Available online at www.sciencedirect.com

SCIENCE DIRECT®

Ecological Economics 50 (2004) 293–314

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

The early history of modern ecological economics

Inge Røpke*

Department of Manufacturing Engineering and Management, Technical University of Denmark, Matematiktorvet, Building 303 East, 2800 Kgs. Lyngby, Denmark

Received 4 September 2003; received in revised form 4 February 2004; accepted 4 February 2004

Abstract

This paper provides a historical perspective for the discussion on ecological economics as a special field of research. By studying the historical background of ecological economics, the present discussions and tensions inside the field might become easier to understand and to relate to. The study is inspired by other studies of the emergence of new research areas done by sociologists and historians of science, and includes both cognitive and social aspects, macro trends and the role of individuals. The basis for the paper is a combination of literature studies and interviews with key researchers from the field. The story opens with the emergence of the new environmental agenda in the 1960s, which was influenced by the scientific development in biology and ecology. Then it is outlined how the environmental challenge was met by economics in the 1960s. Around 1970, the basic ideas of ecological economics were given modern formulations, but it took a long gestation period from the beginning of the 1970s to the end of the 1980s, before ecological economics took shape. During this gestation period, the personal relationships between the actors were formed, and the meetings that were decisive for the formal establishment of ecological economics took place.

Keywords: The history of ecological economics; Sociology of science; History of science

1. Introduction

Ecological economics was institutionalized with the establishment of the International Society for Ecological Economics in 1988 (first conference 1990) and the journal *Ecological Economics* (first issue 1989). Since then, a wide spectrum of research topics has been presented in the journal and at the conferences, and the large membership and the increasing number of regional societies illustrate the broad interest in this new field of research. As the contributions are very diverse, recent years have seen some discussion on the characteristics and delimitation of ecological economics: Is ecological economics a transdiscipline; a new paradigm; something different from environmental economics or, rather, a part of environmental economics, etc.; open for anything with a relation to the environment, or something more

* Tel.: +45 4525 6009; fax: +45 4593 6620.
E-mail address: ir@ipl.dtu.dk.

0921-8009/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2004.02.012

well defined? (Turner, 1999; Spash, 1999; Bergh, 2001; Costanza, 2002; Söderbaum, 2000; Martinez-Alier, 2002, Chapter 2). The question can also be posed in a more normative way: In which direction should ecological economics be developed in the years to come? This paper forms part of a research project dealing with these questions,[1] and the intention with this specific paper is to provide a historical perspective to the discussion. By studying the historical background of ecological economics, the present discussions and tensions inside the field might become easier to both understand and to take a position on.

This paper concerns only the period from the beginning of the 1960s to the end of the 1980s—what could be called the early history of modern ecological economics. The term *modern* ecological economics is used, because the paper refrains from covering the long history of precursors and related ideas that did not lead to an institutionalized establishment of a new field of research (these ideas are well described by Martinez-Alier, 1987; Christensen, 1987, 2001; Cleveland, 1987). The term *early history* is used to embrace the ideas and processes that led to the formal establishment of the journal and the society. With this delimitation, the paper covers only the part of the story that is necessary to discuss the questions raised above, so it can only be a step on the way to answering them, and the intention is to write a follow-up paper on the development of the research field after the establishment of the society. However, I hope that the present paper can also be useful for newcomers to ecological economics by making it easier to become familiarized with the field. As I had not taken an interest in environmental research before the end of the 1980s, I felt the need for such a survey myself, and the work with this paper has emphasized how much there is to catch up with when one has not taken part since around 1970. Finally, the story of ecological economics can be of more general interest, because the development of the field can be seen as an example of a trend towards the establishment of transdisciplinary fields, especially those crossing the border between natural and social sciences.

[1] The research project is supported by the Danish Social Science Research Council.

The story told here is a combination of cognitive and social history. The focus is on the 'social construction' of ecological economics: How did the social conditions influence the emergence of the field? Who took the initiative? What was their motivation and their intellectual baggage? Which areas were combined in the field, and what could the participants agree on? Since Kuhn and the ensuing development of the sociology of science, a story of scientific development cannot be told as a tale about how we are becoming ever wiser. Different perspectives can co-exist; social processes, both outside and inside the research community, and personal strategies, etc. play a part in the formation of scientific fields, so the tale must include several layers. Studies of other scientific fields have been used as inspiration to give a clue as to what to look for when telling a story about ecological economics.

Obviously, the paper is based on literature studies, but much more important are the interviews (a few by telephone) I had with key persons in the formation of ecological economies. These interviews have been necessary both to guide me through the jungle of literature and to give me information that is not available in a written form. From October 2002 until March 2003, I interviewed the following persons: Herman Daly, Mick Common, Robert Costanza, Sylvie Faucheux, Carl Folke, John Gowdy, AnnMari Jansson, Joan Martinez-Alier, Charles Perrings, John Proops, Clive Spash and Peter Söderbaum. Each interview gave me valuable new information, and I have many ideas regarding other persons whom I would like to interview (e.g. to include perspectives from more countries), but time and resources require that a line is drawn. As ecological economics springs from many different roots, it is difficult for one person (in this case with a socio-economic background) to cover the field in a reasonable way—and it turned out to be much more difficult than I had expected. So I hope that others will add to the picture by giving their accounts.

Section 2 summarizes very briefly the theoretical inspiration from studies of other scientific fields. Then the story opens in Section 3 with the emergence of the new environmental agenda in the 1960s and the different discourses related to this agenda. The environmental agenda was influenced by the scientific development in biology and ecology that is dealt with

in Section 4, focusing especially on the emergence of systems ecology. Section 5 outlines how the environmental challenge was met by economics in the 1960s, emphasizing the contributions that later became foundational for ecological economics. Around 1970, the basic ideas of ecological economics were given modern formulations, but it took a long gestation period from the beginning of the 1970s to the end of the 1980s, before ecological economics actually took shape. This gestation period is dealt with in Section 6, supplemented with an outline in Section 7 of the personal relationships between the actors and in Section 8 of the meetings that were decisive for the formal establishment of ecological economics. Finally, Section 9 summarizes briefly the processes related to the theoretical inspiration.

2. Theoretical inspiration

Both historians and sociologists of science have contributed studies on the development of new research areas. These studies cover the emergence of both broad fields such as management studies (Whitley, 1984) and narrower specialties such as radioastronomy, finance, and systems development (Mulkay, 1976, Wenneberg, 1999). Reflecting on his study of radioastronomy, Mulkay (1976) writes that the literature on the emergence of scientific disciplines is scant and that it seems too piecemeal and uncertain to provide convincing hypotheses for his study, which he considers exploratory. Still, in 1999, Wenneberg stated that many case studies had been made, but there is no integrated theoretical development regarding the many questions concerning the constitution and development of theoretical specialties. Although an integrated theoretical framework is not available, the case studies can provide much inspiration regarding what to look for in a study of the emergence of a new scientific specialty or field. Already in 1976, in the introduction to an anthology *Perspectives on the Emergence of Scientific Disciplines*, Lemaine et al. (1976) used the then fragmented studies of disciplines and specialties to formulate general questions that can be used to inform further studies of this kind. These questions provide a useful scheme to facilitate and systematise further analysis, as they help to ensure that factors that may be of crucial importance in specific cases are not ignored. The list emphasizes that the emergence of new research areas has to be studied as a combination of cognitive and social processes: it is not just a study of how ideas develop from each other, but just as much a study of the social processes that enable the ideas to form a new research area. I have used the list as well as specific case studies as inspiration for the work behind this paper, but as the list mostly relates to natural sciences and tends to fit the analysis of the emergence of relatively narrow specialties better, some questions are not relevant and others need modification. In the following, some of the guiding questions are summarized briefly under the headings used by Lemaine et al., who emphasize that the order does not represent their degree of significance.

(1) *Internal intellectual processes*. As all research stems from previous ideas and experience, the intellectual origins can be traced: Which previous scientific or technical developments were important? What were the distinctive scientific problems that provided the focus for the new research area? Were they the outcome of a major theoretical advance, attempts to resolve anomalies, or observations based on empirical data? Did research techniques play any part in changing the direction of scientific inquiry?

(2) *Social processes within the research community*. What was the intellectual background of those scientists who laid the foundation for the field? What was their position in the research community? Did the social organization of the research community affect the dissemination and reception of the initial results? Was a core work ignored initially because the author failed to communicate with those scientists who would have been more receptive to his work?

(3) *External intellectual factors*. Sometimes ideas, observations or techniques evolved in the course of practical activities are transmitted to scientific researchers, e.g. by personal contact between scientists and relevant non-scientists or through the media. To what extent was the scientific development affected by the introduction of information generated outside the research community?

(4) *Immediate institutional context*. The academic context and the associated institutions, such as the university system and the opportunities for professional advancement might favour one specialty more than another. Did research into the new area originate and spread within the university system or within some other social context? Did any changes occur in the social context that were especially favourable or unfavourable to the exploration of the new field? Did the scientists deliberately use institutional mechanisms to overcome opposition from established disciplines?

(5) *Specific economic and political factors*. Research is influenced by economic and political processes in the wider society, including government policies in specific areas. Did scientists respond directly to specific economic or political problems? Were there changes in the economy which affected governmental or industrial support for particular types of scientific research?

(6) *Diffuse social influences*. Since the 1950s, the cost of scientific research has increased, and governments require a more tangible return for their support. Non-scientific considerations tend to play an increasingly important part in determining the direction of scientific development, and scientists have to become more receptive to the requirements of lay audiences. Was this field particularly attractive to new entrants to science, and, if so, why? Was it seen to be especially significant in relation to specific social values? Was there any organized or diffuse movement among scientists (or among lay persons) in its favour?

