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C3ED, Centre d'Economie et d'Ethique pour l'Environnement
et le Développement,
UMR No.063 IRD and UVSQ,
Université de Versailles St-Quentin-en-Yvelines,
47 boulevard Vauban, 78047 Guyancourt cedex, France
E-mail: Jean-Marc.Douguet@c3ed.uvsq.fr
E-mail: Patrick.Schembri@c3ed.uvsq.fr
*Corresponding author

Abstract: This paper reports on research empirically focused on the Brittany region in France, its agricultural sector and the impacts of agricultural activity on water quality. Our goal was to define and estimate indicators that illustrate the confrontation between environmental performance and economic cost criteria, in the context of a comparative scenario analysis related to the growth and technological change paths for agricultural production in the Brittany region. We develop an analysis through comparing the long-term tendencies of sectoral economic activity and selected ecological pressure indicators. Firstly, we identify the main environmental functions of water in the Brittany area and discuss the politics of agriculture. Then we present the structure of the scenario model used in our analysis, and show how the methods support a cost-effectiveness analysis. Finally, we discuss comparatively the results and address issues of uncertainty and data quality related to water and soil pollution.

Keywords: agriculture; cost effectiveness; environment; indicators; modelling; pollution; scenario analysis; sustainability; uncertainty; valuation; water.

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Biographical notes: Jean-Marc Douguet is a Lecturer in Economics at the UVSQ. He works on environmental evaluation themes, especially in agriculture and water pollution, and on the construction and testing of ICT interfaces in agriculture, water resources and fisheries. He is currently working on the EU-funded projects PEGASE (addressing integrated modelling of pesticides in water and policy responses), VIRTUALIS (on multimedia interfaces for environmental learning), ALARM (governance of biodiversity risks) and E-COST (management of coastal zones).

Patrick Schembri has an MA in Economics and a Postgraduate Diploma in Environmental Economics from the University of Pantheon, Sorbonne (Paris), in which he obtained a PhD (in 1997). He has been Senior Lecturer in Economics at the University of Versailles Saint Quentin since 1999, and Research Fellow at the C3ED since 1995. He has been working on environmental policy, natural capital assessment, indicators for sustainable development, energy and agricultural economics, and has contributed in building the M3ED model. He has participated in several national and European research programmes concerning French agriculture and water quality, greenhouse gas abatement through fiscal policy in the European Community, the economic and social aspects of environmental issues, and the application of non-monetary procedures of economic valuation for managing sustainable development.

1 Introduction

Concerns about soil and water pollution by modern agricultural practices are one of the 'contradictions' of industrial development too important to be ignored. Point pollution can consist of direct discharges of animal excrement or be due to the use of pesticides close to streams. Diffuse pollution caused by agricultural practices is generally linked to systematic use of fertilisers and to the use of pesticides. When the abatement capacity of the natural environment, partly linked to dilution, partly to the ability of plants and soils to absorb or fixate nitrates, is exceeded, pollutants reach surface waters by run-off and groundwater by infiltration.

The research reported in this paper was empirically focused on the Brittany region in France, its agricultural sector and the impacts of agricultural activity on water quality in Brittany. The aim has equally been at a methodological level, to develop a framework in terms of environmental functions for analytical tools measuring environmental performance and economic costs of adaptation. The goal is to generate indicators that illustrate the confrontation between environmental performance and economic cost criteria, in the context of a comparative scenario analysis related to the growth and technological change paths for agricultural production in the Brittany region.[1]

Any attempt to measure the potential for achieving a decrease in pollution must take into account costs that are generated when implementing the various technical measures. However, it is essential to make clear the way in which one calculates these costs. Our method is based on a cost-effectiveness analysis. It relies on a clear identification of the ecological problem at stake, in terms of indicators of ecological pressure. It also implies that we identify key economic activities of particular importance and characterise them in a way that is adapted to a cost-effectiveness analysis. In this paper, we develop such an analysis through comparing the long-term tendencies of target sectoral aggregates and the ecological pressure indicators.

The novelty of this approach is linked to the macro-economic scale and the way that the cost-effectiveness concept is projected through time, based on a scenario analysis of the Brittany area. We also develop procedures to take into account both the uncertainties concerning the variability of ecological pressure indicators and the economic potential for realising the ecologically adjusted economic growth paths.

The article is organised as follows. Firstly (Section 2), we identify the main environmental functions of water in the Brittany area and discuss the politics of agriculture. Then (Section 3), we present the structure of the scenario model used in our analysis, and show (Section 4) how the methods support a cost-effectiveness analysis. Finally (Section 5), we discuss comparatively the results and address issues of uncertainty and data quality related to water and soil pollution.

2 Critical natural capital in Brittany: from theory to practice

2.1 A framework to identify critical natural capital

For Hueting (1980), and other researchers following Hueting's approach in ecological economics (e.g. De Groot, 1992), the notion of environmental functions allows a quantification of changes in quantity and quality of natural capital. The distinction between two fundamental dimensions is useful (Ekins and Simon, 1999a,b; Faucheux and O'Connor, 1999):

- the internal functioning of the natural capital systems, a term which underlines the dynamism and structure that are intrinsic to ecosystems and physical processes (as life support and component of the biosphere)
- the functions provided by the natural capital systems for (or, more exactly, evaluated from the point of view of) economic activities and human welfare.

The 'regulation functions', which ensure the stability and the permanence of the biosphere as a habitat for the whole of living beings and processes, are part of the category of internal functions. In the second category, the various 'roles' played by the biophysical environment for the benefit of human beings are placed: source of energy and raw materials, sites for productive activities, transport, consumption and recreation, object of scientific and aesthetic enjoyment, place where wastes are unloaded and pollutants are, consequently, transported or deposited or assimilated, and the *human health and welfare* functions (for instance, the provision of a recreational and cultural area).

As a framework for identifying critical natural capital, we use the structure developed by Ekins and Simon (1999a,b) in the CRITINC project. It is presented as follows (see Table 1).

In the table, Level 1 consists in classifying the characteristics of each type of natural capital. Our typology is adapted from De Groot's classification (1992).

Then, in Level 2, environmental functions are divided into four categories: the source functions, the sink functions, the life support functions (for the ecosystems) and the human health and welfare functions. This classification does not, in itself, illustrate the *links* that exist between the environmental functions of different categories. We may make the distinction between two direct effects on the environment generated by human activities:

- through the use of resources, we tackle issues of the exhaustion of the resource
- from the issue of waste management, we can highlight pollution problems.

The depreciation or exhaustion of the resource not only reduces the stock of the resource but it also threatens the capacity of the environment to abate pollution. These impacts concern the life support functions and the health and welfare functions.

Level 3 introduces the concept of sustainability, defined as the maintenance of important environmental functions. Sustainability standards (norms) that would provide for maintenance are established and are compared to the pressure and state indicators of the situation focused on. This allows the identification of a sustainability gap that can be expressed in physical terms (Ekins and Simon, 1999a,b). Expressed differently, this gap corresponds to the 'distance' – indicated in some sort of physical units or system parameters – between the current situation we are dealing with and environmental sustainability. The reduction of this gap can be considered as an objective of public policy.

Table 1 Structure of identification of critical natural capital

Level 1	*Characteristics of natural capital*			
	Components and processes of ecosystems thanks to which natural capital can provide environmental functions			
Level 2	*Four types of environmental functions*			
	Environment as a provider of raw resources	Capacity of the environment to abate pollution	Environment as a life support	The contribution of the environment to human health and welfare
	Indicators: stocks of resources (e.g. fish stocks)	Indicators: quality of the environment (e.g. air quality)	Indicators: state of habitats and species	Indicators: effects on human health related to the environment, aesthetic benefits, recreational benefits
	Link between national accounts and environmental functions: the idea is to show which economic activities affect which environmental functions			
	Pressure indicators e.g. water consumption by agriculture	Pressure indicators e.g. CO_2 emissions by transport	Pressure indicators e.g. on habitat and species	Pressure indicators e.g. health problems related to pollution
Level 3	*Sustainability: thresholds, safe minimum standards . . . related to pressure and state indicators*			
	Sustainability norms	Sustainability norms	Sustainability norms	Sustainability norms
	Comparison between pressure and state indicators and identification of the sustainability gaps used when identifying environmental policies			
Level 4	*Socio-economic analysis (multicriteria analysis) to contribute to the decision-making process*			

Finally, Level 4 relates to the decision-making processes and policy tools put to work for diagnosing and promoting sustainability.

2.2 The sink function of water

For present purposes, we focus on the 'sink' function of water in the environment, noting that this interacts with the other types of functions.[2]

Due to its granitic and schistose platform, Brittany is not a very aquiferous area. The underground water that can be abstracted is located in little tertiary basins, in alluvium, or in deep cracks in impermeable rocks such as sandstone. The watercourses are therefore fed, to a large extent, by surface flows. An important feature is the construction of numerous dams aimed at supplying the mills, creating pisciculture ponds, developing canals for navigation and making sure they are supplied with enough water (e.g. the pond of Bosmeleac), producing electricity (e.g. the dam of Guerledan), ensuring the provision of drinking water or maintaining some minimum levels of flow.

