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Bioeconomic Models in Agriculture

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Abstract: *Biological process models designed to simulate agro-ecological processes can be quite sophisticated in their approach to modeling a particular sub-component of an ecosystem. They exist for agro forestry, crop production, grassland, soil nutrients, water dynamics and animal/livestock systems. This paper deals with bioeconomic models in agriculture. it outlines the implications of joint products in bio-economic models, types of bio-economic models, farm design model, model of integrated dryland agriculture, the dairy cow model, the multi-objective decision support for agri-ecosystem management model, dynamic-recursive-stochastic bioeconomic model, the integrated land use model, the Ginchi bio-economic model, national and regional models, the multilevel analysis tool for agricultural policy model, the cost benefit analysis for sustainability model and forest land oriented resource envisioning system model. This paper concludes with some interesting findings along with some policy implications.*

INTRODUCTION

In its broadest sense, the bio-economy addresses the production and use of biological resources for conversion into commercial products, ranging from food and feed to bio-based products and bio-energy. The bio-economy therefore encompasses agriculture, forestry, fisheries, food processing, and parts of the energy, chemicals and biotechnology sectors. As a system, the bio-economy has existed since humans first appropriated natural resources for their own gain, such as burning firewood or cultivating crops. In recent years there has been a renewed focus on utilising biological resources more efficiently, so as to reduce pressure on natural resources, as well as starting the transition away from finite fossil resources. There have also been technological advances that have allowed the use of biological resources in the making of plastics and other composite materials and chemicals. Collectively this new ambition has been termed the bio-economy.

The bio-economy warrant further explanation as they are used in a number of countries to make a distinction between different aspects that are the focus of different policies or sectors. Like the definitions of the bio-economy, the boundary between the bio-economy and the bio-based-economy differs between countries, but in general the distinction is made in relation to the production and use of biomass, often with the exclusion of food and feed production. The difference between bioeconomy and bio based economic is shown in fig. 1. Here the distinction is made between the bio-economy, which encompasses the production of biomass, either through primary production or through the collection of waste streams; and the use of biomass for food energy and material uses. The bio-based economy is a subset of the overall bio-economy and addresses only the use of biomass for materials, energy, chemicals and other bio-based processes, with the explicit exclusion of food.

Other conceptual definitions that differentiate between the bioeconomy and bio based economic are used without any consensus yet having emerged. The European Union identifies the bio-based economy as one that '…integrates the full range of natural and renewable biological resources, land and sea resources, biodiversity and biological

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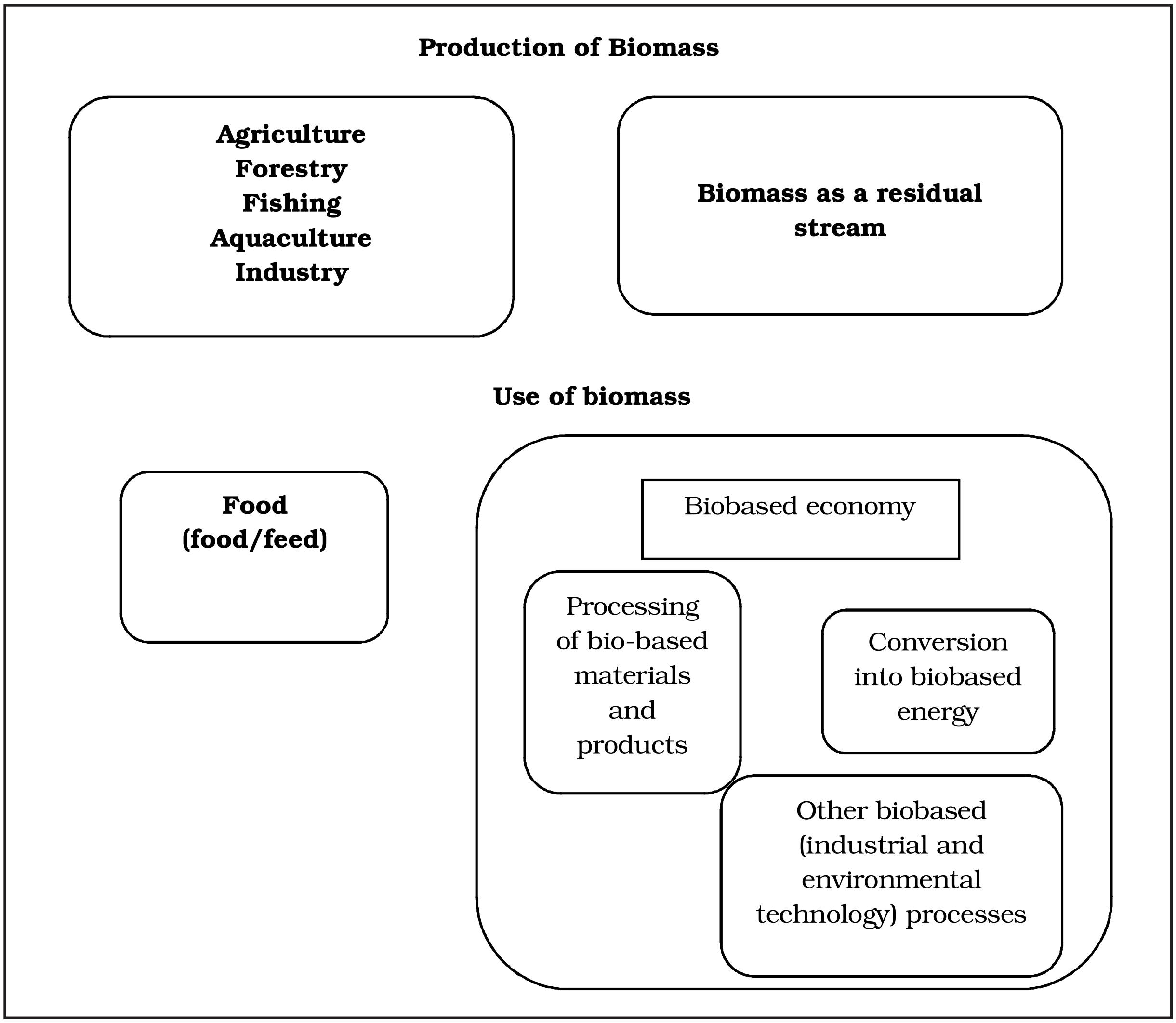