Cutting across points 2 and 4, the social processes within the research community and the institutional context, I will add the importance of looking for innovators, mediators and entrepreneurs among the persons active in forming a new field (concepts inspired by the 'garbage can' model from organization theory, cf. March and Olsen, 1986). As already emphasized, a new field cannot be created by original ideas alone—the ideas have to be diffused, and a 'reputational organization' (Whitley, 2000) has to be established. Sometimes a person can have all the necessary skills, but usually different persons complement each other in the process.

The questions are not answered one by one below—they are only used as inspirational devices regarding what to look for and include in the historical account (and some of the questions are more relevant for the follow-up paper on the more recent development). The story is organized chronologically, and different layers are included. In the final section, the story is briefly summarized in relation to the theoretical inspiration.

3. The environmental agenda of the 1960s: a belated breeding ground

The basic observation in ecological economics is banal and difficult to disagree with: the human economy is embedded in nature, and economic processes are also always natural processes in the sense that they can be seen as biological, physical and chemical processes and transformations. However, the implications of this statement for the study of human societies and economies are not banal. The basic idea of what becomes ecological economics is that the economy ought to be studied also, but not only, as a natural object, and that economic processes should consequently also be conceptualized in terms usually used to describe processes in nature. The physiocrats can be said to have done this by their focus on the product of land as the basic source of input to the economy, but more elaborate ideas concerning the natural aspects of economic processes appeared in the wake of the emergence of thermodynamics in the middle of the 19th century. Thermodynamics inspired individuals to conceptualize economic processes in biophysical terms—in terms of flows of energy and matter. Martinez-Alier (1987) succeeded in revealing many half-forgotten authors who had given what we today would consider to be very interesting and relevant contributions, and he argues that objectively the school of ecological economics has existed since the 1880s, but it was unacknowledged even by its own members (p. 3). Several contributions so effectively 'disappeared' that not even Georgescu-Roegen knew about them when he wrote his epoch-making book *The Entropy Law and the Economic Process* (Georgescu-Roegen, 1971). Thermodynamics also inspired some

to conceptualize biological systems in terms of flows of energy and matter, in particular, Lotka's contribution from 1925 is often pointed out as central, so energy was an obvious measure to cut across biotic and abiotic processes and to provide a common perspective on processes in nature and society.

In discussions about the reasons for the lack of breakthrough for this perspective, the division of labour between disciplines is usually emphasized (Costanza et al., 1997). Some of the most important contributions came from chemists such as Ostwald and Soddy (who had both been awarded the Nobel Prize for other contributions), and their attempts to cross the border to the social sciences was met with harsh critique, e.g. Martinez-Alier (1987, Chapter 12) draws attention to Max Weber's critique of Ostwald and his defence of the separation between the sciences. Other reasons are also mentioned, e.g. some contributions were written in 'obscure' languages, and the perspective was in opposition to the dominant marginalist thinking in economics, to the labour theory of value and to dominant thinking in biology. While these reasons are all relevant, it can also be suggested that these authors did not succeed in establishing the new perspective, because they did not provide answers to the most pressing problems of the time when they were writing. Other problems were considered more relevant by the academic community as well as by broader social groups.

In line with this argument, the ideas could not set root before new social conditions and discourses had prepared the ground. Therefore, the story of modern ecological economics started in the 1960s with 'processes at work in the wider society' and 'diffuse social influences' (points 5 and 6 on the list of Lemaine et al.). The breakdown of borders between scientific disciplines also plays a role, but in the beginning only at the individual level. Later in the process the more general acceptance of transdisciplinarity became important.

Several social changes and related discourses were instrumental in preparing the ground for ecological economics. Firstly, the new conceptualization of pollution and environment that became part of the general public awareness from the beginning of the 1960s. One of the most important kick-starters was Rachel Carson's eye-opening book (Carson, 1962) pointing out the severe impact of pesticides. Another was the protest movement against the dangers of nuclear fallout and waste disposal, initiated by Barry Commoner and other scientists in 1958 and a few years later extended to deal with the dangers of chemical fertilizers and detergents (Worster, 1994, p. 354; Craige, 2001, p. 80). The increasing public interest in the impact of pollution, strongly encouraged by social movements, led politicians to take the first steps towards regulation. As Weale (1992) pointed out, most Western countries went through an almost parallel development having established councils of independent experts and branches of the bureaucracy by the end of the 1960s and the beginning of the seventies (p. 14).

Two other related discourses characterized the 1960s and the beginning of the 1970s: the dramatic increase in world population and the question of the sufficiency of food and other resources. Since the Second World War and the succeeding decolonization, the newly independent countries had been expected to strive for 'development', but eventually this development was seen to be undermined by the fast growing population in developing countries. The population issue was brought to the forefront by Paul Ehrlich in the provocative book *The Population Bomb* (Ehrlich, 1968). As a biologist, he had an obvious inclination to perceive human beings as a species and to see the problems that might follow when the number of individuals from a species increases dramatically. Related to the population issue is the Malthusian concern about resources: Can we grow enough food, and will we run out of resources? Paul Ehrlich and others deeply questioned the sufficiency of food production. The issue of resources had been given some attention in the wake of the war (e.g. the establishment of Resources for the Future in the 1950s), but had not really attracted popular interest until the publication of *The Limits to Growth* in 1972 (Meadows et al.). With this book, the resource aspect of the global challenge was put on the agenda. The United Nations Conference on the Human Environment in Stockholm in 1972 demonstrated that the challenges in relation to the environment, population growth and resources were now widely acknowledged.

Finally, the discourse on energy became central from the beginning of the 1970s. There was a concern

about energy in relation to the discussion on resources, but the real breakthrough for this concern required the oil price shock in 1973 and the ensuing years of energy crisis. With the new powerful discourses on pollution, population, resources and energy, the breeding ground for ecological economics was well prepared.

Among the persons who were instrumental in initiating the new discourses, several biologists played an important role. Carson, Commoner and Ehrlich had a background in different branches of biology, and many others could be mentioned. In the next section the Odum brothers are introduced in relation to the presentation of ecology, which became a framework for understanding the connections between the different issues.

4. Systems ecology

Several biologists were important actors influencing the discourses in the 1960s and taking part in the emerging environmental movements. Apart from those already mentioned, the brothers Eugene and Howard T. Odum were among the prominent biologists, and their special contribution was to promote the integration of the scientific perspective of ecology into the environmentalist movement. Ecology first really developed into a specific branch of biology in the 1950s (Kaarhus, 2000). Ecology had existed as the study of the interaction between organisms and their conditions for survival since the expression was coined by Haeckel in 1866 (and the first society was established in the 1920s), but in the 1940s, it was still considered a subordinate branch of biology compared to more basic disciplines such as physiology and morphology (Craige, 2001, p. 39). Most ecological studies had organisms as their point of departure and considered the relationships to other plants and animals, but some contributions pointed in new directions, e.g. Shelford and Clements on holism, Tansley's introduction of the ecosystem concept in 1935 also including the physical environment of the organisms, Hutchinson's and his student Lindeman's application of methods from the physical sciences in the study of natural systems. Lindeman pioneered a new methodology for studying ecosystems through the analysis of energy flows based on the conversion of biomass units into energy units (Craige, 2001, p. 35). These innovative contributions were synthesized by E. Odum, when he published his textbook *Fundamentals of Ecology* in 1953—a book that became a landmark for the establishment of ecology with a systems perspective. Contrary to other textbooks, the book introduced the whole before the parts, starting with the ecosystem level and proceeding with the organisms that were parts of the system. Furthermore, the description of the ecosystems included both biotic and abiotic components, using energy as the common denominator that integrated biotic and physical components. In the presentation of this perspective, E. Odum was much influenced by his younger brother H.T. Odum, who had a training in meteorology, had studied with Hutchinson and had become acquainted with Lotka's book (Craige, 2001, p. 35, based on information from Frank Golley). In the second edition of Fundamentals in 1959, HT wrote the chapter on ecological energetics (Hall, 1995). The research of the Odum brothers in the fifties contributed substantially to the development of new methods to study energy flows in a systems perspective. In particular, their study of coral reefs from 1955 was a breakthrough. An important methodological innovation arose from the increasing concerns over the effects of nuclear fallout and radiation on living organisms. The authorities financed research on how radiation could permeate a biotic system, and this research was based on the use of radioactive isotopes, which made it possible to track the movement of materials and energy through an ecosystem (Craige, 2001, Chapter 3).

At this time, the holistic studies of ecosystems in terms of energy flows were combined with a notion of equilibrium or stability: ecosystems tended to develop towards maturity—a stable state (homeostasis) where the interdependencies inside the system were highly complex, mutual dependencies and cooperation were just as important as competition, and a high diversity was achieved. This notion corresponded with traditional understandings from previous studies of ecological succession in natural landscapes (Worster, 1993, Chapter 13), and it fed well into the emerging environmentalist movement: human beings should preserve harmonious ecosystems in their own best interest. Furthermore, societies should learn from nature. Biologists should not only be concerned with nature in a narrow sense, but should widen their

perspective to issues that were usually considered only social. Charles Hall, a student of H.T. Odum, has put it this way: "I remember the incredible excitement when it dawned on me and other graduate students in Chapel Hill back in the late 1960s that the ecology we were studying was about far more than the rivers and estuaries we were measuring at the time and that our province should include essentially the entire world of the interface between society and nature in its broadest sense" (Hall, 1995, p. 159). A special part of the engagement in social issues concerned economics. Through their experience with environmentalism, the Odums learned the importance of economic considerations in decision making and found it necessary to communicate also in economic terms to explain to politicians and voters the importance of ecosystems. Their experience sowed the seeds of later discussions on valuation.