The shortfall in groundwater has led to widespread use and abstraction of surface water for drinking purposes. Currently, more than a hundred abstraction points provide 80% of the adduction of water. In total, 268 million m^3 of water are consumed per year. The withdrawals of surface water represent 82% of the annual volumes of water and the consumption of drinking water accounts for 86.5% of these withdrawals (see Table 2).

Table 2 Demand for drinking water in 1995

Consumption		*Industrial use*		*Irrigation*	
Surface water	*Groundwater*	*SW*	*GW*	*SW*	*GW*
190,217	39,486	25,526	8,166,100	4,056,200	485,800

Sources: DIREN and Region Bretagne, 1998

In recent years, chemical pollution has degraded the quality of this vital resource, to the extent that some of the local populations and the restaurants of public institutions (such as schools, for instance) choose to consume bottled water. In particular, the nitrate content of tap water has been reaching unacceptably high levels. This has become a major issue of regional governance. Households, and industrial and agricultural activities generate the most important types of pollution.

Household pollution is characterised by the presence of pathogenic bacteria, suspended matter, organic matters, nitrates and phosphates. The higher the population density and the closer houses are to each other, the higher the pressure on the natural environment becomes.

Concerning industrial wastes, the farm-produce industries (nearly 200 such industries exist in the Brittany area) constitute a major source of pollutants in the water environment. More than 65% of the volume of pollutants are produced by three main sources of polluters: the slaughterhouses, the dairy industry and the vegetable canning industry. A high contribution also comes from chemical substances than can be oxidised, notably nitrates and phosphates. Chemical industries and/or surface treatment industries also generate some sub-products. Their pollution is calibrated as a function of their toxicity. The potential risk for the milieu is very localised in the region. Out of the 30 industries taken into consideration, six generate 80% of the pollution and five sites are at the source of 83% of the effluents: Fougeres, Lannion, Saint Brieuc, Redon and Rennes.

The situation strongly degenerated from 1987 to 1992, but seems to have stabilised since then. Overall, in the Brittany region, 24% of water samples collected in 1997 have exceeded the threshold of 50 mg/l at least once and, in the case of 28% of water samples, maximum concentrations of between 40 and 50 mg/l have been observed during the same year (Region Bretagne, 1999). Phytosanitary products (or pesticides) also constitute a source of water pollution. The main contamination of surface water results from the spreading of herbicides on sweet corn crops and also their use in non-agricultural activities. In the case of agricultural usage, the percentage of losses measured at the outlet are low (below 1%), compared with the quantities that are globally spread at the scale of the catchment. For non-agricultural uses, the spreading of herbicides on waterproof areas leads to them being directly transported to surface waters by run-offs, during rainy periods. The losses in these cases can be very high compared with the quantities that are being spread.

2.3 The political importance of water in the Brittany area

Water quality can thus be considered as 'critical natural capital'. Its maintenance is at the heart of sustainable economic processes. As such, water pollution plays a crucial role in the conflicts concerning the choices of orientation of development measures taken in the Brittany area. On the basis of empirical studies, we identify three main themes of disagreement within the Brittany community:

- the orientations of policies of restoration of the quality of water and, more generally, of the environment (for instance, a rejection of the project to construct a treatment plant)
- the denunciation of certain actions or non actions undertaken by some governmental institutions (for instance, officially permitting the illegal extension of pigsties, construction of pigsties in excedentary zones, non-transposition by the French government of the Nitrate Directive as a whole)
- claims related to the role played by the agricultural sector in the area (for instance, the idea of 'terroir', agricultural products of high quality. . .).

These three themes are strongly linked to the question of the mode of production. The intensive system that is actually developed in Brittany is based on a concept of mass production with low costs and high returns. This has led to the regrouping of lands, the modification of landscapes, a decrease in levels of employment and an increase in the size of farms, hence a strong dependency on the market and on the commercial bank system. All of this has contributed to an increase in pollution due to the high concentration of polluting matters, an over-production crisis, and the 'freeing up' of markets.

The Association 'Eau et Rivieres de Bretagne' appealed to the European Commission in 1992 by lodging a complaint against the French Government for its defective/faulty transposition of EEC Directive No. 80 on the quality of water, related to human consumption.[3] The advice of the European Commission, in the last step in the legal procedure before submission of the case to the European Court of Justice, stipulates that 'by not ensuring the restoration of the quality of surface water aimed at human consumption, the French government did not fulfil its obligations'. It is clear that, although regulations do exist, the lack of motivation to implement them and the maintenance of contradictory political views dramatically decrease the overall performance. The problem is two sided since it requires a refereeing between the exploitation of natural resources and of the rural space, and its protection in terms of life support environment. These conflicts are related to value systems that view the evolution of the economy in the region in radically different ways. Two themes are at the heart of the debate:

- a conflict between the uses that can be made of resources extracted from ecosystems
- a conflict over choices of production methods.

The legitimacy of the agricultural lobby reposes on the development of the agricultural sector since the end of the Second World War. The type of development adopted, generated certain cohesion around the objective of *progress* within the Brittany society. The agricultural lobby is made of various entities that reflect different modes of production porcine, poultry, vegetables, dairy products, etc. It is integrated, to a large extent, within the agro-industrial system, and is close to unions such as the FNSEA (National Federation of the Farmer Unions) and the CDJA. This lobby is characterised by a strong mobilisation, for instance during the strike at the prefecture of Morlaix in 1961 and at the Road Bridge in Morlaix, as well as a strong influence on economic and political milieu.

Recent poultry, porcine and vegetable production controversies reveal a strong agricultural lobby favouring an agricultural model based on world competitiveness (see Canevet, 1992). This latter is characterised by a strong dependency on markets and competition, mass production being preferred to production systems with high value added. Certain social groups (associations for environmental protection, of consumers, and of farmers) are strongly opposed to this position. The emergence of a counter-power is based on the establishment of a link between numerous movements with varying interests. Grouped in associations or 'communities' ('Collectif Coherence' was created in 1998, 'Collectif Pure Water' in 1992), these advocates of water protection, consumers associations, farmers, and more generally citizens who are keen to protect the environment, highlight inconsistencies of the present situation (see Network sustainable agriculture, 1998, 1999). They denounce as unscrupulous the legalisation of illegal extensions of pigsties and the inconsistency of the orientation taken by environmental policies (lack of implementation of the Nitrate Directive, weakness in the application of the European measures for the protection of environment (MAE), and diversion from the logic of the PMPOA, a French programme of environmental improvement at the farm level).

Originally concerned with local problems, some of these associations have broadened their range of actions and claims.[4] This protest movement now constitutes a real counterweight to the intensive agriculture lobby and intervenes in the decision-making process, both concerning the definition of norms and the implementation of actions.

The Guingamp trial (1996) was a striking manifestation of this rise in power. This issue had a media effect at a national scale, although it directly affected only 180 consumers. It constituted the first visible step towards the questioning of the current system of water management. The media, by providing information to local populations on a regular basis, brought a real rise in environmental awareness. Various actions have since been initiated, focused on themes as varied as water management in the centre of the Brittany area (1998) and future agricultural orientations (e.g. meeting in Pontivy, 1999). The impacts of these actors are varied since they both improve the environmental awareness of local populations and have an impact at the political and legal levels (see Table 3).

The position taken by industries in charge of the distribution of water is also noticeable. They have adapted their strategy as a response to problems caused by water degradation. Accused and condemned for having distributed water which did not comply with European norms, they and certain associations (Eaux et Rivières de Bretagne), took the French government to court for having badly transposed European environmental regulations. The water companies highlighted the inconsistency of the position taken by the French government who encouraged actions that limited the impacts of agricultural activities on the environment, while still not questioning, nor forbidding, the development of certain cattle breeding, and also not condemning farmers who are in illegal situations.