Figure 1: Distinction between the bio-economy and the bio-based economy

materials plant, animal and microbial, through to the processing and the consumption of these bio-resources'

Most bio-economy strategies make reference to the use of technology as a fundamental component of the transition towards a more bio-based economy. It could be observed that the Netherlands places the emphasis on biomass production, innovation, sustainability and coherent policy, while Sweden is focusing on innovation, market introduction, support for small and medium-sized enterprises and general supporting policy. Germany has established a national Bio-economy Council with the focus on the economy, innovation, education and policy.

Whether or not the definition of the bio-economy makes reference to technology, it is clear that technological advances will play a role in helping to unlock certain value chains from a range of existing and future potential resource streams. Advances in technology are being looked at to help improve existing material pathways such as food production or timber harvesting, making them more efficient or effective, as well as opening up new pathways involving wastes, residues and other materials that have proved more difficult to harness to date. The bio-economy will therefore need to integrate both technological enhancement in existing sectors, and simultaneously developing new ones.

JOINT PRODUCTS IN BIO-ECONOMIC MODELS

Each production activity has several outputs. In simple model wheat production, products are grain, pollution and straw. Adopting this vision, one should not approach the external effect cost or benefit for other economic agent as a direct consequence of wheat production; there is a need to identify what production activity generates this cost to other agents nitrate pollution in physical quantities. Based on this model one can consider pollution, as an output of the activity that produces both wheat and pollution as outputs. This means that for calculating the externality as a cost, first there is a need to have some knowledge about it as a physical product, and we need to measure it in physical terms tons of soil erosion, kg of NO3 pollution, etc.

One can provide a mechanistic, cause-effect explanation of what is behind the external costs or benefits. Very frequently one can find empirical approaches, trying to find statistical relations between some crop production and some externality, like soil erosion. They are purely empirical: there is a complete lack of analysis of the processes that connect, for example, grain production with soil erosion. What produces erosion is not the wheat production itself, but the way it is produced, what type of tillage is used, in what period, in connection with the weather, with the type of soil, the previous crop and many other technical issues.

In other words, it is the process of production, represented by a specific activity. A certain amount of nitrate leaching is not provoked by maize production, but by a certain production activity of which maize grain is one of the outputs i.e. a wheat-maize rotation with a specific input combination. The relation between a maize non-linear production function and the level of nitrate pollution can be extremely complicated to define and, if defined, it will not be in a chain of cause-effect relationships because there is not a direct relation between these two variables, the empirically obtained function will be applicable only to the specific situation where it was estimated. Each agricultural technique represented by each production activity is related, in a defined environment soil-weather with one value of pollution or erosion, and there is no functional form that can be a priori applied to represent the relationships between two of the joint products, as they are an outcome of extremely complex processes. These can be better represented by fixed technical coefficients relating activities and products. Of course, it can be possible, out of a post-modeling exercise, to estimate non-linear relationships between different outputs of the model, using parametric procedures. But no functional form should be introduced a priori in the optimization model. The results of simulations done using a biophysical model can be synthesized in an appropriate way and introduced as linear technical coefficients in a mathematical programming model. And this procedure can be applied in a dynamic model as well as in a comparative-static one. The quality of soil, in terms of its production capacities, changes with the way it is used over time. This implies that, by essence, this issue should be analyzed using a dynamic approach. That is why the biophysical models are perfectly appropriate for doing this. In brief, modeling the relations between agriculture, natural resources and environment needs to mobilize different types of models and knowledge.