Systems ecology co-developed with a more widespread meta-theoretic interest in general systems theory. The takeoff for systems theory dates back to a series of transdisciplinary conferences supported by the Macy Foundation in the US just after the Second World War (Kaarhus, 2000). The theme was "Circular Causal and Feedback mechanisms in Biological and Social Systems", and in the wake of these conferences the perspective of cybernetics or systems theory emerged. The focus was on similarities between patterns of interaction in natural and social systems and on self-regulation inside systems through communication and feedback mechanisms. The formal study of systems brought concepts such as emergent properties into common use as well as the mantra 'the whole is more than the sum of its parts'. Important contributions during this period were from Wiener (1948) and Bertalanffy (1950). In the 1960s, Forrester developed a formal language that became used in the models behind *The Limits to Growth* (Meadows et al., 1972), and H.T. Odum also developed a formal language of his own (Hall, 1995). In 1971, H.T. Odum's influential book *Environment, Power, and Society* (Odum, 1971) was published, summarizing his insights from studying the energetics of ecological systems and applying it to social issues.

Both systems' thinking and ecology came to influence several scientific fields. A field having much in common with the later development of ecological economics was ecological anthropology. Gregory Bateson was strongly influenced by the Macy conferences and imparted cybernetic explanations to anthropology, and his student Roy Rappaport made an influential study (Rappaport, 1968) of a small group of people in New Guinea, where he considered the territory and the society as an integrated ecosystem with, e.g. rituals serving as mechanisms for regulating the system (Kaarhus, 2000).

As mentioned, the concept of ecology came into widespread use. As Worster (1993, p. 156) puts it: "The science of ecology has had a popular impact unlike that of any other academic field of research. Consider the extraordinary ubiquity of the word itself... On several continents we have a philosophical movement termed 'Deep Ecology', but nowhere has anyone announced a movement for 'Deep Entomology' or 'Deep Polish Literature'." In 1970, the American magazine, *Newsweek*, announced the dawning of "the Age of Ecology", and in 1971 the sales of the Odums' Fundamentals peaked with almost 42,000 copies sold (Craige, 2001, pp. 47, 80).

5. Scientific response: economics

The emerging environmental agenda called for contributions from the social sciences. The new demand led partly to the recovery of earlier contributions relating to issues now labelled 'environmental', and partly to the application of available tools for the analysis of new issues. In economics, different strands of intellectual development occurred based on different traditions. The economics of natural resources already had a long history dating back to Malthus and Jevons in the 19th century and to Hotelling in the 1930s, and after the Second World War the American government focused on the issue of natural resource scarcity and initiated studies in this field. In 1952, the President's Materials Policy Commission published the Paley Report (Paley Report. The President's Materials Policy Commission, 1952), which expressed concern with the soaring demand for materials, and in 1955 a transdisciplinary conference on "Man's Role in Changing the Face of the Earth" (Thomas, 1956) provided a broad documentation of environmental problems with a focus on the possible exhaustion of mineral resources (Fischer-Kowalski, 1998). In response to these concerns, the independent research organization Resour-

ces for the Future published the much cited *Scarcity and Growth* (Barnett and Morse, 1963) in 1963, and in the following years the literature on the optimal use of renewable and non-renewable resources, common property problems, etc. grew rapidly (Peterson and Fisher, 1977).

In a related, but relatively independent strand of development, the focus on resources was supplemented with a focus on the amenities associated with unspoiled natural environments—aesthetic value, recreation, etc. This concern for the best use of the natural environment also goes back a long way, to John Stuart Mill, but systematic economic analysis of amenities and conservation appeared in the 1960s (Krutilla, 1967, Fisher and Peterson, 1976), sometimes referred to as amenity economics.

The third field to take off in the 1960s concerned pollution. Fisher and Peterson (1976, p. 12) point to Allen Kneese's revival of Pigou's concept of externalities in relation to a study of water pollution as the starting point (Kneese, 1962). Others had contributed to the exploration of externalities, but they had little influence on mainstream development. Kapp, in particular, was later rediscovered, see, e.g. Spash, 1999 and Costanza et al., 2001—in this German edition of the 1997 introductory book, the German editorial group has included Kapp. Welfare economics took on the study of the environment specified in the following tasks: the background of the economic system's allocative failures, the measurement of the surplus foregone due to these failures, and the design of allocation systems capable of realizing the foregone surpluses (Crocker, 1999). These tasks became the core of environmental economics when this field came into being in the beginning of the 1970s.

Stated very crudely, these different strands of thought corresponded to the three functions of the environment for the economy that later appeared in introductions to environmental and resource economics:

- resources for production
- assimilative capacity to absorb pollution
- direct utility related to the enjoyment of nature (amenity value).

Several issues cut across the fields and they have theorems in common, but the textbooks tend to preserve the distinction between natural resource and environmental economics (Pearce, 2002), with aspects of amenity appearing in both main categories.

In the formative period of modern environmental and resource economics in the 1960s, serious concerns regarding the scope of the problems were sometimes voiced. Boulding's essay on spaceship Earth (Boulding, 1966) stroke a responsive chord, describing the transition from a "cowboy economy" without limits to a "'spaceman' economy, in which the earth has become a single spaceship, without unlimited reservoirs of anything, neither for extraction nor for pollution". Boulding referred to basic physical laws in his argument, and this perspective was shared by two other near simultaneous contributions from Daly (1968) and Ayres and Kneese (1969), followed by a more elaborate report by Kneese et al. (1970). Daly, who draws on the work of Boulding (earlier contributions than the spaceship paper) and Georgescu-Roegen (see below), intended to recast economics as a life science focusing on the metabolistic character of economic activities, the "passage of low-entropy matter-energy through its life-supporting input–output transformations into high-entropy waste" (p. 403) and emphasizing the large size that the human economy had achieved in relation to the natural environment. Ayres (who was educated as a physicist) and Kneese took their point of departure in the law of conservation of mass and viewed the economy in terms of materials balances: the inputs of raw materials, foods, etc. to the economic system are "partly converted into final goods and partly become waste residuals. Except for increases in inventory, final goods also ultimately enter the waste stream" (p. 284). This implies that disposal of residuals is a normal and inevitable part of economic processes as are the related external diseconomies. Externalities are not exceptional cases, as they are often considered in the economic literature, but pervasive and persistent, and as population and production grow, they become progressively more important (Ayres and Kneese note that they are in line with Kapp in their perspective on externalities).

Whereas Daly and Ayres and Kneese share the fundamental perspective, they apply different tools for modelling the interactions between the economy and the environment: Ayres and Kneese relate to the general equilibrium framework, whereas Daly proposes an input–output model including both economic

and ecological sectors. As Peter Victor (1972) has pointed out in his comparison of the models, Ayres and Kneese do not consider what happens to the materials once returned to the environment: "In a sense, Ayres and Kneese have gone as far as the ecological door but no further", whereas Daly's model "recognizes the interactions that go on outside the part of the world that is termed economic" (pp. 27, 39). So the wastes can interact with other ecological components and affect the supply of 'free goods' from the ecological sector to the economic sector. Victor (1972) also outlines the few other models that were around at the time, (Isard, 1969 is especially interesting for his combination of economic and ecological modelling) and develops a model of his own.

In 1971, the groundbreaking work by Nicholas Georgescu-Roegen appeared, *The Entropy Law and the Economic Process*. He had already published some thoughts about entropy in the introduction to a collection of theoretical papers (Georgescu-Roegen, 1966), but in the new book, he elaborates extensively on the implications of the entropy law for economic processes and how economic theory could be grounded in biophysical reality. The scope of the book is extremely broad including physics, economics, philosophy of science, etc. Some have seen the book as a breakaway from Georgescu's earlier work on pure theory, but others have emphasized the continuity, as his preoccupation with the nature of economic value constitutes a common thread (Gowdy and Mesner, 1998). In relation to later controversies of ecological economics, it is important to mention that Georgescu was very critical of single-measure theories of value and utility and that he repudiated energy theories of value.

The contributions from Boulding, Georgescu-Roegen, Daly, Ayres and Kneese had much in common with the ideas brought forward in relation to systems ecology. It was probably not accidental that these authors had broad scientific backgrounds: Boulding and Georgescu-Roegen were the very unusual kind of Renaissance men, cutting across several disciplines, including meta-theories such as systems theory, Daly had studied ecology, and Ayres and Kneese combined physics and economics (also others who later became important contributors to ecological economics had broad disciplinary backgrounds). Whereas the literature in relation to the three functions of the environment for the economy basically applied the already available theoretical and methodological tools to analyse new phenomena, the studies related to entropy, materials balances, metabolism, etc. implied a reconsideration of the relationship between society and nature (Fischer-Kowalski, 1998 tracks the use of the concept of metabolism in relation to social systems). Human society is also always nature; social processes are integrated with metabolic processes, and the enormous increase in human population and economic activities imply that nature's basic support of human life can be threatened. This understanding called for new approaches to conceptualize the relationship between society and nature, and added the more basic perspective of life support functions to the three functions mentioned above.

The seeds were sown for modern ecological economics, but the concept did not appear until several years later. Lotka had used the concept biophysical economics (Cleveland, 1987), but the word was never really taken on, and in the 1970s, Georgescu used the term bioeconomics to characterize his own perspective. However, the same term is used in relation to the economics of renewable resources, e.g. in the title of a book by Colin Clark (Mathematical Bioeconomics: The Optimal Management of Renewable Resources (Clark, 1976)), which might explain why neither this term became successful.

6. The gestation period: from the beginning of the 1970s to the end of the 1980s

In the beginning of the 1970s, the basic ideas that later became foundational for ecological economics were given modern formulations, but it took more than 15 years before ecological economics actually took shape as a field of research.[2] In this section, some general trends characterising the long gestation period are outlined.