Table 3 Protest actions against the degradation of water quality

Actors	*Objectives*	*Means of action*
180 consumers in the town of Guingamp (1996)	(i) Legal action against the 'Lyonnaise des Eaux' (Water company) for not respecting drinking water norms (ii) The water company denounces the French government for not respecting the nitrate Directive (iii) Question current water treatment investments for non sustainability	(i) Legal action at national level (ii) Legal action at Euscale (iii) Denounce the increase of the water bill. Mediatisation at the national level; relation price-quality of water; water is produced by rivers so the protection of rivers if not only an environmental objective
200 Households in St Brieuc (1996)	(i) Denounce the attitude of public authorities concerning a real water policy. Mismatch between the price increase and the decrease in water quality. Weakness of financial aids for 'green' agriculture (ii) Use of charges to fund PMPOA (iii) Rejection of the pollution/ depollution cycle (iv) Push precautionary principle with regards to the impacts of water degradation on human health	(i) Non payment of amounts corresponding to the charge in the water bill
Association of consumers for the protection of the environment (1996)	(i) Environmental awareness amongst the population (Eaux et rivieres de Bretagne, ERB) (ii) Drinking water and protection of the environmental milieu (iii) Techniques to treat the water (iv) Land use management (PMPOA) (v) Increase in water bills	(i) 1st of January 1998: ERB can present: 45 definitive decisions, 67 running procedures, 71 debates of the administrative council concerning contentious actions

Table 3 Protest actions against the degradation of water quality (continued)

Actors	*Objectives*	*Means of action*
Group 'Pure water' includes associations of consumers and farmers for environmental protection (1992)	(i) Water as a common interest (ii) Drinking water and protection of the environment (iii) Water treatment techniques (iv) Land use management (PMPOA) (v) Increase in water bills	(i) Environmental awareness campaign (ii) Mediatised demonstrations – as was the case for instance in St Brieuc where thousands of bottles were left in front of the prefecture
Coherence group (1999)	(i) For changes in agricultural practices and water policies (including associations of consumers and farmers in favour of environmental protection)	(i) Demonstrations in Pontivy in June 1999

Midway between the agricultural lobby and political powers, the pressure groups find their legitimacy in the emphasis placed on the claims coming from different entities of society. This approach is therefore not sectoral, as is the case of the agricultural lobby; instead, it is citizen-centred.

3 A scenario approach for the analysis of agricultural options

3.1 Evaluation concepts

Our objective is to define methods for evaluating the costs that are generated by the operationalisation of a sustainable development strategy. In economics, it is habitual to ask if the value of a benefit obtained, or of the loss avoided are worth the investment of economic goods and labour needed to obtain it? Yet the 'demand' for environmental quality, which may include provision for future generations and a demand for protection from environmental harm, cannot easily be expressed as a value in monetary terms. We propose, therefore, that the problem of resource management for maintenance of essential and desired environmental functions be approached in terms of cost-effectiveness. The requirements are, firstly, to determine environmental standards or norms, for pollution emissions or natural resource consumption, in physical terms, independently of any notion of economic optimisation; and secondly, to find the most efficient option to reach defined norms.

In order to give an operational specification to this general framework, supplementary information and analytical propositions must be introduced. These include:

- explanation of the spatial and temporal scales at which the sustainability criteria will be applied
- the scientific or other justifications for the threshold levels or 'norms' that are proposed
- explanation of the analytical framework that will be applied to quantify the economic opportunity costs associated with the respect of the specified standards, including whether or not full respect is required immediately or via a transition path over a number of years.

This approach explores the question, what might a 'greened' or 'environmentally adjusted economy', that respects the specified sustainability standards, look like? It is thus a scenario-type approach. Indicators are developed that measure the *cost of achieving sustainability*. In effect, a monetary figure may be sought for the minimum cost that would have to be borne in order, through preservation, prevention, protection or restoration measures, to respect the designated sustainability norms. This would be a quantification of the opportunity cost of achieving sustainability.[5]

3.2 Agricultural activities in the Brittany area

Less than half a century ago, Brittany was described as a relatively poor area dominated by subsistence small-scale mixed farming. In only one generation, a model of intensive agriculture, largely open to the market economy, was introduced in this area and now provides 12% of the value of total French production from only 5% of the agricultural surface (Canevet, 1992). After more than 30 years of continuous growth, the porcine, poultry and dairy production of this area is ranked very high at the national level. The dynamism of Brittany, its complex network of professional organisations and the density of the farm-produce industry plants have upset the mixed farming system and favoured the development of an industrial type of agriculture.

Using the *Tableaux de l'agriculture Bretonne* (Agreste, 1997), it is possible to organise the economic information on agriculture in Brittany as summarised in Table 4. These figures reveal the importance of agriculture for the local economy. The 61,300 regional farms, although of modest size (on average 29 hectares in 1996), together provide 21% of the national production in milk, 56% of the production of pork, 31% of that of veal, 47% of that of chicken, 49% of that of turkey, 75% of the production of cauliflower, 72% of that of artichokes and 36% of the production of early potatoes. Recent developments are also characterised by a concentration of the means of production and the focus on certain products (see Table 5).

All the signs illustrate a strong quantitative growth in the agricultural sector. Brittany appears to be highly specialised in animal production. Canevet notes that:

> "despite the non negligible specialisation in the production of certain vegetables (which made the reputation of the area), the intensification of animal production is such that animal products still represent from 88% to 90% of final agricultural production while, on a national average, plant crops dominate slightly." (Canevet, 1992, p.26)

Nearly 90% of the land use in Brittany remains focused on products such as sweet corn, used to feed the cattle.

Table 4 Economic situation of agricultural in Brittany

Agriculture in Bretagne	*1970*	*1996*
Importance of agricultural activities		
Proportion of farmers in the area	24%	8%
Weight of Brittany agriculture at the national level		3.1% GDP
Weight of agricultural activities at the regional level		7.1% GDP
Agricultural structures		
Farms	150,915	61,300
Families of farmers	590,600	217,539 (1995)
Permanent salaried employees	33,800	6189 (1995)
Used agricultural surface (ha)	1,986,559	1,838,800
Agricultural incomes		
Values of animal deliveries (million francs)	4064	36,106
Values of vegetables deliveries (million francs)	759	5309
Intermediary consumption (million francs)	1523	28,058
Amount of subsidies		1,781,858,000 (42,651 FF/farmer)
Activities linked to agriculture		
Net turnover of farm-produce industries [IAA] (million francs)	14,133	95,665
Gross value added at factor costs	1842 *(1975)*	11,698 *(1995)*
Average number of salaried employees in the IAA	30,645	51,007

Source: Agreste, 1997

Table 5 Agricultural production in the Brittany area, 1966 and 1996

Agricultural production in the Brittany area	*1966*	*1996*
Bovine meat (tonnes)	148,997	275,651
Porcine meat (tonnes)	241,370	1,140,806
Chicken (tonnes)	125,531	548,589
Turkey (tonnes)	3193	300,691
Delivered milk (million litres)	1597	4667
Surface where fodder plants grown (ha) …	1,165,615	1,129,250
. . . amongst which sweet corn (ha)	76,774	353,000
Wheat (tonnes)	513,000	2,108,800
Sweet corn grains (tonnes)	30,000	664,600

Source: Agreste, 1997

3.3 Four scenarios of agricultural practices

From these observations on the Brittany area, we have identified one scenario perspective for 'continuing current tendencies' that we call *laisser faire*, and three alternative agricultural systems that we call '*raisonné* agriculture', '*économe* agriculture' and '*organic* agriculture'.

3.3.1 Scenario 1 – Laisser faire: intensive-productivist agriculture

The 'business as usual' practice pursues an intensive-productivist type of agriculture and does not take ecological disruptions into consideration. Any agricultural impact on the environment, and more specifically on water, can be addressed, if at all, by using restoration methods (de-nitrification equipment and treatment of water).

The intensive-productivist type of agriculture is the type of agriculture that, at present, we find most in Brittany and in France as a whole. It has permitted, for several decades, a process of economic accumulation, and it is thanks to it that the country has become more than self-sufficient in food products.

3.3.2 Scenario 2 – Integrated agriculture (the raisonné agriculture)

The *raisonné* (reasoned) intensive-productivist agriculture scenario uses management practices that aim to improve farming efficiency through a comprehensive approach, for the physical, social and economic dimensions of farming. Production techniques and programming are sought that are adapted to the specificities of each plot of land and of each agricultural practice. The intensive character does not disappear, but the wish to limit the negative impacts of the activity on the natural environment encourages the development of a 'precision' type of agriculture.[6]

The '*raisonné* agriculture' scenario thus represents practices aimed at reconciling the use of fertilisers to the real needs of the crops, taking account of the presence of certain elements in the soil and of the production potential of the plant. This implies a specialisation of agricultural systems. Concerning the protection of plants, the '*raisonné*' methods reject blanket treatments. *Raisonné* agriculture also deals with cattle breeding and, more specifically, with the feeding of animals, the construction of buildings in which cattle breeding is taking place, and the management of effluents.

3.3.3 Scenario 3 – Careful husbandry (the économe agriculture)

The concept of '*agriculture économe*', which we translate as careful husbandry, seeks to reconcile output goals with the agronomic principles of balance between soils, plants and animals. It is still often an intensive-productive type of agriculture, but one that relies on a frugal and autonomous approach to agricultural practices (less energetic wastes, less European funding). This type of agriculture is largely inspired by the research of the CEDAPA (see Pochon, 1991, 1998).

The idea is that what is produced by the soil must adequately correspond to what the animals consume. The excrements of the animals should provide to that same soil the nutrients needed to maintain the fertility of the soil and its humus. A balance between cattle breeding and crops, including fallow years, allows the reconstitution of humus; earthworms proliferate, the structure of the soil becomes softer and easier to cultivate. Cattle breeding should be in buildings where the ground is covered with straw rather than concrete. Ruminants, bovines and ovine animals must be fed with grass for as long as possible. The maintenance of soil fertility is a productive investment; it can be done partly through the restitution of the elements generated by the plants from the crop.