TYPES OF BIO-ECONOMIC MODELS

For this purpose, a classification is carried out taking into account consideration of spatial and time scales. Fishery and forestry models are a special case in the bio-economic literature. Some can simulate fish population dynamics or timber growth at a very detailed level. The objective is usually to determine what fishing effort or timber extraction maximizes profits – or any other welfare function – while considering renewable capacities. Most models are concerned with identifying maximum yields – referred to as sustainable yields – at which levels of stocks and profits can be maintained. Environmental sustainability usually enters these models through the impacts on the stock carrying capacity or intrinsic growth rates.

FARM MODELS

At the farm scale, the farm system is considered as a decision unit of agricultural system. This method allows understanding the functioning of the production unit and the interactions between production activities. The variety of bio-economic models used to assess environmental issues at the farm level, illustrates the need for diagnosis at this scale. The farm level approach is mainly used to address i) environmental policy questions; i.e. to support policy design and decision making, ii) to assess the sustainability of farm and iii) to help farm producers understand and manage their production systems. Farm models could be static or dynamic.

STATIC MODELS

Bouman *et al.*, (2000) assessed the trade-offs between farm income and the reduction of erosion and nitrate pollution. The approach used by him combines a biophysical model and a mathematical programming model. The mathematical programming tool developed in their study is a statistic multi-objective programming model. The key idea is to maximize farmers' returns and minimize both soil erosion and nitrate leaching, so as to preserve the quality of soil and water resources. The biophysical model Erosion-Productivity Impact Calculator is used to simulate the interactions among weather, hydrology, erosion, nitrate pollution, pesticide pollution, plant growth, soil tillage and management, and plant environmental control sub-models. These data are introduced in the economic model as discrete variables through an engineering production function. The main activities considered on the farm are dairy farming, sheep breeding, and cereals and sugar beet. The monthly feed requirement for the dairy and sheep production are linked to forage cropping.

The multi-objective programming models coupled with crop simulation models appears as a useful tool to address agricultural–environmental issues. This model allows analyzing the trade-offs between farm revenue, level of pollution in terms of nitrates percolation and soil erosion. The results show that, in the described conditions, it is difficult to find solutions with high revenue and low nitrate pollution and erosion. The management that allows limiting erosion in most cases increases nitrate pollution, at least with the alternative activities that are considered in the exercise. The modeling framework presented in this study considers inputs and outputs prices as exogenous. Livestock dynamics are not taken into account.

Bullock, D. *et al.*, (2009) developed the farm system simulator model in response to the need for research on public policy impacts in the EU. It aims to provide policymakers with "an integrated tool for ex-ante impact assessment of agricultural, environmental and rural development on the sustainability of agriculture and sustainable development". Farm system simulator model is a static bio-economic model to assess at the farm level the impact of agricultural and environmental policies on farm performance and on sustainable development indicators. It consists of a data module for agricultural management and a mathematical programming model. Farm system simulator model for agricultural management aims to identify current and alternative activities and to quantify their input and output coefficients both yields and environmental effect using the biophysical field model Agricultural Production and Externalities Simulator and other data sources. Farm system simulator model seeks to describe farmer's behavior given a set of biophysical, socio-economic and policy constraints, and to predict farmer decision-making responses under new technologies, policy market and environmental changes. Farm system simulator model is applicable to crop-based and livestock-based farm types. The principal outputs generated from farm system simulator model for a specific policy are forecasts on land use, production, input use, farm income and environmental externalities in terms of nitrogen surplus, nitrate leaching, pesticide use, etc. Input data are fitted in the economic model as discrete variables by using engineering production function. The economic model is static, while it takes into account the dynamics of biophysical processes. The model can include farmers' risk aversion through the Risk module. For this purpose a global utility function, defined as gross margin minus risk, is maximized.