From the beginning of the 1970s, the field of environmental and resource economics grew rapidly. At that time, the literature in the field was still very

[2] Interestingly, a parallel development can be observed for the field industrial ecology that shares several roots with ecological economics; see Erkman (1997).

sparse ("in environmental economics there was very little... there were sort of 12 books and you kind of knew all the authors", as Clive Spash puts it, so he planned to keep up a collection of everything published in the field...), but the demand arising from the increasing public regulation of the environment stimulated the growth. The field became institutionalized in 1974 with the establishment of the dedicated *Journal of Environmental Economics and Management* (JEEM), co-edited by Allen Kneese and Ralph d'Arge, and when the Association of Environmental and Resource Economists (AERE) was established in 1979, the journal was adopted by the association. The increase of funding for the field made possible the establishment of research groups and schools, e.g. in Wyoming, New Mexico, Colorado, UC Riverside. Several of the persons who became influential in the field surfaced in these years, e.g. David Pearce and Partha Dasgupta in the UK, Karl-Göran Mäler in Sweden, Roefie Hueting in the Netherlands, just to mention a few who also became important in relation to ecological economics (some of them in an ambivalent sense in the more recent history). During the 1970s and 1980s, the growth in the field of environmental economics was highly concentrated on two main issues: valuation of the benefits of environmental amenities and the costs of pollution control, and the design of and choice among policy instruments (JEEM Special Issue, 2000; Cropper and Oates, 1992)—both issues strictly inside the framework of welfare economics. Simultaneously, resource economics became highly mathematically formalized. The distinction between environmental and resource economics continued to exist, although they came to share the welfare economic framework and methodology.

The perspectives then related to entropy, metabolism and materials balances received a humble position in relation to the development of mainstream environmental economics. It is interesting to see the difference between the review paper by Fisher and Peterson from 1976, where they allocate relatively great space to the materials balance view (including Daly and other contributors) and call the study by Ayres and Kneese 'very important' (p. 3)—and the review by Cropper and Oates from 1992, where only a note (p. 679) refers to the "materials-balance" approach, mentioning Kneese et al. (1970) and Mäler (1974, 1985). JEEM had few papers related to these issues, so the following small story is illustrative: Once, Daly met Allen Kneese, Daly asked him what had happened to the 1969 paper, and Kneese shook his head and said 'nothing, it disappeared'.

The message that externalities are pervasive and potentially threatening for the life support of the human economy was nearly invisible in environmental economics at that time. Limits to growth were mainly considered in relation to the question of resource scarcity—which probably explains why Peterson and Fisher only refer to Georgescu-Roegen in their survey article on natural resource economics (1977) and not in the one on environmental economics, and Cropper and Oates do not refer to him at all. Mainstream economists took on the role of explaining that there are no limits to economic growth—especially after the publication of *The Limits to Growth* in 1972. The main arguments were introduced in Barnett and Morse's classic from 1963: the price system and technical change will do the job; they were repeated at a conference 'Scarcity and growth reconsidered', held by Resources for the Future 25 years later in 1978 (Smith, 1979). Another example was the symposium issue of *The Review of Economic Studies* from 1974 on the economics of exhaustible resources with contributions from Solow, Stiglitz, Dasgupta and Heal and others.

Despite the humble role of the physical–biological perspectives inside environmental economics, the ideas were diffused and developed during this long gestation period. Georgescu-Roegen's book is very demanding to read, but for some readers the book had a decisive impact on their further work, e.g. for some of the persons who later became central for ecological economics, such as Joan Martinez-Alier, Charles Perrings (Perrings, 1987) and John Gowdy. Gowdy remembers when he got the book to prepare for a course that Georgescu-Roegen was teaching as a visiting professor at West Virginia University in the middle of 1970s: "I remember staying up all night reading that book, which I never do. It was just an incredible book, surely difficult to understand, but it just covered everything: philosophy, physics, anthropology. It was the broadness and the depth too". The diffusion of Georgescu's ideas was made easier by some of his later and more accessible texts (Georgescu-Roegen, 1976, 1977); his ideas were also spread through his personal

contacts (e.g. Miernyk, the regional economist who was Gowdy's mentor). Georgescu-Roegen had studied in France in the late 1920s and later went there several times as a visiting professor. He had close connections to Francois Perroux, whose student René Passet became much influenced by Georgescu-Roegen's ideas. In 1979, Passet, who also cooperated with ecologists, published the book *L'économique et le vivant* (Passet, 1979), which became important for the diffusion of related ideas in French speaking countries. Very important for the further development and diffusion of the ideas were Daly's books and papers on steady state economics (especially Daly, 1977), because they are so well written and expose a mastery of metaphors. However, despite the diffusion of the ideas, the economists involved in related research were still scattered and few.

While the ideas did not have much impact in relation to environmental economics in this period, a new field opened for the diffusion of the ideas in relation to energy studies. In the wake of the energy crisis, the research devoted to the relationship between energy and economy increased rapidly, and part of this research applied a biophysical perspective. Studies on the role of energy and other natural resources in social and economic development had precursors, especially from the 1950s (see Cleveland, 1987), but these were still relatively isolated contributions, so it was not until the 1970s that the field attracted sufficient attention for a real takeoff. In particular, researchers from physics and engineering and from systems ecology were active contributors, but there were also a few economists (Cleveland, 1987 summarizes contributions from Ayres, Odum, Hannon, Herendeen, Hall, Kaufmann, Costanza, himself and others, mainly American. Also Europeans, who later became central for ecological economics, worked with energy studies, e.g. Mick Common, John Proops, Sylvie Faucheux and Karl-Erik Eriksson). The overall perspective was to emphasize the heavy dependence of modern civilization on fossil fuels. As Mick Common puts it: "You can't understand the last two hundred years of human history without understanding energy. We could have accumulated vast amounts of capital, but it wouldn't have done what it has done for us, had it not exploited fossil fuels. Energy is what you need to do work, and doing work is what economics is about".

Some of the important themes and observations in this research concerned:

- Energy quality: the importance of distinguishing between the quality of different energy sources having the same heat content, as their capacity for work is very different. The decrease in energy use per unit of GNP can partly be explained by an increased use of high-quality fuels (Cleveland et al., 1984).
- Labour productivity: much technical change has produced capital that relies on increased use of fossil fuels per labourer, so the increase in labour productivity can, to a large extent, be attributed to the increasing use of fossil fuels (Cleveland et al., 1984).
- The efficiency of food production systems: although agriculture captures solar energy, modern agriculture tends to become less energy effective. Energy inputs in the form of fertilizers, the use of machinery, pesticides, etc. increases more than the energy in the crops (Pimentel et al., 1973).
- Increasing energy costs: ever more energy is required to extract both energy and other resources, so the Energy Return on Input of energy (EROI) tends to fall (Cleveland et al., 1984). The increasing energy costs become evident when it is considered that capital and labour depend on input of low entropy matter and energy.
- Empirical models: new methodologies to do empirical energy accounting in practice were developed, especially input–output models that were used to calculate direct and indirect energy costs of goods and services. The modelling research was strongly stimulated by the increased availability of computer power. Combined with economic models on distribution, etc. they could also be used for analysing effects of energy taxation.
- Valuation: controversies developed regarding the relationship between energy inputs, prices and values, including both the positive discussion on whether prices actually correlate with the direct and indirect energy inputs embodied in goods and services and the normative discussion on whether embodied energy provides a good measure of the value of goods and services (Costanza, 1980 was a much debated contribution). In both cases, the

discussion on where to place the system boundaries in the calculations is central.

Simultaneously, the field of studying ecosystems in terms of energy and material flows developed further. H.T. Odum got a large number of followers (Hall, 1995 illustrates this with a genealogical tree), and also in other countries, different authors pioneered ecological energetics, e.g. J. Phillipson in the UK and F. Ramade in France (one of Passet's contacts).

The 1970s and the beginning of the 1980s saw a new wave of interest in general systems theory. This was stimulated by the work of the physicist Ilya Prigogine and his research group in Belgium who introduced the concept of self-organizing, dissipative structures (Prigogine, 1973; Prigogine and Stengers, 1977, 1985). Whereas classical thermodynamics focussed on equilibria in 'isolated' systems, Prigogine and others studied systems that are closed with regard to matter, but receive and give off energy. Such systems can be far from equilibrium, the processes taking place can be irreversible, and new structures can emerge—dissipative structures that are dependent upon continuous supply and the giving off of energy. The processes can be analysed by using the mathematics related to non-linear dynamics that was integrated with systems theory in the 1960s. With a basis in the new thermodynamic perspective, some physicists began to study biological evolution and the emergence of life on earth, extending the overlap between physics and biology. When Prigogine was awarded the Nobel Prize in chemistry in 1977, it gave occasion for further diffusion of his ideas, and his cooperation with the chemist and theorist of science, Isabelle Stengers, contributed to bringing the new insights beyond the realm of specialists, e.g. the concepts of bifurcations and chaos became well known. A very important consequence of this development in relation to environmental issues was the increased awareness of uncertainty and basic ignorance: when a small change can lead to a dramatic change in outcome, the human impact on the environment can entail far greater risks than previously acknowledged. This point was emphasized in Perring's contribution from 1987, where he carried on the work by Georgescu-Roegen, Daly, Ayres and Kneese on analysing the physical production and environment as a whole, and where he included inspiration from Prigogine.

In the broad field of socio-economics (including institutional and evolutionary perspectives, etc.), related patterns of thought became more widespread, e.g. the use of concepts such as path dependency and lock-in effects in innovation economics. Theories concerning qualitative changes of capitalism, such as those related to the French regulation school, also had features in common with the modern systems thinking.[3] However, most socio-economists concentrated on social issues—the economic crises of the 1970s and 1980s, unemployment, technological change, imperialism, etc.—so only few socio-economists took on environmental issues. This was also the case in France, where heterodox economics was dominant in the 1970s and 1980s. Sylvie Faucheux remembers that René Passet was much criticized by his colleagues at Sorbonne for establishing a PhD programme on environment in the beginning of the 1980s, and when she chose this programme she was told by other teachers and fellow students that there were no prospects in that field. In the US, there was enough interest in the environment among socio-economists to have papers in the journals *Review of Social Economy* (The Association for Social Economics) and *Journal of Economic Issues* (The Association for Evolutionary Economics), but the environment was usually considered a minor issue.