3.3.4 Scenario 4 – Organic agriculture

The scenario for an *organic* agriculture (in French it is termed *biologique*) represents a category of alternative practices that, like the previous types of agriculture, are based on the questioning of an intensive-productive system. It puts great attention on the quality of the products and human health. Also designated as a 'sustainable agriculture', it is based on the precise knowledge of the bio-geo-chemical cycle of the plant rather than on the narrow analysis of the nutritional requirements and of their systematic chemical protection, and envisages social dimensions, such as equity to farm workers, ensuring safety in all work environments, and contributing to local community viability.

The economic actors (farmers and others) who implement 'organic agriculture' use a variety of practices aimed at respecting the ecological equilibrium, soil fertility, the environment and animal welfare, e.g. crop rotation techniques, choose crop varieties that are adapted to the soils and the climate, and forbid cattle breeding in confinement.[8]

The four types of agriculture presented above reflect a diversity of the *scales* taken into consideration, as well as the *priorities*. In Table 6 we propose, on the basis of our interviews and documentary analysis, a hierarchy of the main *social values* related to the scenarios. We distinguish three major axes for the social values: economic profitability, environmental protection, and impacts on the territory. The numbering system in the table, illustrates the relative order of priority.

Table 6 Hierarchy of priorities in each type of agriculture

Social values/ scenarios	*Economic profitability*	*Protection of the environment and quality of products*	*Territorial impacts*
Intensive productivist agriculture	1 Necessary for the survival/maintenance of the local economy and agricultural activity, mass production, reliance on the market and aspiration to minimal costs	3 Only constitutes one necessary element in the production process (production factor)	2 Territorial development is necessary to ease commercial exchanges (motorways, airports . . .)
'*Raisonné*' agriculture	1 Aspiration to a minimal cost and to a gross excess of maximal exploitation, importance of intermediary costs and importance of the market	2 Selling argument for agricultural products or used in the management of framsdans (norm 'ISO'), importance of the image given, better use of inputs	3 Objective: maintenance of agricultural activity in the Brittany area, strong links with the farm-produce industries

Table 6 Hierarchy of priorities in each type of agriculture (continued)

Social values/ scenarios	*Economic profitability*	*Protection of the environment and quality of products*	*Territorial impacts*
'Careful husbandry' agriculture	2 Objective: high value added, less inputs used, less European fundings	1 Integration of environmental considerations at the farm scale (as production factor) and from a more general angle	3 Dynamic type of agriculture preferred, especially if it creates jobs
Organic agriculture	3 Objective: high value added	1 The agricultural activity evolves in harmony with natural processes	2 Objective: human and animal welfare, job creation

Economic profitability is a recurrent theme, expressed in terms of aspiration towards *low cost mass production* in the first two cases of agriculture and in terms of *high value added* in the latter two types of agricultural system (pursued alongside the protection of the environment and the quality of agricultural products).

3.4 The major environmental pressures

Until 1990, analysis of the degradation of water quality was limited to the notification of any increase in the nitrate content of water and of the eutrophication of continental waters.[9] This pollution gives rise to a lack of oxygen in natural environments and to the development of 'green tides' (43,000 tonnes of algae (ulves) were collected in 1997). The whole of the Brittany area has been classified as a Nitrate Sensitive Area under the Nitrates European Directive (no.91/676 of 12 December 1991), and 71 districts have been listed as Zones of Structural Excesses, in which more than 170 kg of nitrates of animal origin are found per hectare.[10]

Analyses of water quality in the Brittany area since 1971 highlight an increase of average nitrate content from 8.5 mg/l in 1972 to 39 mg/l in 1994 (DIREN and Region Brittany, 1998). Numerous water samples exceed, or have occasionally exceeded, the threshold of 50 mg/l that is imposed by the Drinking Water Quality European Directive 80/778. Some water abstraction units have had to invest in de-nitrification equipment. Forecasts for 2005, anticipate the exceeding of nitrate norms for two-thirds of the water abstractions in Brittany if nothing is done.

Soils are also affected by eutrophication, when excessive quantities of nutrients generate a decrease in oxygenation in the soils and stop micro-organisms from functioning normally.

Nitrates come mostly from agricultural activities in the form of animal faeces, synthetic fertilisers and industrial and domestic wastes. The main source of pollution, for 60% of nitrates of animal origin in the Brittany area, is cattle (bovine) farming. However, the target sector mainly accused is pig raising, whose 25% of nitrate pollution has a more concentrated impact that is also much more visible and smelly.

Excessive fertilisation is another main cause of pollution by nitrates. On the one hand, an excess of nitrates compared to the expected crop uptake can be caused by a superfluous use of nitrates aimed at ensuring a good return, or by a bad estimation of what amount of nitrates does actually remain in the soil. In this case, improving the measurement of crop requirements and soil content constitutes a means to limit an otherwise excessive application of fertilisers. On the other hand, an excess of nitrates related to the difference between the expected and the actually realised crop output, leads to an ex-post excessive fertilisation. Aiming for a high productivity increases the probability of not achieving the original objective due to the deficiency of another growth factor. Even if agronomic techniques can improve the adequacy between the expected output and the outcome actually generated, external parameters can still, at any time, limit the size of the crop compared with what it was originally hoped. It is, therefore, the very *logic of intensive agriculture* that is at the heart of the problem.

4 Modelling the scenarios

In this section, we present a modelling technique, the M3ED-AGRI, as a methodological basis to formulate cost-effectiveness analysis integrating economic and environmental considerations. Four steps will be followed: we will first present the M3ED-AGRI (Section 4.1), explaining the incorporation of environmental pressures (Section 4.2), the scenario specifications (Section 4.3) and the framework of the cost-effectiveness analysis (Section 4.4). The subsequent Section 5 will then present and discuss the scenario analysis results.

4.1 The regional AGRI model

The M3ED-AGRI model represents agricultural activity in the Brittany area, and is intended to examine the influence of water quality norms on physical yields coming from agricultural production. We focus on the adjustment costs that the agricultural sector would face if such a measure were to be adopted with a view to protecting the environment. The modelling technique, based on the dynamic dimension of systems, seeks to highlight the elements of conflicts that occur when resources are being allocated between plant and animal production sectors, in the context of overall environmental constraints on output growth.

In formal terms, M3ED-AGRI is a sub-model, or module, of the dynamic M3ED (*Modèle Economie-Energie-Environnemen – Développement*) simulation developed at the C3ED during the 1990s and implemented for various French, as well as Netherlands, national economy studies (see Douguet and Schembri, 2000; also Schembri, 1999a,b).

A disaggregating is carried out within the agricultural sector module M3ED-AGRI, based first of all on the main division in agricultural production between plant and animal production activities. Then a further differentiation is made between various types of crops and animal husbandry. Each 'plant production' sub-module provides some information concerning nitrate, phosphoric and potassium products, the needs for phytosanitary products, and this information is then related to the used surface. Similarly, each sub-module of 'animal production' indicates the quantity of water being consumed and the dejection related to that activity. Each sub-module also illustrates the quantity required of technical capital.[11]

The modelling technique takes into account the nitrate, phosphate and potassium imports (coming from animal origin) and the export of the these same elements by the plant crops. In a certain way, we re-trace the 'nitrate cycle'. These features appear in Table 7.

Table 7 The structure of the M3ED-AGRI module

Input table		*Production*					*Exports*
	Production animal		*Animal production*	*Plant production*	*Surface*	*Total production*	*Plant production*
Organic emissions	Ai	Organic fertilisers	–	Bi	Si		Exi
		Chemical fertilisers	–				
		Pesticides	–	Pi	Sp		
		Water	Oa	Ov			
		Surface	Sa	Sv	St		
		Total production	Xa	Xv	Xt		
		Proportion in France			Xf		
		Proportion in Europe			Xe		
		Export			Ext		

Notes: *Ai* represents the nitrate, phosphorus and potassium emissions that come from animal production; *Bi* represents the plants' needs in nitrate, phosphorus and potassium, per hectare; *Pi* is the rate of use of pesticide per crop; *Oa* is the water consumption by the cattle; *Ov* is the water consumption for irrigation; *Sa* is the animal density'; *Sv* is the yield per hectare; *Xa* and *Xv* are, respectively, the animal and plant productions *Si* is the nitrate, phosphorus and potassium concentration; *Sp* is the rate of use of pesticides per hectare; *St* is the total usable agricultural land; *Xt* is the total agricultural production in the Brittany area; *Xf* is the weight of the agricultural production in France, while *Xe* is the weight of French agricultural production in Europe; *Ext* is the agricultural production which will be exported; *Exi* represents the levels of nitrate, phosphorus and potassium that are exported by the plant crops.