Three different livestock activities can be modeled in Farm system simulator model, namely dairy, beef, and small ruminants' sheep and goats. Feed requirements for each different animal types and decisions as to the length of the grazing period are also taken into account for dairy activities. The feed requirements of the herd in terms of fiber, energy and protein are covered by roughage produced on farm fresh, hay or silage, purchased roughage (hay or silage), concentrates produced on-farm or purchased concentrates. The quantities of on-farm produced and purchased feed depend mainly on prices of crop products including feed and inputs.

Thanks to its modular structure, the Farm system simulator model can be used as a tool for facilitating future policy analysis and for understanding future farming systems. Also, farm system simulator model has been set-up such that it can readily simulate farm types in very different contexts relating to climate, soils and socio-economic conditions and for different purposes.

FARM DESIGN MODEL

Groot *et al.*, (2012) and Domen and Habets (1998) developed the farm design model. It aims at exploring the synergies and trade-offs between socio-economic and environmental objectives, such as economic performances and organic matter balance. Desquilbet, M., and Lemarié, S., (1997) introduced a multi-objective optimization to address the multi-functionality of agriculture; employing Pareto based Differential Evolution. More specifically, Farm design couples a bioeconomic farm balance model to a multi-objective optimization algorithm that generates a set of alternative farm configurations that performed better than the original configuration. These alternative management options are then evaluated in terms of Pareto optimality in a normative approach.

The farm is the central management unit, consisting of interrelated components. Each component represents production activities defined by inputs and outputs. Groot et al., (2012) note that the farm balance model is a static model that calculates the "flows of organic matter, carbon, nitrogen, phosphorus and potassium from a farm and the resulting material balances, the feed balance, the amount and composition of manure, labor balance and economic results on an annual basis". A steady state situation on the farm is assumed. Crop yields do not respond dynamically to fertilizer levels or other management operations. Required nutrients are calculated from the target crop yields and nutrient concentrations in products. Similarly, animal yields do not respond dynamically to management. Animal production is specified in terms of products such as milk, meat, wool, eggs which result in a set of energy and protein requirements ultimately compared with the feed balance. Various types of animals, dependent on the livestock present on the farm and the structure of the herd, can be considered provided that their requirements are expressed in the selected units for energy, protein, structure and saturation. The multi-objective optimization program then maximizes four objectives, namely the operating profit and organic matter balance, and minimizes the labor requirement and soil nitrogen losses. The model was implemented for a 96 ha mixed organic farm in the Netherlands.

This modeling study demonstrated the usefulness of multi-objective optimization in the design of sustainable farming systems by means exploratory studies. It can serve as an exploratory tool to generate alternative management options that perform better with respect to a selected set of outcomes. It highlights how balancing crop-livestock interactions can help improve resource use efficiencies at farm scale. Including a water balance and incorporating erosion explicitly in the model would be valuable additions. Accounting for the added value generated by processing of crop and animal products and including resources transfer at regional level in terms of labor and land would also provide interesting complementary insights. Also, uncertainty on prices and policies is not addressed in this study. According to Flores-Sanchez *et al.*, (2011) the model is generic enough to accommodate farming systems in environments that are contrasting in bio-physical conditions, farming systems configurations and data availability, since it has been used in arid regions in Mexico and in student projects in Uruguay, Nepal and India.

MODEL OF INTEGRATED DRYLAND AGRICULTURE

Kingwell and Pannell (1987) proposed the model of an integrated dryland agricultural system. It is a mathematical programming model of a representative farm of the agricultural system of the eastern wheat belt of Western Australia. It is the outcome of many years of interdisciplinary work with the participation of economists, natural scientists of different disciplines, as well as farmers and computer engineers. Model of an integrated dryland agricultural system is one of the first models integrating biophysical and economic components. The use of this model is essentially normative, in the sense that it explores the possibilities of integrating technological changes with respect to different time of rotations, introduction of new varieties, changes in the tillage systems and their effects as well on economic as on environmental variables. Kingwell (2003) reported that this model has been used in Western Australia for a very long period. In the last years, the relatively rough biophysical components have been substituted using outputs of more advanced biophysical models.

Model of an integrated dryland agricultural system is representative of an adequate for the specific agricultural systems of Western Australia, whose farming system is very homogeneous. However, it can only be questionably applied to other contexts.

THE DAIRY COW MODEL

M. S. U. Khan (2007) proposed a linear programming model for dairy farm. It has been designed to examine the economic and environmental effects of improved productivity of Dutch dairy farming. The objective function of the model maximizes labor income. The central element in the model is a dairy cow with a fixed milk production. A fixed ratio is considered between the number of young stock and the number of dairy cows to guarantee replacement of dairy cows. Surplus calves are sold. The area of grassland and division between grazing and mowing is dependent on the interactions among animal requirements, season of the year, price of concentrates and price and availability of other forages. These interactions are all considered in the optimization process. This model has a strictly normative approach. This means that it does not try to reproduce a given situation and to simulate impact of policy changes, as most of the other models do, but to provide guidelines to farmers in order to ameliorate their practices.