In relation to ecology, chaos theory encouraged the questioning of the idea that an ecosystem has only one stable equilibrium. A new generation of ecologists emphasized that natural systems are always exposed to stress, shock and changes, also before humans had any impact, so ecosystems can be expected to have multiple equilibria and to evolve over time. In an influential article from 1973, Buzz Holling suggests that it is more relevant to focus on the resilience of ecosystems (Holling, 1973). Whereas this idea and the following development of the field of adaptive environmental management still stick to the systems framework of thinking, other biologists jumped to more radical conclusions. Some used chaos theory as

[3] I realized this in the beginning of the 1980s, when I gave a lecture on long wave theories and qualitative changes of capitalism. After the lecture, a PhD student working with self-organising dissipative structures in relation to pre-biotic evolution (Rasmussen, 1985) came up and told me that our thinking had much in common. This lead to a small study group where we explored these common features.

a steppingstone for questioning systems thinking altogether. In his outline of the history of modern ecology, Worster (1993, Chapter 13) emphasizes this line of thought, referring to another article from 1973 by Drury and Nisbet and later papers that challenge systems ecology fundamentally—the ideas of emergent properties, of attributing anything to a system level, etc. Chaos theory was thus used to support the re-emergence of population biology based on an 'individualistic' focus. However, in relation to the development of ecological economics, the systems perspective was, and still is, dominant—albeit in a modernized version with a focus on continuous change, resilience and ecosystem services.

Another general trend of the 1970s and 1980s was the increasing interest in transdisciplinarity and problem-oriented research and education. In Scandinavia, new universities were offering problem-oriented educations, and e.g. in relation to the emerging field of energy studies, transdisciplinary work was promoted by research programmes. In the UK, e.g., John Proops received a joint grant, funded half by social science and half by natural science money; he was jointly supervised by an economist and a physicist when he did his PhD on 'Energy, Entropy and Economic Structure' in an economics department. "At that time they tried to stimulate transdisciplinary work. This was the early 1970s—another world", as Proops puts it.

In the next section, the main actors behind the establishment of ecological economics as a field of research are presented. As the personal stories concern both the 1960s and the 'gestation period', several issues from the previous sections will reappear in a kind of bottom-up perspective.

7. The persons

As Richard Whitley (2000) has pointed out, research fields can be seen as reputational organizations. Sometimes new research fields can grow out of established fields and use the well-established reputational organization of a discipline or a specialty to take the first steps of publication and achieving recognition. However, this can be difficult if the new field is more or less at odds with established wisdom, and then the establishment of a more independent reputational organization can be decisive. As a precondition for this, personal relations and organizational talent are important. How did this come about for ecological economics?

The core relationships behind the establishment of ecological economics were those between Herman Daly, AnnMari Jansson, Robert Costanza and Joan Martinez-Alier. They were the main initiators behind the first meetings and publications, and the journal. I have chosen to give brief outlines of their stories—also because they illustrate important general points. The 'small' stories and the 'big' story complement each other.

Herman Daly was educated as an economist, and his main interest in the beginning of the 1960s was development problems. He went to do his PhD at Vanderbilt University, because they had a programme in economic development, focusing on Latin America. Daly did not know Georgescu-Roegen, when he went to Vanderbilt, but Georgescu taught the theoretical courses on economics and statistics that Daly had to take. Daly immediately realized that Georgescu was the biggest intellect around and that he could learn the most from him on almost any subject, so he devoted a lot of effort to Georgescu's class. Georgescu on his part was happy with an admiring student and shared his thoughts with Daly concerning his work on the entropy law and the implications for economic theory. Since then Daly has always acknowledged that he was much influenced by Georgescu's grounding of economics in the physical world. Daly also identifies two other sources behind his interest in environmental issues. One was Rachel Carson's book that got him interested in ecology, and the other was his interest in economic development, which brought him to the northeast of Brazil, a poor area, where the issue of rapid population growth and limited natural resources became urgent in the mid- and late 1960s. From the mid-1960s, Daly worked at the economics department at Louisiana State University, interrupted by shorter stays at other universities. During the late 1960s and the 1970s Daly worked mostly on his own, developing the ideas of steady state economics. He had contacts to many other core persons related to the environmental debate, such as Paul Ehrlich and Dennis and Donella Meadows, but he was not part of a group with common interests. Daly tried to relate to environmental economics, for instance, he attended

the conference 'Scarcity and growth reconsidered' in 1978. The conference generated a lot of discussion and conflict, in which both Daly and Georgescu-Roegen took a very active part, and although relatively gentleman-like, it was around that time that Daly realized a really fundamental difference between his own perspective and that of mainstream environmental and resource economics. Daly's basic interest had always been to influence economics, and he had not really considered the need to do anything else, but he was becoming susceptible to new strategic ideas.

AnnMari Jansson was educated as a zoologist, and initially her research focused on the behaviour of pigeons. When her husband Bengt-Owe Jansson, a marine biologist, became involved in the establishment of a field laboratory on the island of Askö, A.M. Jansson's research topic was not very practical, so in the middle of the 1960s she turned to marine ecology, specialising in the study of green algae as living space for small animals. During the 1960s, the emission of nutrients to the Baltic Sea grew rapidly and the green algae exploded. In the beginning, A.M. Jansson perceived this as disturbing for her research, as she intended to focus on a purely scientific problem, but gradually it became more difficult to ward off societal issues regarding the background of the pollution. Around this time, the public interest in the environment resulted in bureaucratic initiatives (from the government agency for technical development) to stimulate Swedish research in nature and the environment, and a representative travelled to the US to find researchers who could be invited to Sweden to give inspiring talks. Through this initiative, H.T. Odum (HT) came to Sweden in 1970, and his talks were real eye-openers for A.M. and B.-O. Jansson. He had studied marine systems in Texas and described them in a way that not only covered the different species, but also how everything was connected. A.M. Jansson had started to look at food chains, but HT took the systems perspective much further through a coherent way of describing ecosystems and modelling flows of energy and nutrients—experiments became connected in new and convincing ways. However, A.M. and B.-O. Jansson were exceptions to the rule: most other Swedish ecologists were sceptical towards this fast speaking American, who talked mostly about energy flows, etc. that was not considered real ecology. Actually, in line with this view HT moved, around this time, from the University of North Carolina to an environmental engineering department at University of Florida. The phone call from Florida came while he was in Sweden, causing some excitement as overseas calls were rather unusual. After HT's visit to Sweden, B.-O. Jansson was invited to be a guest professor with Odum at the University of Florida, and A.M. Jansson joined him. Odum was happy to train them, and they both followed courses and contributed as teachers from 1971 to 1972.

Not long after A.M. and B.-O. Jansson's return to Sweden the energy crisis came. Because of the crisis new funds were allocated to research in energy—alternative energy sources, the importance of energy in the economy, the environmental impacts of energy use, etc. As A.M. and B.-O. Jansson were much inspired by what they had seen in Florida, A.M. Jansson formed a small group and suggested having a similar study in Sweden using the island of Gotland as an object of study to demonstrate the techniques. The idea was to make an integrated study of Gotland, including the importance of energy for both nature and society. The dedicated funds for energy research were decisive in making such a transdisciplinary project possible. The typical reaction of ecologists to such a project was sceptical, as Gotland comprised so many different ecosystems, and even the understanding of a small lake was still deficient. When A.M. Jansson got the money she contacted Odum to get one of his students to go to Sweden, so James Zuchetto came and worked with her for several years, also supported by a Rockefeller scholarship (for a short introduction to the project, see Jansson, 1985). The project also implied the first cooperation with economists. The energy research council established a steering group for the project, and they appointed prominent people, one of them being Karl-Göran Mäler, who was one of the few Swedish economists working with environmental issues at that time. The economist working directly in the project was Ing-Marie Andréasson-Gren, and A.M. Jansson remembers that in practice it was quite difficult to cooperate across disciplines: as a practician, she herself wanted to work on Gotland, whereas the economist felt much more comfortable studying numbers in her office. The projects related to Gotland lasted for several years, and by the end in 1982 Carl Folke started as a student with A.M. Jansson, also contributing to the Gotland

studies. Carl Folke became an important driving force behind another transdisciplinary cooperation in Sweden regarding environment and economics—the Eco–Eco Group, which was founded in 1984 and included, among others, Peter Söderbaum, Karl-Erik Eriksson and his student Thomas Kåberger.

While A.M. Jansson was preparing and doing her Gotland project, the group around H.T. Odum was growing. In 1973 H.T. Odum founded the Center for Wetlands at the University of Florida, and in relation to a large transdisciplinary project on the wetlands of South Florida he attracted many researchers and students. Among the students was *Robert Costanza*. He was studying architecture, and for his masters degree he worked on the land use history of South Florida as part of Odum's large project. Costanza's unusual project included the development of maps based on aerial photographs illustrating the history of South Florida, in particular, the compelling history of the Everglades. The work was based on systems modelling (supported by a few years of science training before the study of architecture), and through this work he became interested in the development of ecological systems over long time periods. Therefore, it was natural to continue with a PhD in systems ecology and environmental engineering sciences in relation to Odum's group. The focus on systems was central, so he also studied general systems theory. As a part of his dissertation, Costanza did some research on energy flow accounting in both natural and economic systems. This work brought him into contact with the energy analysts at Illinois University, in particular, Bruce Hannon. Hannon used input–output modelling in energy accounting, and was becoming interested in applying input–output models to ecological systems. At Illinois, they had a centre for advanced computation with one of the early supercomputers that allowed them to do large matrix calculations that could not be done elsewhere, so the researchers started doing in practice some of the calculations that until then had mainly been only theoretical. Through his work with the dissertation Costanza also came to know Daly's books, and he talked with Odum about them. Just after Costanza had finished his PhD in 1979, Daly organized a symposium at the 1980 meeting of the American Association for the Advancement of Science—a symposium on 'Energy, Economics, and the Environment', where Costanza presented his results. Daly encouraged him to publish the results that appeared in the *Science* paper on embodied energy and valuation (Costanza, 1980).