The AGRI model of agricultural supply thus portrays, in a stylised way, the diversity of structural farming conditions in the Brittany area as well as the potential for substitution between the various agricultural and cattle breeding practices.[12] The model allows the estimation, at a regional level, of what the adaptation costs of the farmers' supply might be, following the setting of regulations aimed at protecting water quality.

The regional production, which is made up of crop and animal components, is formulated as follows:

$$Q_{AGR}(t) = a_v(t).Q_{AGR}(t) + a_a(t).Q_{AGR}(t) \tag{1}$$

$$a_v(t) = \frac{\sum_n Q_n(t)}{Q_{AGR}(t)} \ ; \ n \in \mathrm{N}$$
$$a_a(t) = \frac{\sum_b Q_b(t)}{Q_{AGR}(t)} \ ; \ b \in A$$

In Equation (1), t represents the date at which the various alternative agricultural options start being implemented (year 2000 in the context of our simulations).

The plant (vegetal) crop production depends on the yield per hectare, on the used surface and on a growth factor linked to the demand for agricultural products:

$$Q_n(t) = \begin{cases} \rho_n(t).S_n(t).\varpi_v(t) \text{ pour tout } t < \bar{t} \\ \rho(\Phi(\varepsilon_n, t), \bar{\rho}_n).S_n(\bar{t}).\varpi_v(t) \text{ pour tout } t \geq \bar{t} \ ; \end{cases} \tag{2}$$

$$\varpi_v(t) = \frac{Q_v(t)}{Q_v(0)}$$
$$\rho_n = \frac{Q_n(0)}{S_n(0)}$$

where ρ_n corresponds to the yield per hectare for the crop n; $\sigma(\varepsilon_n, t)$ is a function of distribution of a time lag, where ε represents the time that is necessary to reach an objective of productivity, S is the surface, and ω is the growth factor.

Depending on the objective of productivity previously defined, we can measure the impacts of different types of agricultural practices on the use of pesticides, and the net emissions of nitrates (see Table 8).

Table 8 Parametric configuration for (plant) crop production

	Wheat	*Corn*	*Barley*	*Oat*	*Fodder*	*Colza*
*Exports**						
Kg of nitrate per quintal	1.9	1.5	1.5	1.9	1.2	3.5
Kg of phosphorus per quintal	0.9	0.7	0.8	0.8	0.55	1.4
Kg of potassium per quintal	0.7	0.5	0.7	0.7	1.2	1.0
Production						
Surface in ha**	165,384	62,642	67,100	20,272	284,504	21,280
Return (in q/ha)**	78	70	70	55	111	32
*Fertilisers***						
Kg of nitrate per quintal	3	1.79	2.64	4.14	1.40	8
Kg of phosphorus per quintal	0.53	0.49	0.97	0.74	0.307	1.308
Kg of potassium per quintal	0.862	0.8	0.99	1.218	0.505	2.154

Notes: * norms CORPEN; ** AGRESTE (1991); *** Bonny and Carles (1993)

Animal production depends on various things, including the surface that is needed, and the growth factor linked to the demand for cattle.

$$Q_b(t) = \kappa_b . N_b(t) . \alpha_b$$

$$N_b(t) = \begin{cases} \left(\varphi_f^b\right)^{-1} . \sigma_b . \varpi_a(t) \text{ pour tout } t < \bar{t} \\ \varphi\left(\Phi\left(\varepsilon_b, t, \left(\bar{\varphi}_f^b\right)^{-1}\right)\right)\sigma_b . F_f^b(\mathrm{t}) . \varpi_{\mathrm{a}}(\mathrm{t}) \text{ pour tout } t \geq \bar{t} \text{ ;} \end{cases} \quad (3)$$

$$\kappa_b = \frac{Q_b(0)}{\alpha_b . N_b(0)}$$

$$\sigma_b = \frac{N_b(0)}{S_{ep}(0)}$$

$$\varphi_f^b = \frac{F_f^b(0)}{S_{ep}(0)}$$

where Q_b represents the quantity of meat actually produced and N is the number of animals in the cattle; K_b refers to the net average weight; σ_b is the number of animals per unit of ‘spreadable agricultural surface’ (that can be dosed with pesticides – estimated as 70% of the 'useful' agricultural land); $\phi^b{}_f$ refers to the quantity of fertiliser *f* of animal origin *b* per unit of surface that can be spread with fertilisers; α_b is the fraction of the cattle slaughtered at the end of the initial year; and $\bar{\omega}_a$ is the growth factor related to the demand for agricultural products of animal origin (see Table 9).

Table 9 Parametric configuration for animal production

	Bovine	*Pork butcher sows*		*Poultry*	*Ovine and Caprine (goat)*
Kg of nitrate per head cattle*	47.68	10	9.88	0.44	8
Kg of phosphorus per head of cattle*	19.9	3	15	2.55	3.6
Kg of potassium per head of cattle*	50.25	2.2	11	1.45	9.6
Average net weight in kg**	327.6	89.8	149.7	1.25	14.05
Proportion of slaughtered animals**	0.239	2.22	0.148	0.0043	0.96
Load per ha***	1.389	3.9	1.1	35	

Notes: * norms CORPEN; ** AGRESTE (1991);
*** size of the sample (AGRESTE 91) compared to the size of spreadable surface

4.2 Ecological pressure indicators

Concerning the emission of pollutants, the model calculates 'pressures' on the environment that are caused by agricultural production. Each type of emission has different weights allocated per type of crop or animal husbandry. We calculate the average quantities of fertiliser that are spread per hectare, to which the supply rates in nitrate, phosphorus and potassium are applied. In this way, all crop production is associated with a certain amount of consumption of fertiliser, written as follows:

$$F_f^n(t) = \begin{cases} \phi_f^n . Q_n(t) \text{ for any } t < \bar{t} \\ \bar{\phi}_f^n . \left[\Gamma(\Phi(\varepsilon_n, t), Q_n(t))\right] \text{for any } t \geq \bar{t} \, ; \end{cases} \quad (4)$$

$$\phi_f^n = \frac{F_f^n(0)}{Q_n(0)} \text{ with } f \in \Phi$$

where $\sigma^n{}_f$ represents the quantity of fertilisers used to obtain a 1/5th of the agricultural product *p*. The index *f* includes the nitrate, phosphorus and phosphate-enriched fertilisers. All animal production is characterised by the use of nitrate, phosphorus and potassium.

$$F_f^b(t) = \begin{cases} \eta_f^b . N_b(t) & \text{for any } t < \bar{t} \\ \eta(\Phi(\varepsilon_f^b, t)\overline{\eta}_f^b).N_b(t) & \text{for any } t \geq \bar{t}\,; \end{cases} \quad (5)$$

$$\eta_f^b = \frac{F_f^b(0)}{N_b(0)}$$

where η^b_f represents the average use of nitrate, phosphorus and potassium for each animal, over a year.[13]

Animal excrements constitute an important source of nitrates. The development of intensive cattle breeding leads to an increase in the quantity of polluting substances. Moreover, the geographic concentration of these practices makes the sewage farm lands progressively saturated. In such situations, the quantities of nitrate being applied exceed the capacity of both soils and crops to abate the pollution, hence generating important ecological perturbations.

Our ecological pressure indices are designed to give a synthetic assessment of the residual or 'net' quantities of nitrate, potassium and phosphorus in the Brittany area:

$$\mathrm{B}_f(t) = \sum_b F_f^b(t) + \sum_n F_f^n(t) - \sum_n \psi_f^n . Q_n(t) \quad (6)$$

where

$$\psi_f^n = \frac{f_n}{Q_n}$$

B_f corresponds to the remaining quantities of pollutants generated by agricultural activities.

Such an approximation focuses on the various inputs (such as the fertilisers of organic origin (F^b_f) and the fertilisers of mineral/inorganic origin (F^n_f), as well as the outputs (exports secured by the crops) ($\psi^n_f . Q_n$). A general assessment can therefore be conducted for nitrates, phosphorus and potassium, measuring the environmental performance of agricultural activities at a regional level.

With the use of this type of composite indicator, the loss of some information is inevitable. An important part of research consists in highlighting the existence of compromises and uncertainties with regard to information availability and quality (Douguet and Schembri, 2000).

4.3 *Specifying the scenarios in the M3ED-AGRI model*

The modelling exercise initiated here aims at defining a few key environmental pressure indicators, designated at the regional scale and in a dynamic way, which can be used in the context of a regional cost-effectiveness analysis. The following example is related to a specific scenario to each particular specification of the required ecological pressure indicators. The evaluation exercise consists in measuring the 'gap' between the various simulated tendencies. This gap constitutes an estimated value of the adaptation cost of the system, associated with the shift from one tendency to another.

