visions

The results of the strategic problem orientation step are the starting point for construction of sustainable future visions in which the identified unsustainabilities and problems have been solved. Stakeholder participation is important here, so workshops are an important tool in this step, though other participatory methods are also possible. The relevant question is how this societal need or function can be fulfilled in a sustainable way in the far future, assuming that it is always possible to define a societal need or function in a particular backcasting study.

Furthermore, different types of future visions are possible. For instance, within the STD program, a generic sustainable future vision was generated that contained several solutions for different major unsustainabilities, while in the university-based Sustainable Household (SusHouse) project, several more detailed scenarios were generated that depicted different sustainable lifestyles that could be seen as each other's substitutes. In addition, SusHouse scenarios did not only contain a vision and a description of main characteristics, but were elaborated with storyboards depicting daily life stories within a specific scenario, proposals for product-service systems supporting the sustainable scenario, and sometimes with images. It seems that generating single visions or several scenarios have each specific advantages and drawbacks, but a systematic evaluation of this has not been done yet. Furthermore, quite a number of specific methods are available for constructing future visions and normative scenarios. Scenarios or future visions can either stress the vision part, the feasibility, or the creative part. It is also possible to add first estimates or preliminary assessments for particular aspects like environmental improvement potential, consumer acceptance, socioeconomic aspects, etc.

4.3 Step 3: Backcasting Analysis

Though the overall approach is named after this step, it is actually the step that is least elaborated and described in the backcasting literature. Methods like elaboration of future visions, writing essays, explorative research, expert workshops, and stakeholder workshops have been suggested. Others have proposed to guide the backcasting step with specific guiding questions like “What are the necessary changes to make this future vision or scenario become true?” Several varieties can be distinguished in this step:

- A quick one just meant for identifying attractive solutions or clusters that would enable radically increased eco-efficiency. This was, for instance, done at the STD program (Weaver et al. 2000).
- A more elaborated variety, asking for the changes necessary for achieving a specific future vision or sustainable normative scenario, which was applied in the SusHouse project (Quist et al. 2001). This meta-question can be split into specific questions:
  - Which technological changes are necessary?
  - Which cultural and behavioral changes are necessary?
  - Which structural-institutional changes are necessary?
  - Which organizational changes are necessary for realizing the desirable sustainable future state?
- A very detailed one defining and describing also in-between states. For instance, if the final state is set in 2040, reasoning back from 2040 the state of 2030 can be described, before describing the state of 2020 and 2010. Though this variety is commonly used for explaining backcasting, it has hardly been applied in professional practice.

4.4 Step 4: Elaboration and Defining Follow-Up Agenda

Elaboration can take many forms and depends strongly on capacity, budget, and time available. Assessments, analyses, and feasibility studies are important in the first part of this step, while defining follow-up activities and agendas that enable implementation and realization on the longer term are important in the second

Table 42.7 Methods and tools for backcasting

Step 1: Strategic problem orientation
Setting demands and basic assumptions
System and regime analysis
Stakeholder analysis
Problem and trend analysis
Socio-technical mapping
Step 2: Generating future visions
Idea articulation and elaboration
Generation of multiple perspectives
Creative techniques
Step 3: Backcasting analysis
WHAT-WHO-HOW analysis: technological, cultural-behavioral, organizational, and structural-institutional changes
Stakeholder identification: required stakeholders and actions
Drivers and barriers analysis
Step 4: Elaboration and define follow-up agenda
Scenario elaboration (turning vision into quantified scenario)
Scenario sustainability analysis
Generation of follow-agenda
Transition pathway
Step 5: Embed results and stimulate follow-up
Dissemination of results and policy recommendations
Generation of follow-up proposals
Stakeholder meetings

part of this step. Differences can be noticed too. For instance, in the SusHouse project, several normative scenarios were elaborated and assessed by small research teams and the results were fed into another stakeholder workshop. At the STD program, backcasting was used to identify promising clusters and directions within a single future vision, and those clusters were subjected to feasibility study and further elaboration in particular projects. This enabled to involve more specialized researchers, while stakeholder involvement became more focused too.

4.5 Step 5: Embedding of Action Agenda and Stimulating Follow-Up

As the aim of backcasting for sustainable strategies is to bring about change in processes, system innovations, or transitions toward sustainability, it is important that the outcomes of the backcasting study are embedded and taken further by stakeholders or groups of stakeholders. It has already been mentioned that each societal group has to deliver its contribution, while it cannot be blueprinted due to the complex nature of social change and social learning processes. Nevertheless, the future vision can act as a guiding image or leitmotiv, while R&D and action agenda contain a bundle of possible pathways and suggestions that must be elaborated by appropriate stakeholders.

Table 42.7 below provides a schematic overview of methods and tools by step.

5 Conclusions

In this chapter, it has been argued that backcasting is a useful tool for engineers to develop pathways leading to system innovations and transitions for sustainability. It has provided an overview of the current variety in backcasting and has presented a methodological framework that covers most of this variety, which was illustrated using a backcasting study on novel protein foods and meat alternatives that was conducted at the STD program in the Netherlands. This chapter has also elaborated the backcasting framework into a methodology that can be applied to define strategy processes in engineering design.

It has been argued that backcasting is in particular useful in case of complex societal problems, when there is a need for major change, when dominant trends are part of the problem, when there are side effects or externalities that cannot be satisfactorily solved in markets, and when long time horizons allow for future alternatives that need several decades to develop. Backcasting is very well equipped to deal with sustainability, as sustainability is a normative concept and backcasting is a normative approach to foresight leading to normative scenarios and dealing with the question what is the future we would like to have. Though very often a problem-oriented perspective is taken, it is also possible to start a backcasting project with a socio-technical option.

Backcasting is less well equipped to deal with emerging technologies such as nanotechnology. Those cases are technology driven, and the dominant direction is to push the technologies based on the expectation that they fulfill a need, whereas in backcasting, needs and the articulation of alternative solutions to fulfill those needs have most added values. In case of emerging technologies like nanotechnology, GMO's, and ICT, there are strong normative aspects at play and a constructive technology assessment approach (see also Chapter 35) is more appropriate in these cases.

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