Daly's presence at Louisiana State University (LSU) motivated Costanza to apply for a position at the Center for Wetland Resources at LSU, and Daly was happy to see him there. Through Daly's interest in ecology he had got to know some of the people in the life sciences department at LSU, and when Costanza came in for the job interview, Daly was there and heard his talk. Daly was not on the search committee, but his positive opinion might have played a minor role. When Costanza started, he came and sat in on Daly's seminar on economics—Daly remembers this as a fantastic year, when not only Costanza, but also Cutler Cleveland (a marine science student—Costanza's first graduate student, who later had his PhD with Bruce Hannon) and Gabriel Lozada (a physics student) took part in the study of Georgescu-Roegen's book and several other books. Like the transdisciplinary work in AnnMari Jansson's group in Sweden, the connections at LSU stimulated the idea of cooperation between ecology and economics.

Joan Martinez-Alier was educated in economics, in particular, agricultural economics, in Spain in the 1960s. In the period from 1966 to 1973, he studied and worked at Oxford University, writing on the book 'Labourers and Landowners in Southern Spain' (Martinez-Alier, 1971) and beginning to work on 'Haciendas, Plantations, and Collective Farms' (Martinez-Alier, 1977). These studies concerned mainly social problems, but when he carried out field studies in Peru in the early 1970s, he came into contact with ecological anthropologists and began to take an interest in environmental issues. Martinez-Alier was part of the Spanish exile circle critical of the Franco-regime, and through this circle he met another economist specialising in agriculture, J.M. Naredo, who in 1974 drew Martinez-Alier's attention to Georgescu-Roegen's book. The book greatly stimulated his interest in the conceptualization of economic processes in terms of energy, and 2 years later, when he came across the work of Podolinsky through reading the correspondence between Marx and Engels, he began to track down the precursors of this way of thinking. He published his first article on Podolinsky in Spanish in 1979, and in 1980 he had the chance to

invite Georgescu-Roegen to Barcelona for a few days and to show him the correspondence on Podolinsky (Martinez-Alier returned to Spain after the death of Franco in 1975). Georgescu found this extremely interesting and helped Martinez-Alier with very detailed comments on his first article on Podolinsky in English in 1982. In the beginning of the 1980s, Martinez-Alier knew very few of the people whom he later met in relation to ecological economics. He had corresponded with Herman Daly on Podolinsky, Soddy, etc. around 1979–1980, and they had a short meeting when Daly went to Barcelona for a conference in 1984 and then kept in touch.

8. The meetings

In the beginning of the 1980s, the Swedes took the first steps towards a broader international cooperation between ecologists and economists. B.-O. Jansson was on the board of the Marcus Wallenberg Foundation for International Cooperation in Science, which supported scientific workshops, and he suggested having a workshop that could bring together ecologists and economists (the idea was supported by, e.g., Erik Dahmén who had written a much debated book on pricing the environment in the late 1960s (Dahmén, 1968). In preparation for the symposium, A.M. Jansson wrote again to H.T. Odum to ask for suggestions regarding persons who might be interesting to invite, and on top of the list from Odum she found Herman Daly, whom she did not know. Mäler, who was also on the organizing committee, invited most of the other economists, e.g. A.C. Fischer, A.V. Kneese, R. d'Arge and P. Dasgupta. The symposium was held at an exclusive hotel at Saltsjöbaden in Stockholm in September 1982, and the results were later documented in proceedings (Jansson, 1984).

The contributions from systems ecologists (e.g. H.T. Odum, R. Costanza, C. Hall, F. Golley), energy analysts with a background in engineering or physics (e.g. R.A. Herendeen, B. Hannon, K.-E. Eriksson) and other natural scientists (e.g. D. Rapport, D. Pimentel) were more numerous and elaborate than the contributions from the economists—some of the famous economists did not even contribute papers (d'Arge, Dasgupta), Kneese was very brief, and Fischer stayed inside the traditional domain. Daly's contribution ('Alternative strategies for integrating economics and ecology') stood out as the most important attempt from the economists' side to meet the challenge of the symposium, and AnnMari Jansson and later Carl Folke (who read the book in the editing phase) were very enthusiastic about his perspective. The meeting was also instrumental in establishing a contact between AnnMari Jansson and Robert Costanza, who later visited and worked in Sweden on different occasions. In relation to this meeting, A.M. Jansson got the idea of using the sand dollar as a symbol of the cooperation between ecologists and economists, and asked a colleague to draw it—the sand dollar still appears on the back cover of the journal.

Partly inspired by the meeting in Stockholm, Costanza and Daly started planning a special issue of the journal Ecological Modelling on ecological economics (Costanza, 2003). The editor of the journal, Svend Erik Jørgensen, had also been invited to the meeting in Stockholm, and he was supportive of the idea. This special issue seems to be the first publication where the concept ecological economics was used to describe a common endeavour. The authors were found through the contacts and knowledge of Costanza and Daly, e.g. Daly knew David Pearce and Roefie Hueting. There was no American group of like-minded people at this time, but mutual acquaintance was developing, and e.g. Richard Norgaard and Paul Christensen appear among the authors here.

Another series of meetings was instrumental in bringing together some of the persons who established ecological economics. The initiative came from an institution in Vienna, the European Coordination Centre for Research and Documentation in the Social Sciences (papers on the history of the institution can be found in Charvat et al., 1988). The aim of this institution was to promote interchange between researchers from Eastern and Western Europe, and in 1985 they financed a meeting in Prague on environment and society. A.M. Jansson received the invitation through the Swedish research council, and at this meeting she came into contact with David Pearce, whose enthusiasm and interest in developing countries and questions of justice impressed her. A.M. Jansson accepted to host the next meeting in Stockholm on Economics and Ecology, and she included David Pearce on the organizing committee. At this

meeting in 1986, Joan Martinez-Alier was one of the participants. He does not remember how he knew about the meeting, but he does remember that it took place a week after the Tjernobyl accident, so the cows were not allowed outside in the fields in the good weather. Martinez-Alier agreed to host the next meeting in Barcelona in 1987.

Before this meeting, in 1986, Martinez-Alier went to the US and met several persons who later joined ecological economics. As mentioned, he already knew Daly, but he met Richard Norgaard, Paul Christensen, Charles Hall and others for the first time. When Martinez-Alier arranged the meeting in Barcelona, he found ways to also include Americans, although the series of meetings was mainly intended for Europeans—however, the meeting was still dominated by Europeans. Whereas the previous meetings in the series have not left many traces, the meeting in Barcelona became legendary. Through a web of personal contacts several persons were brought in who had not taken part in any of the previous meetings, e.g. René Passet, Charles Perrings, John Proops, Martin O'Connor, Mick Common, Silvio Funtowicz, Paul Christensen, Richard Norgaard and others—and of course, several of the participants from previous meetings took part (Daly, A.M. Jansson, Costanza, Hannon, Herendeen) (a list can be found in Costanza, 2003).[4] Contacts preceded this meeting (Perrings was the PhD advisor of O'Connor, who was studying in Paris at the time, attracted by the strong position of heterodox economics in France; O'Connor had been in contact with Proops; Proops had been in contact with Hannon and Herendeen, etc.), but many participants met for the first time at this meeting. Compared to the 1982 meeting in Stockholm the group of economists was different, partly because most of them worked directly with conceptualizing the natural limits to the economy and the flows of energy and matter supporting economic processes (more were familiar with the work of Georgescu-Roegen), partly because some of them applied a politically more radical perspective (e.g. Martinez-Alier, Passet, O'Connor). Generally, the balance between natural and social science perspectives was tilted somewhat towards the social sciences, and among the natural sciences ecology was not as dominant as it had been in 1982. Many participants remember the meeting as very inspiring, maybe because they experienced that so many people actually shared perspectives that were usually held by isolated individuals. It was discussed what these shared perspectives could be called; several suggestions came up. Considering Worster's description of the impact of the concept of ecology, it is perhaps not surprising that 'ecological economics' won.

The meeting is considered by many as foundational for the journal and thereby indirectly for the society. During 1987 and early 1988, Costanza and Daly negotiated with several potential publishers of the journal, finally deciding on Elsevier Science (A.M. Jansson was also involved in the negotiations with Elsevier) (Costanza, 2003). When the first plans for a journal were discussed (before the Barcelona meeting) David Pearce took part; he was expected to play an important role (A.M. Jansson, personal communication). However, he partly withdrew as he took on the task of starting another journal related to environment and development. Costanza became the chief editor, and Daly, A.M. Jansson and Pearce the initial associate editors. Elsevier argued that the chances for *Ecological Economics* would be much improved, if it were supported by a society. This encouraged a quick establishment of the society in 1988 with Costanza as the first president, and the first issue of the journal appeared already in February 1989. Several of the people from the Barcelona meeting were included on the editorial board of journal, but the composition of the board differed markedly from the composition of participants in the Barcelona meeting: several influential mainstream environmental and resource economists were included (e.g. d'Arge, Fisher, Mäler, Turner), and whereas the 38 participants at the Barcelona meeting were distributed

[4] It can also be interesting to consider who was not there. E.g. it seems surprising that Robert Ayres was not there. He had elaborated the materials balance approach and his work was well known by several participants—and later included in an anthology of foundational papers of ecological economics (Costanza et al., 1997). Maybe at that time, Ayres was more of a technological optimist than most of the participants in the meeting. Peter Söderbaum was disappointed not to be invited either to this meeting, or to the 1982 meeting in Stockholm, in spite of his early contributions to the Swedish discussion on environment and economics (e.g. Söderbaum, 1975) and his connections with A.M. Jansson. Maybe Mäler actively opposed his participation in the Stockholm meeting because of a dislike of socio-economics. David Pearce was invited, but did not come.

among 29 Europeans, 6 from the US, and 3 from other countries, the 45 board members were distributed among 17 Europeans, 20 from the US, and 8 from other countries. At this time of institutionalization, the early history of modern ecological economics can be considered to end and the more contemporary history to start.