We thus need to compare the time-paths of the main economic aggregates and of the ecological pressure indices. The estimation of economic control costs is obtained from the analysis of the difference – the gap – between the evolution of an economic aggregate and the trend that this same aggregate would follow if the economic activity remained ecologically non-adjusted. As outlined earlier, four scenarios, which illustrate the pursuit of distinctive objectives, have been distinguished:

- Scenario 1: an intensive-productivist regime, '*Laissez-faire*', continues the recent past tendencies for agricultural production in the Brittany area. The dynamism is based on the commercial logic of the market, the the environment being viewed as a production factor (vis., irrigation water and land).
- Scenario 2: 'Agriculture *Raisonnée*' is an agriculture based on a systemic view (links between the functioning of the farm and the dynamic environment, cf. Besnault, 1998) which aims at generating a product of high quality as well as respecting and protecting the environment within which it functions. The intensive character of agricultural practices does not disappear, but the wish to limit the impacts of the activity on the environment is highlighted.
- Scenario 3: 'Agriculture *Econome*' privileges efficiency, hence productivity, while avowedly respecting agronomic principles that underlie the balance between soils, plants and animals. It seeks to find ways to best use resources from soil, water and natural energy.
- Scenario 4: *Organic* agriculture is based on a specific concept of the quality of products and of human and animal health. Modes of agricultural production are based on a good physiological state of living beings that reinforces their capacity to resist external stresses. If prevention is not enough, treatment methods are based on the use of natural products, reducing the need for chemical substances. The commercialisation of organic products is regulated by labelling and certification.

The differentiation between scenarios in M3ED-AGRI modelling is achieved, in quantitative terms, by assigning different values for key technical coefficients, notably those relating to plant production (yield per hectare), animal density, land areas utilised, spreading of animal wastes, and use of chemical inputs (nitrates, pesticides). These scenario specifications are shown in Table 10. The quantitative differentiation is the basis for our dynamic cost-effectiveness analysis, as described below. However, there are also qualitative societal value dimensions underlying the scenario themes, which are not discussed here.

4.4 The cost-effectiveness analysis

Our evaluation perspective seeks a dynamic measure of environmental performance and of the adaptation costs associated with implementation of policies aimed at controlling water quality. The analysis of the economic adaptation cost consists in taking an economic aggregate as a reference (in this case, regional agricultural product), and then confronting its time path with that which would be observed following an ecological adjustment. The characterisation of environmental performance is also made in terms of comparisons between the *laissez faire* and ecologically adjusted evolutions, for the selected ecological pressure indices (emissions of nitrate and the assessment of nitrate residues).

It is important to underline the dynamic dimension of this evaluation approach, which is based on *the comparison of simulated tendencies*, as opposed to the comparison of figures at a specific moment in time.

Table 10 Presentation of technical coefficients for each scenario

		Laissez-Faire		*Raisonné*		*Econome*		*Organic*	
		Cereal output (kg/q)	*Surface*	*Cereal output*	*Surface*	*Cereal output*	*Surface*	*Cereal output*	*Surface*
Organic fertiliser	Wheat	3	No limit	Same as in Laissez-Faire	Max. 170 kg of nitrate/ha	Same as in Laissez-Faire	Max. 140 kg nitrate/ha	Same as in Laissez-Faire	Max. 170 kg nitrate/ha
	Sweet corn	1.79							
	Cereals	1.40							
Chemical fertiliser			No limit		No limit		No limit	0	–
Return (qx/ha)	Sweet corn – cereals	111	Animal density: Bovine: 1.33 Porcine: 2.7 Sow: 0.87 Poultry: 35	111	Same coefficients as in the scenario Laissez-Faire	111 (max 33% SAU)	Animal density: Bovine: 1.33 Porcine: 2.23 Sow: 0.66 Poultry: 35	111 (max 33% SAU)	Same coefficients as in the économe scenario
	Sweet corn – grains	90		90		90		90	
	Other cereals cereals	85		85		70		40	
	Grains	–		–		7–8 T (max 55% SAU)		7–8 T (max 55% SAU)	

$Q_{agr}^{ref}(t)$ represents the *laissez faire* agricultural output for an economy which is not subjected to the constraint of environmental control, and $Q_{agr}^{i}(t)$ is the ecologically adjusted agricultural product for an economy in which specified measures have been taken. A measure of the economic adaptation cost results is derived from the *laissez faire* output, the part that is 'destroyed' (vis, not produced) as a consequence of respecting the ecological constraint.

$$C_i(t) = Q_{agr}^{ref}(t) - Q_{agr}^{i}(t) \ . \tag{7}$$

The loss of economic growth due to the ecological constraint is a measure of the opportunity cost, which can be set in proportion to the *laissez faire* product, by defining:

$$\mathrm{X}_i(t) = \frac{C_i(t)}{Q_{agr}^{ref}(t)} \ . \tag{8}$$

This measure constitutes an estimate of the total economic cost associated with the transition towards ecologically adjusted agricultural practices. In this way, we suggest a dynamic interpretation of the 'loss in growth', since the model that is used shows the evolution of the economic cost over the whole temporal horizon considered.

We adopt the same approach to define environmental performance. The index of ecological pressure that we have selected is the residual quantity of nitrate generated by each alternative regime of agricultural activity that we test. The calculation of the environmental performance is made by comparing the net emissions of nitrate generated by the *laissez faire* scenario with those derived from the alternative scenario *i*:

Equations 10.9 and 10.10 have been renumbered 9 and 10.

$$P_i(t) = B_f^{ref}(t) - B_f^{i}(t) \tag{9}$$

In this way, the economic value attributed to one unit of pollutant can be defined as:

$$V_p^{i}(t) = \frac{\Delta C_i(t)}{\Delta P_i(t)} \tag{10}$$

The cost-effectiveness analysis aims at defining the economic value of one unit of pollutant with reference to an environmental norm. Here, it is assumed that each of the different 'adjustment' scenarios can reach the latter. With this in mind, we choose to conceptualise any *agricultural practice* as follows:

> *Proposition 1:* an agricultural practice *i* is parameterised as an ecologically adjusted action which increases (decreases) the probability of improving water quality by decreasing (increasing) the emissions of nitrate for a given economic cost (gain), in terms of additional loss (gain) of output which would be associated with the implementation of the practice.

From a dynamic perspective, we have to consider the evolution over time of the marginal cost associated with an agricultural practice. We refer here to the following proposition.

> *Proposition 2:* the implementation of any agricultural practice *i* implies an adaptation cost which can be measured in terms of additional loss of growth, net of the surplus of realised performance.

This mode of evaluation allows us to highlight the importance of adaptation periods when we compare the economic and ecological criteria of evaluation for the various suggested scenarios. This is a well known issue in economics, the difficulty associated with the time-lag between the sacrifice implied by the implementation of pollution control measures that occurs in the short term, and the beneficial effects on the environment that can be observed in the long run. Our second criterion of classification is calculated as a *difference of rates*, i.e. by subtracting the growth rate of the economic loss by the growth rate of the environmental performance, for each alternative agricultural practice.

$$G_i(t) = \frac{\Delta C_i(t)}{C_i(t)} - \frac{\Delta P_i(t)}{P_i(t)} \tag{11}$$

This fundamentally dynamic criterion highlights the importance of time-lags necessary to implement the adjustment modes selected, as well as the economic cost which is associated to them. If, for example, there is a slowing down of the annual average growth rate of the marginal cost, this may be interpreted as evidence of the importance of learning effects associated with the implementation of the alternative forms of agriculture.

5 The results of the scenarios

5.1 Evolution of agricultural production and nitrate emissions

The simulations have been made using the M3ED-AGRI modelling over a period of 20 years (2000–2020). Our first result is that the value of agricultural production (in million francs 1990) may experience a double evolution, depending on the scenario (see Table 11).

In both the *laissez faire* and *raisonné* scenarios, agricultural production increases monotonically. This growth is less rapid in the case of the *raisonné* scenario; however a slowing down of growth rates characterises both cases. The *économe* and *organic* scenarios are characterised by a stabilisation of production in the ‘long run’. In the *économe* scenario, it is the animal production whose share decreases; in the *organic* scenario, by contrast, it is the plant production whose share diminishes considerably due to a lesser yield per hectare.