9. Concluding remarks

This version of the early history of modern ecological economics is intended to cover several different aspects and layers. In this section, some of the observations are briefly summarized and related to the theoretical inspiration from the sociology of science. Furthermore, the motivations of the initiators are brought into focus, as these were decisive for the shaping of the field.

All research stems from previous ideas and experience, and in the case of ecological economics the *internal intellectual processes* have a long history. Most of the precursors were inspired by thermodynamics to rethink both natural and social processes in new terms, and in the modern versions the same basic ideas were reformulated and extensively elaborated. Researchers from several different fields were involved in the modern reformulations: systems ecology, different strands of economics (heterodox biophysical economics, environmental and resource economics, agricultural economics, socio-economics), energy studies mainly based on physics and engineering, and general systems theory. The development of new research techniques played a part in the elaboration and actual operationalization of the ideas, e.g. the use of radioactive isotopes in ecological research and the use of computers for modelling.

Diffuse social influences and *specific economic and political factors* were crucial for the breakthrough of modern ecological economics. Ecology played a part in promoting the new social discourses on pollution, population, etc. that in turn created a strong social demand for research on environmental issues. Inside economics the demand led to the recovery of earlier contributions and to the application of available tools for the analysis of environmental issues. A small minority responded by developing biophysical perspectives that more basically questioned the mainstream conceptualization of the relationship between economy and nature. Such perspectives had a strong potential for radical critique of the rationale of economic growth, so they tended to be at odds with both the dominant political forces and mainstream economic thought. The more radical economists who could have been expected to take an interest in these perspectives were mainly occupied with social issues, thereby contributing to the long gestation period for ecological economics. When environmental policies began to be implemented, the political and administrative demand for research increased, but this mainly stimulated environmental economics focusing on valuation and regulatory instruments. However, the increasing environmental problems and especially the energy crisis also opened up opportunities for more heterodox research, e.g. resources became available for more transdisciplinary research.

Some of the work on energy and environment took place outside the academic world and constituted *external intellectual factors* influencing the paths taken by academic research. In particular, energy research became one of the fields where a more general trend towards including a broader group of actors in relation to research became visible. Furthermore, the environmental issues might be seen as part of the background for the increasing interest in transdisciplinary work, which changed the *immediate institutional context* for researchers. Gradually an increased political demand for transdisciplinarity in education and research developed. Transdisciplinary seminars and workshops were funded, and this trend supported some of the innovators who could have had difficulties in the rigidly structured disciplinary academic world.

The modern (re)formulation of the basic ideas of ecological economics was in place around 1970, but a long gestation period followed before the field was named and institutionalized. The establishment depended upon the *social processes within the research community*. First, the ideas had to be diffused before a critical mass of interested researchers was formed, and personal contacts were instrumental in this process. Second, co-operative initiators were needed. Some of the original contributors were not suited to founding a school of ecological economics: Georgescu-Roegen (born 1906) was not exactly known for his cooperative talents, and his later years

were marked by bitterness, as he found that his contributions were not sufficiently appreciated by the economics profession (Daly, 1995); Boulding (born 1910) spread his activities over a very broad field, e.g. his Quaker background led him into peace and conflict research, so the 'spaceship' perspective was only one interest among several others (Mott, 2000). H.T. Odum (born 1924) had many followers, but with his absorption in the development of the emergy concept and the related endless calculations, he tended to antagonize many other researchers, especially social scientists (for a short introduction to the emergy concept, see Herendeen, 1999). So ecological economics had to wait for the next generation, A.M. Jansson (born 1934) and Daly (born 1938), who were open-minded, cooperative and committed to the combination of environmental and social issues—and who could both mediate the older researchers' contributions and add their own perspectives. In the 1980s, they were both supported by close cooperation with younger researchers, Jansson by C. Folke and Daly by Costanza. Jansson says that Folke's interest and initiatives, e.g. the establishment of the Eco–Eco Group, were decisive for her—otherwise she thinks that she would have returned to natural science. Daly emphasizes that most of the work with the establishment of the journal and the society fell on Costanza, as Daly left for the World Bank just after the start. Daly says about Costanza: "He is extremely good at working and organizing. . . I continued to help out, but the entrepreneurship of the journal was really his". With Costanza, ecological economics got an entrepreneur who really knew how to manage in the highly competitive academic world.

The Swedish ecologists took the initiative to arrange the first workshop on integration of ecology and economics; it is worth dwelling on their motivations. First of all, they were acutely aware of the increasing environmental problems, and they found it difficult to make themselves heard by decision makers. They had the impression that other groups, especially economists, were much more powerful, and economists tended to voice anti-environmentalist arguments—attacking 'The Limits to Growth' ideas, demonstrating trust in technical change, etc. If it were possible to attract influential economists to the environmentalist cause, much would be won. C. Folke is very clear on this point: Maybe it would be interesting to cooperate with anthropologists, sociologists or political scientists to achieve a deeper understanding of the relationships between society and nature, but it would not have much effect—it would be much more effective to go for the economists in the first place (Costanza advances another argument why anthropologists were not an obvious choice: they tended to be more interested in ancient societies than in present-day problems). When A.M. Jansson first started to cooperate with economists, she was not aware of any basic differences between different groups of economists, except the distinction between micro and macro economists—the important point was to find economists who were interested in the environment, and they were still in short supply. As Daly formulates the situation: "At that time—it looks strange from the perspective of today—anyone who showed an interest in the environment was sort of a natural ally". Therefore, it was not considered important whether the economists were mainstream neoclassicists or heterodox economists.

At the same time, some of the most active economists behind ecological economics, such as Daly and Martinez-Alier, were at odds with mainstream economics. Daly's motive for engaging in cooperation with ecologists was related to the development of mainstream environmental and resource economics, where the biophysical perspective virtually disappeared for a long period. He would really have liked to change the discipline from inside rather than creating a new field, but he came to the conclusion that this was not realistic. The publication of the Brundtland report in 1987 and the promotion of the concept of sustainable development also affected environmental economics, but this belongs to the story about the period that followed the founding of ecological economics.

At the time of the establishment of the journal and the society, the field of ecological economics was very open. Only little could be said about the outlines of the field, but two points were made repeatedly in the first position papers (e.g. Costanza, 1989 and other papers in the first issue of the journal): First, ecological economics was seen as a meeting place for researchers committed to the environmental issue—they believed that limits had to be taken seriously and that several environmental problems were critical. Related to the acknowledgement of limits, the issues of equity and distribution also

figured prominently. Second, to meet the environmental and related social challenges transdisciplinary work was considered essential, and pluralism was emphasized as a key word. Besides these proclamations, I imagine that most participants in the Barcelona meeting would agree with the idea that I ventured to call the basic idea of ecological economics (in Section 3): the human economy is embedded in nature, and economic processes are also always natural processes in the sense that they can be seen as biological, physical and chemical processes and transformations; therefore, the economy ought to be studied also, but not only, as a natural object, so economic processes should also be conceptualized in terms usually used to describe processes in nature.

Despite the agreement on these general issues, the field of ecological economics was obviously born with some in-built tensions. The participants in the establishment of the field represented a broad combination of disciplinary backgrounds, and basically different views on the meaning and practice of science were represented, as well as basically different perspectives inside the discipline of economics. Furthermore, a geographical tension was in built from the beginning, as well as different political perspectives, different views of the role of scientists, etc. How the field grew up from the very general statements of agreement, and what the in-built tensions meant for the development, is not a matter of the early history of ecological economics, so this will be left for the next chapter of the story.

Acknowledgements

Firstly, I am very grateful to the ecological economists who spent their time telling me about their experience and views: Herman Daly, Mick Common, Robert Costanza, Sylvie Faucheux, Carl Folke, John Gowdy, AnnMari Jansson, Joan Martinez-Alier, Charles Perrings, John Proops, Clive Spash and Peter Söderbaum. They have contributed much more to the paper than can be seen from the few direct references to personal communication, as they have suggested books and papers, set me on tracks to explore, commented on a first version of the paper, etc. Needless to say, I have not been able to follow all their suggestions. Secondly, I wish to thank Søren Wenneberg from the Copenhagen Business School for being so helpful in introducing me to the sociology of science, especially the study of scientific specialties. Thirdly, I am grateful to Marina Fischer-Kowalski for helpful comments and encouragement. Finally, this work was made possible by funding from the Danish Social Science Research Council, for which I am grateful.

References

Ayres, R.U., Kneese, A.V., 1969. Production, consumption, and externalities. The American Economic Review 59, 282–297.

Barnett, H., Morse, C., 1963. Scarcity and Growth: The Economics of Natural Resource Availability. John Hopkins University Press, Baltimore, MD.

Bergh, J.C.J.M. van den, 2001. Ecological economics: themes, approaches, and differences with environmental econonomics. Regional Environmental Change 2, 13–23.

Bertalanffy, L. von, 1950. An outline of general system theory. British Journal for the Philosophy of Science 1, 139–164.

Boulding, K.E., 1966. The economics of the coming spaceship earth. In: Jarrett, H. (Ed.), Environmental quality in a growing economy. John Hopkins University Press, Baltimore, USA.

Carson, R., 1962. Silent Spring. Houghton Mifflin, Boston.

Charvat, F., Stamatiou, W., Villain-Gandossi, Ch. (Eds.), 1988. International Cooperation in the Social Sciences. 25 Years of Vienna Centre Experience. European Coordination Centre for Research and Documentation in the Social Sciences, Vienna.

Christensen, P., 1987. Classical roots for a modern materials-energy analysis. Ecological Modelling 38, 75–89.

Christensen, P., 2001. Early links between sciences of nature and economics: historical perspectives for ecological and social economics. In: Cleveland, C.J., Stern, D.I., Costanza, R. (Eds.), The Economics of Nature and the Nature of Economics. Edward Elgar, Cheltenham, UK.

Clark, C.W., 1976. Mathematical bioeconomics: the optimal management of renewable resources. John Wiley and Sons, New York.