Concerning the net emissions, the same divergence shows up. The evolution of net nitrates emissions, i.e. the difference in quantity of nitrates between the quantity of nitrates spread by the farmers and that absorbed by the plants, seems to increase in the *laissez-faire* and *raisonné* scenarios (see Table 11). In the *raisonné* scenario, the increase is smaller. In the two other (*économe* and *organic*) scenarios, the nitrates emissions strongly decrease because of several factors in combination – the less important yield, the fact that the surface used to develop the cultures/crops, and because of the lower density of animals. By referring only to nitrates emissions in the various possible evolutions of agriculture in the Brittany area, we are limiting the impact of our analysis. It is clear that the problem related to the use of pesticides is also an important source of concerns; but we do not present results here (see, however, Douguet, 2000).[14]

Table 11 The main simulation results

	Raisonné		*Econome*		*Organic*	
	2010	*2020*	*2010*	*2020*	*2010*	*2020*
Final agricultural output* (millions of francs 1990)	46,877 (48,482)	49,131 (52,806)	44,475	43,368	44,773	43,769
Net emissions of nitrate* (tonnes)	286 (307)	288 (322)	202	145	166	96
Ecological performance						
Tonnes	19.7	31.9	103	174	139	223
Per cent	6.4	10	33	54	45	69
Cumulated tonnes	77	360	439	1936	368	2306
Economic cost						
Millions of francs 1990	1594	3662	3996	9425	3698	9024
Per cent	3.28	7	8	17.8	7.6	17
Cumulated	5934	34,078	15,447	86,854	14,120	81,690
Marginal cost (francs 1990 per ton)	38,532	56,796	7037	11,215	6906	7084
Growth rate per annum**	2.53	3.56	3.62	3.38	5.42	4.28
EC Nitrate Directive						
Time required for adjustment (number of years)	23		8		10	
Instantaneous cost of adjustment (millions of francs 1990)	46,189		8124		14,120	
Instant. marginal cost (francs 1990 per ton)	100,889		33,032		38,322	

Notes: *Numbers in brackets refer to the *laissez faire* scenario
**For intervals (2005–2010) and (2010–2020)

Economic costs are, as we have explained, estimated by reference to the decrease in the level of agricultural production, by comparison with the level of production in the *laissez faire* scenario. The environmental performance is judged by comparing the net emissions of nitrate in the *laissez faire* reference scenario with that of other scenarios of sustainable agriculture. With all the necessary precautions about our simple scenario specifications, we obtain the result that the *raisonné agriculture* scenario is characterised by a relatively high cost of de-pollution for an environmental performance that is relatively low. The *économe* and *organic* scenarios, by comparison, have lower additional costs while achieving significant environmental performance improvements. These cost-effectiveness results, relative to the *laissez faire* scenario baseline, are shown in Table 11.

5.2 Adaptation costs to respect the EC Nitrate Directive

We have made the (simple) hypothesis that, as of the year 2000, all farmers agree to respect the European norm for nitrates in a uniform way (170 kg of nitrates of animal origin per hectare). We then focused on the identification of the adaptation costs imposed by such an initiative and the time required for reaching the target.

From Table 11, we observe that the form of *économe* agriculture, which imposes a more stringent norm on nitrates of animal origin (140 kg of nitrates per hectare), gives the best economic cost per unit of environmental performance.

The adaptation costs for the cases of the *économe* and *organic* scenarios are roughly comparable in magnitude, at around 35,000 FF (5 to 6000 euros) per tonne of nitrates, over a time horizon of 8 to 10 years. In the case of the *raisonné* agriculture, by contrast, it would take around 20 years to reach the target at a cost of around 100,000 FF (around 15000 euros) per tonne of nitrate. Thus, the *raisonné* type of agriculture generates an environmental performance that is relatively lower than the other two adjustment scenarios, for economic costs that seem to be far more heavy.

The three agriculture regimes all generate increasing marginal costs of ecological performance. Therefore, we can highlight the importance of the inertia cost associated to agricultural practices and the time of adaptation that is necessary for the transition towards sustainable types of agriculture to take place at a regional level.

5.3 Brief discussion and interpretation of the results

These results, although valid for orders of magnitude only, reveal the importance of the economic adaptation costs that the agricultural sector would have to bear in order to respect the European norm on nitrates.

Sectoral economic growth, for the *raisonné* agriculture scenario, is estimated to be 1.1% per annum. The economic surplus is assigned, in the scenario, to agricultural production and also to the funding of programmes aimed at improving agricultural practices and waste treatment which, as stressed in Table 11, constitutes an important investment. The improvement of environmental performance (relative to the *laissez faire* scenario) is essentially linked to a limitation in the quantity of nitrate fertilisers of animal origin being spread. However, as the results show, only a stabilisation of the pressure indicator is envisaged in the long run. Respecting the Nitrate Directive, as it is suggested in the *raisonné* scenario, does not produce any real improvement in the environmental situation (it simply slows the degradation).

The *économe* scenario is characterised by a slightly lower economic growth of 0.9%. However, the magnitude of the investment in the agriculture sector is less that what is needed in the case of the *raisonné* scenario. So, in the modelling, the amounts taken from the economic surplus specifically to fund the activities whose objective is to improve agricultural practices and waste treatment are correspondingly lower. Concerning the indicators of ecological performance, the improvement of the situation is particularly related to a change in modes of production, which reduces the quantities of fertilising substances of animal origins that are spread. This is an important consequence of this perspective since it does not seek to respect the Nitrates Directive as the main objective of the approach, but to focus on some lower levels of spreading of nitrate substances of animal origin. This approach embraces an agronomic dimension. The evolution of the production is related partly to technical changes, but also to the selected mode of production in a farm.

The *organic* agriculture scenario assumes a growth of 0.8% over the 20 years. A slight increase in the agricultural production occurs in the simulation period. However, a very small part of the economic surplus is allocated to the funding of activities that are aimed at converting agricultural activities, and to the implementation of cleaning systems and treatment of wastes of animal origin. The ecological performance is relatively very good. This is due to the fact that nitrate fertilisers of chemical and animal origin are not used in this scenario. Here, as in the *économe* scenario, the respect of the Directive is not particularly pursued. On the contrary, the operational feature is to modify the modes of production in the agricultural sector. *Organic* agriculture presents some advanced technical skills and also some interesting elements of modes of production. This alternative is thus characterised by a complementarity between environmental functions, and the respect of environmental functions that are *internal* to the natural capital system, which is the premise for the provision of the environmental functions that are provided for human activities.

In Table 12, we make a summary picture of the characteristics and implications of each scenario of sustainable agriculture that have been mentioned in our analysis.

Table 12 Summary picture of the scenarios

	Raisonné scenario	*Économe scenario*	*Organic scenario*
Economic growth rate	The economy grows at approximately 1.1% p.y	The economy should grow by 0.9% p.y	The economy should grow by 0.8% p.y
	Corresponding increase in agricultural production	Stagnation of agricultural production	Slight increase in the agricultural production
Distribution of economic surplus	Technical evolution of the agriculture	Structural and technical evolution of the agricultural sector	
	Maintenance of important funding to improve agricultural practices and waste treatment systems	Less funding of agricultural and depollution activities	
Evolution of demand	The economy keeps, in this perspective, its role in exportation	The *économe* and *organic* scenarios seek above all to meet the needs of the local and national population	
	Few elements concerning the demand can be included due to its exogeneity in the M3ED-AGRI modelling	The role of agriculture at the international level, in both cases, is diminished	

Table 12 Summary picture of the scenarios (continued)

	Raisonné scenario	*Économe scenario*	*Organic scenario*
Social climate	Social conflicts occur because: some costs linked to the implementation of polluting technique	The aspirations of the local population being more taken into account, the risk of social conflicts is diminished	
	The acceptance or not of the degradation of water quality	Changes in the orientations of the modes of institutional regulations (subsidies...)	
Environmental impacts	The evolution of the impacts of the degradation of the natural capital should remain constant in time. The functions that are internal to the natural capital system are not taken into account as such	There could be an improvement in the health of natural capital systems, both from the point of view of the environmental functions provided to human activities and for international environmental functions. This is linked to the fact that environmental pressure decreases with time	

6 Conclusions

Any dynamic measure of environmental performance must be set in the context of uncertainties about the impacts generated by human activities on the natural environment. In particular, the spatial and temporal variability of the emissions themselves makes it difficult to estimate impacts related to the use of fertilisers. Similarly, the notion of environmental quality must be approached at different scales in complementary ways. Measures that can be obtained by using a regional statistical database, give useful orders of magnitude but cannot tell a complete story because water and soil quality has significance essentially of a *local* nature.

The analysis presented in this chapter has sought to develop an evaluation framework that can partly act as a bridge between the ‘local’ scales of agricultural practice and the more aggregate scales of national and European environmental performance objectives. In this search for a multi-scale framework, we have adopted the following distinctive analytical components:

- the notion of environmental functions is employed to highlight the multiple roles of water in the Brittany economy and society
- the notion of critical natural capital (CNC) is developed and applied in order to highlight the sense in which the situation of degradation of water quality due to the agriculture in Brittany constitutes a crisis in which major action is urgently required

- an appraisal has been made of relevant and practical indicators of environmental pressures and economic output that can be used to characterise – in an illustrative way – the economic costs and environmental performance changes associated with different adjustment scenarios
- a structural modelling approach has been developed which permits, in a comparative scenario framework, the evaluation of economic costs that may be associated with shifts towards agricultural practices that are less environmentally harmful.

In the context of this research, the model acts both as a *'receiver'* of information about the 'stakes' of implementing water quality control policies, and as an *exploratory tool* to investigate the possibilities related to the adaptation measures envisaged for the agricultural sector. This is why the variability of ecological norms encourages the use of a scenario-based approach. We relate a specific form of agriculture, i.e. an adequate scenario, to each particular specification of the required norms.

From this, we can conclude that taking into account the variability corresponds to measuring the gap between the various simulated tendencies. This gap then constitutes an estimated value of the adaptation cost of the regional agricultural sector and of the achieved environmental performance that results from the transitional shift between the tendency and the dynamic schemes that have been suggested.

The formulation of scenarios exploring the possible evolution of agricultural activities in the Brittany area is, obviously, very provisional. The simulation results should therefore be interpreted as giving orders of magnitude useful for policy discussion purposes. More refined comparative studies could be developed on the basis of parameterisations that take account of a greater range of social, geographical, international trade and other dimensions. The present analysis nonetheless emphasises the relevance of using structural modelling when measuring ecological performance and economic costs and when the nature of the 'costs and benefits' problem being looked at is fundamentally dynamic and extends into the long term.

References

Agreste (1991) *Tableau de l'Agriculture Bretonne*, Direction Régionale de l'Agriculture et de la Forêt.

Agreste (1997) *Tableau de l'Agriculture Bretonne*, Direction Régionale de l'Agriculture et de la Forêt.

Besnault, C. (1998) 'L'agriculture raisonnée, une initiative interprofessionnelle', *C.R. Académie Agricole Française*, Vol. 84, No. 2, pp.87–90.

Bonny, S. and Carles, R. (1993) 'Perspectives d'Evolution de l'emploi des engrais et des phytosanitaires dans l'agriculture française', *Cahiers d'économie et Sociologie Rurales*, p.26.

Canevet, C. (1992) *Le Modèle Agricole Breton*, Rennes: Presses Universitaires de Rennes, p.400.

De Groot, R.S. (1992) *Functions of Nature: Evaluation of Nature in Environment Planning Management and Decision-Making,* Groningen: Wolters Noordhoff, p.345.

DIREN and Région Bretagne (1998) *La Bretagne, des Hommes, un Territoire. Atlas de l'Environnement en Bretagne*, Rennes.

Douguet, J.M. (2000) 'Systèmes agraires et soutenabilité: un enjeu pour une eau de qualité en Bretagne, un problème d'évaluation', *Thèse de Doctorat ès Sciences Economiques*, Guyancourt, France: Université de Versailles Saint-Quentin-en-Yvelines.

Douguet, J.M. and Schembri, P. (2000) 'CNC: quantification et modélisation du capital naturel critique pour la mise en œuvre d'une politique du développement durable en France', *C3ED Rapport de Recherche*, February, Final Report for Research Contract No. 97085, funded by the French Ministry of Land Use Planning and Environment, 1997–1999.

Ekins, P. and Simon, S. (1999a) 'Making sustainability operational: critical natural capital and the implications of a strong sustainability criterion', *Summary Progress Report for the European Commission*, May, Contract No. ENV4-CT97-0561.

Ekins, P. and Simon, S. (1999b) 'The sustainability gap: a practical indicator of sustainability in the framework of the national accounts', *International Journal of Sustainable Development,* Vol. 2, No. 1, pp.32–59.

Faucheux, S. and O'Connor, M. (1999) 'Natural capital and the national product: a controversial terrain', *International Journal of Development Planning Literature*, Vol. 14, No. 2, pp.233–274.

Faucheux, S. and O'Connor, M. (2001) 'Natural capital, the greened national product and the monetization frontier', in E. van Eerland, J. van der Straaten and H. Vollebergh (Eds) *Economic Growth and Valuation of the Environment: A Debate*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, Chapter 10, pp.225–274.

Hueting, R. (1980) *New Scarcity and Economic Growth: More Welfare Through Less Production*, Amsterdam: Holland Publishing Company.

O'Connor, M. and Ryan, G. (1999) 'Macroeconomic cost-effectiveness and the use of multi-sectoral dynamic modelling as an environmental valuation tool', *International Journal of Sustainable Development*, Vol. 2, No. 1, pp.127–163.

O'Connor, M. and Steurer, A. (in press) 'The AICCAN, the geGDP, and the monetisation frontier: a typology of 'environmentally adjusted' national sustainability indicators', *International Journal of Sustainable Development*.

Pochon, A. (1991) *Du Champs à la Source, Retrouver l'Eau Pure*, CEDAPA.

Pochon, A. (1998) *Les Champs du Possible, Plaidoyer pour une Agriculture Durable*, Paris: Syros.

Région Bretagne (1999) 'Session spéciale sur les perspectives de l'agriculture en Bretagne', Rennes.

Schembri, P. (1999a) 'Adaptation costs for sustainable development and ecological transitions: a presentation of the structural model M3ED with reference to French energy–economy–carbon dioxide emissions prospects', *International Journal of Environment and Pollution*, Vol. 11, No. 4, pp.542–564.

Schembri, P. (1999b) 'Environmentally adjusted domestic product and emission control policies: a dynamic simulation modelling approach', *International Journal of Sustainable Development*, Vol. 2, No. 1, pp.164–184.

Notes

[1] This article is partly based on an analysis undertaken as part of the CRITINC project 'Making sustainability operational: critical natural capital and the implications of a strong sustainability criterion', Project number PL9702076, funded by the European Commission's Environment and Climate RTD Programme – Theme 4, 'Human Dimensions of Environmental Change', during 1998–2000. The Project Co-Ordinator was Paul Ekins at Keele University, School of Politics, International Relations and the Environment, UK. Thanks especially to Sandrine Simon (who worked on the CRITINC project at Keele) and to Martin O'Connor at the C3ED.

[2] For a more detailed characterisation of water's functions in Bretagne (Brittany), see Douguet (2000).

[3] This Directive has been transposed in the internal legal system by a series of decrees (3rd January 1989, hence 9 years after the European Directive) and of circulars (1st April 1990) which allowed nitrate (and other products) contents that exceed the maximum acceptable amounts.

[4] For instance the association 'Eaux et Rivières en Bretagne', previously called 'Association for the Protection of Salmon in Brittany', had been created to protect the stock of salmon, viewed as a real patrimony of the area. This association became a group for the protection of the environment and of the consumers in 1989.

[5] Recent reports and papers by members of the C3ED have presented examples of empirical work carried out in this norm-based cost-effectiveness perspective, using a dynamic multi-sector scenario simulation model for a national economy (see O'Connor and Ryan, 1999; Schembri, 1999a,b). The underlying methodology is discussed in Faucheux and O'Connor (2001); see also O'Connor and Steurer (in press).

[6] In order to formulate this scenario, we have been guided by the programme of action developed by the National Association FARRE. FARRE means Forum for '*raisonné*' Agriculture that respects the Environment. In this scenario, we have focused on the '*raisonné*' dimensions of agricultural practices. However, the figures that we reached do not seem to correspond with that provided by this association (FARRE, 1 rue Gambetta, 92100 Boulogne). This NGO considers that '*raisonné*' agriculture constitutes a return to traditional principles of agronomy and agricultural practices, but implemented with new rational management methods that have been introduced through 'systematic agriculture' (Besnault, 1998). A convention has codified the rights and obligations of the farmers, in the context of this network.

[7] The French term is '*agriculture économe*', which might be partially translated as 'frugal' agriculture.

[8] The data that we have used in this study have been provided by the Groupement des Agriculteurs Biologiques des Côtes d'Armor (Association of Biologic Farmers of Brittany) or have been collected in the documents related to the schedule of conditions of *organic* agriculture (Ministry of Agriculture), e.g. Decree of the 21/12/92 on the approval of the texts on organic modes of production in cattle farming as well as the law no.80–502 of the 4th of July 1980 on the orientation of agriculture as amended by the law no.1202 of the 30/12/88 (JO. 31/12/88).

[9] The importance of non point (diffuse) water pollution, created by phytosanitary products, has been progressively realised and highlighted. Very probably, it is the visibility of their impact that made nitrates the main focus of attention.

[10] All four '*départements*' of Brittany have been classified as 'vulnerable zones' by the Prefect of the area, who is also the Co-ordinator of the Loire-Brittany Basin, on the 14th of September 1994.

[11] Prefectorial decrees have regulated the use of atrazine and diuron for the four departments in Brittany since the 1st of September 1998.

[12] In this presentation we do not go into the technicalities of defining and measuring the 'technical' capital; we mention simply that the M3ED is a dynamic multi-sector model that accounts for the use and production of 'capital' in each sector, hence the allocation of 'saving' and 'consumption' (both intermediate and final) each period.

[13] The organic nitrate generated by cattle farming is measured from the number of animals that are present on the farm and from the norms defined by the CORPEN (Orientation Committee for the reduction of the Pollution of Water by Nitrates).

[14] In this first analysis, the same rate of exports has been applied to the whole set of scenarios. Developing finer scenario propositions would be hazardous. Even if the exportation rates are kept identical across all scenarios, it is plausible that the objective of exports associated with the *raisonné* type of agriculture is not the same as for the other agriculture transition regimes. One shifts notably from a type of agriculture whose rationale is based on mass production (the *laissez faire* and *raisonné* scenarios) to a production rationale based on the creation of value added (the *économe* and *organic* scenarios).