Cleveland, C.J., 1987. Biophysical economics: historical perspective and current research trends. Ecological Modelling 38, 47–73.

Cleveland, C.J., Costanza, R., Hall, C.A.S., Kaufmann, R., 1984. Energy and the U. S. economy: a biophysical perspective. Science 225, 890–897.

Costanza, R., 1980. Embodied energy and economic valuation. Science 210, 1219–1224.

Costanza, R., 1989. What is ecological economics? Ecological Economics 1, 1–7.

Costanza, R., 2002. New editor for ecological economics. Ecological Economics 42, 351–352.

Costanza, R., 2003. The early history of ecological economics and the international society for ecological economics (ISEE). ISEE, Internet Encyclopaedia of Ecological Economics.

Costanza, R., Perrings, C., Cleveland, C. (Eds.), 1997. The development of ecological economics. Edward Elgar, Cheltenham, UK.

Costanza, R., Cumberland, J., Daly, H., Goodland, R., Norgaard, R., 1997. An introduction to ecological economics. St. Lucie Press, Florida.

Costanza, R., et al., 2001. Einführung in die Ökologische Ökonomik. Lucius and Lucius, Stuttgart.

Craige, B.J., 2001. Eugene Odum. Ecosystem Ecologist and Environmentalist. The University of Georgia Press, Athens and London.

Crocker, T.D., 1999. A short history of environmental and resource economics. In: Bergh, J.C.J.M. van den (Ed.), Handbook of environmental and resource economics. Edward Elgar, Cheltenham, UK.

Cropper, M.L., Oates, W.E., 1992. Environmental economics: a survey. Journal of Economic Literature 30, 675–740.

Dahmén, E., 1968. Sätt pris på miljön: samhällsekonomiska argument i miljöpolitiken. Studier Och Debatt 16, 3.

Daly, H.E., 1968. On Economics as a Life Science. Journal of Political Economy 76, 392–406.

Daly, H.E., 1977. Steady-State Economics. W.H. Freeman and Co., San Francisco.

Daly, H.E., 1995. On Nicholas Georgescu-Roegen's contributions to economics: an obituary essay. Ecological Economics 13, 149–154.

Ehrlich, P., 1968. The Population Bomb. Sierra Club-Ballantine, New York.

Erkman, S., 1997. Industrial ecology: an historical view. Journal of Cleaner Production 5, 1–10.

Fischer-Kowalski, M., 1998. Society's metabolism. The intellectual history of materials flow analysis: Part I. 1860–1970. Journal of Industrial Ecology 2, 61–78.

Fisher, A.C., Peterson, F.M., 1976. The environment in economics: a survey. Journal of Economic Literature 14, 1–33.

Georgescu-Roegen, N., 1966. Analytical economics: issues and problems. Harvard University Press, Cambridge, MA.

Georgescu-Roegen, N., 1971. The entropy law and the economic process. Harvard University Press, Cambridge, MA.

Georgescu-Roegen, N., 1976. Energy and economic myths. Pergamon Press, New York.

Georgescu-Roegen, N., 1977. Inequality, limits and growth from a bioeconomic perspective. Review of Social Economy XXXV, 361–375.

Gowdy, J., Mesner, S., 1998. The evolution of Georgescu-Roegen's bioeconomics. Review of Social Economy LVI, 136–156.

Hall, C.A.S. (Ed.), 1995. Maximum Power. The Ideas and Applications of H.T. Odum. University Press of Colorado, Colorado, USA.

Herendeen, R.A., 1999. EMERGY, value, ecology and economics. In: Bergh, J.C.J.M.van den. (Ed.), Handbook of Environmental and Resource Economics. Edward Elgar, Cheltenham, UK.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecological Systems 4, 1–24.

Isard, W., 1969. Some Notes on the Linkage of the Ecologic and Economic Systems. Paper delivered to the Regional Science and Landscape Analysis Project, Department of Landscape Architecture, Harvard University and the Regional Science Research Institute.

Jansson, A.M. (Ed.), 1984. Integration of economy and ecology. An Outlook for the Eighties. Proceedings from the Wallenberg Symposia. Askö Laboratory, Stockholm.

Jansson, A.M., 1985. Natural productivity and regional carrying capacity for human activities on the island of Gotland, Sweden. In: Hall, D.O., Myers, N., Margaris, N.S. (Eds.), Economics of ecosystem management. Dr. W. Junk Publishers, Dordrecht, The Netherlands.

JEEM Special Issue, 2000. Journal of Environmental Economics and Management. 25th Anniversary Issue, vol. 39, p. 3.

Kaarhus, R., 2000. Økologisk antropologi. Natur, kultur og subsistensformer. In: Nielsen, F.S., Smedal, O.H. (Eds.), Mellom himmel og jord. Tradisjoner, teorier og tendenser i sosialantropologien. Fakbokforlaget, Bergen, Norway.

Kneese, A.V., 1962. Water pollution: economic aspects and research needs. Resources for the Future, Washington, DC.

Kneese, A.V., Ayres, R.U., d'Arge, R.C., 1970. Economics and the Environment. A Materials Balance Approach. Resources for the Future, Washington, DC.

Krutilla, J.V., 1967. Conservation Reconsidered. American Economic Review 57, 777–786.

Lemaine, G., Macleod, R., Mulkay, M., Weingart, P. (Eds.), 1976. Perspectives on the Emergence of Scientific Disciplines. Mouton and Co., The Hague.

March, J.G., Olsen, J.P., 1986. Garbage can models of decision-making in organizations. In: March, J.G., Weissinger-Baylon, R. (Eds.), Ambiguity and Command. Ballinger, Cambridge, MA.

Martinez-Alier, J., 1971. Labourers and Landowners in Southern Spain. Allen and Unwin, London.

Martinez-Alier, J., 1977. Haciendas, plantations, and collective farms: agrarian class societies, Cuba and Peru. F. Cass, London.

Martinez-Alier, J., 1987. Ecological Economics. Energy, Environment and Society. Basil Blackwell, Oxford, UK.

Martinez-Alier, J., 2002. The Environmentalism of the poor. A study of ecological conflicts and valuation. Edward Elgar, Cheltenham, UK.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W., 1972. The limits to growth. Universe Books, New York.

Mott, T., 2000. Obituary: Kenneth Boulding, 1910–1993. Economic Journal 110, F430–F444.

Mulkay, M.J., 1976. Methodology in the sociology of science: Some reflections on the study of radio astronomy. In: Lemaine, G., Macleod, R., Mulkay, M., Weingart, P. (Eds.), Perspectives on the Emergence of Scientific Disciplines. Mouton and Co., The Hague.

Odum, H.T., 1971. Environment, power, and society. Wiley-Interscience, New York.

Paley Report. The President's Materials Policy Commission, 1952. Resources for freedom. 5 vols. U.S. Government Printing Office, Washington, DC.

Passet, R., 1979. L'économique et le vivant. Payot, Paris.

Pearce, D., 2002. An intellectual history of environmental economics. Annual Review of Energy and the Environment 27, 57–81.

Perrings, C., 1987. Economy and environment. A Theoretical Essay on the Interdependence of Economic and Environmental Systems. Cambridge University Press, Cambridge, UK.

Peterson, F.M., Fisher, A.C., 1977. The exploitation of extractive resources. A survey. Economic Journal 87, 681–721.
Pimentel, D., et al., 1973. Food production and the energy crisis. Science 182, 443–444.
Prigogine, I., 1973. Can thermodynamics explain biological order? Round table with Ilya Prigogine and others of the Brussels school. Impact of Science on Society XXIII, 159–179.
Prigogine, I., and Stengers, I., 1977. The new alliance. Part 1 and 2. Scientia, pp. 319–31 and 643–53.
Prigogine, I., Stengers, I., 1985. Den nye pagt mellem mennesket og universet. Nye veje i naturvidenskaberne. Forlaget ASK, Århus, Denmark. (Translation of: La Nouvelle Alliance: Metamorphose de la Science, 1984).
Rappaport, R.A., 1968. Pigs for the ancestors. Ritual in the ecology of a new guinea people. Yale University Press, New Haven.
Rasmussen, S. 1985. Aspekter af instabiliteter og selvorganiserende fænomener. Phd dissertation, Technical University of Denmark.
Smith, V.K. (Ed.), 1979. Scarcity and Growth Reconsidered. John Hopkins University Press, Baltimore, USA.
Spash, C., 1999. The development of environmental thinking in economics. Environmental Values 8, 413–435.
Söderbaum, P., 1975. Tilväxttänkande eller ekologisk grundsyn. Ekonomisk Debatt 2, 113–120.
Söderbaum, P., 2000. Ecological economics. A Political Economics Approach to Environment and Development. Earthscan Publications, London.
Thomas Jr., W.L., 1956. Man's role in changing the face of the Earth. University of Chicago Press, Chicago.
Turner, R.K., 1999. Environmental and ecological economics perspectives. In: Bergh, J.C.J.M. van den (Ed.), Handbook of Environmental and Resource Economics. Edward Elgar, Cheltenham, UK.
Victor, P.A., 1972. Pollution: Economy and Environment. George Allen and Unwin, London.
Weale, A., 1992. The new politics of pollution. Manchester University Press, Manchester.
Wenneberg, S.B., 1999. Den nye videnskab. Et studie af videnskab i forandring. Samfundslitteratur, Copenhagen.
Whitley, R., 1984. The fragmented state of management studies: reasons and consequences. Journal of Management Studies 21, 331–348.
Whitley, R., 2000. The Intellectual and Social Organization of the Sciences. Oxford University Press, Oxford, UK. (2. ed., 1. ed. 1984).
Wiener, N., 1948. Cybernetics. Or Control and Communication in the Animal and the Machine. MIT Press, Cambridge, MA.
Worster, D., 1993. The Wealth of Nature. Environmental history and the ecological imagination. Oxford University Press, New York.
Worster, D., 1994. Nature's economy. A History of Ecological Ideas. Cambridge University, USA. (1. ed. 1977).