The macro dairy farm model is developed at farm level and based on a static approach. It does not consider the interaction between farm and the system environment nor the possibility of resource transfer between farmers. The farmer is assumed risk neutral. This modeling framework was built to serve the purposes of a wider project. The main objective of this project concerns an analysis of possible effects of changing circumstances on Dutch dairy farms. The model developed can be used to examine different questions in the field of institutional and technical change on dairy farms. Moreover, it offers the possibility to examine questions for dairy farms that differ in intensity and in size. The Dairy farm model was used by van Calker *et al.* (2004) to determine how farm management adjustments and environmental policy affect different sustainability attributes. Compared to the previous version of the model, it includes economic and ecological indicators. The net farm income is included for measuring economic sustainability, while eutrophication potential, nitrate concentration in groundwater, water use, acidification potential, global warming potential and ecotoxicity are included as ecological indicators. The ecological indicators are determined from the Life Cycle Assessment method.

THE MULTI-OBJECTIVE DECISION SUPPORT FOR AGRI-ECOSYSTEM MANAGEMENT MODEL

May, L. R., Rodemeyer, M. and Le Buanec, (2001) developed the Multi-Objective Decision support tool for Agri-ecosystem Management model. It is a multi-objective linear programming model used to address economic and environmental analysis of sustainable farming practices. It consists of a set of relational databases and analytical functions which allows computing the economic and environmental impacts of farming decisions related to land use alternatives with respect to nitrogen balance, energy input, soil erosion and global warming potential of the production process. This framework is composed of six hierarchically linked modules: i) a plant production module which stores the sequential plant production activities; ii) a farm module which integrates the farm capacities and animal production system; iii) an economic module which allows the calculation of gross margin; iv) a Linear Programming module which optimizes land use in terms of economic returns and soil erosion targets; v) an ecological module which allows the ecological evaluation of cropping practices; vi) and a last module which considers the site specific soil and calculate erosion for each plant production activity. These modules describe production activities in a way that allows an economic and ecological analysis of the production process. As such, the model can be considered as complying with a positive approach; however, as the level of tolerated soil loss has to be predefined in the optimization, it could also be interpreted as a goal-orientated normative model.

Multi-Objective Decision support tool for Agri-ecosystem Management Model is a farm simulation tool that enables the modeling of farm decisions, and their economic and environmental effects. It allows simulating scenarios for different land use options and goal attainment levels, as well as policy scenarios, such as the influence of prices and policy regulations on farmers' decisions and the effect of the resulting agricultural practices on the indicators of sustainability. Prices and policy regulations are the driving forces of the model. The model is static and refers to a partial equilibrium situation, ie it takes into account neither the variability of climatic conditions nor the influence of market on farmers' behavior and the interaction between farmers. This model presents other limitations since livestock is fixed and the interactions between animal and crop practices are not explicitly described.

Multi-criteria optimization tools can help to illustrate the interdependencies in agroecosystems and estimate trade-offs. Fox, K.J., Hill, R.J. and Diewert W.E. (2004) have applied the Multi-Objective Decision support tool for Agri-ecosystem Management model in various studies in north-east Germany. Because of its modular and hierarchical structure, Multi-Objective Decision support tool for Agri-ecosystem Management model can be applied to various agro-ecological problems. However, for specific applications, adjustments have to be made. According to Zander and Kächele (1999), this modeling framework is well suited for single farm analysis as well as for regional models, for static as well as dynamic approaches. However, until now it has only been applied in a static way at farm level.

Multi-Objective Decision support tool for Agri-ecosystem Management model is hosted by the Institute of Socio-Economics at the Leibniz Centre for Agricultural Landscape Research. As per the report by Tanure (2013), the Bio-economic Macro model announces "a novel conceptual macro-model with a system approach of the agricultural and livestock production environment". This static modeling approach adapted several sub-models of pre-existing studies: (i) meteorological; (ii) pasture; (iii) animal; (iv) crop–livestock integration; (v) crop; (vi) soil; (vii) pasture-animal; (viii) and pasture-soil to produce necessary biophysical inputs data for the economic model.

DYNAMIC-RECURSIVE-STOCHASTIC BIOECONOMIC MODEL

Belhouchette *et al.*, (2012) developed a dynamic-recursive-stochastic bioeconomic model to evaluate the sustainability of farm irrigation systems in the Cebalat district in northern Tunisia. This modeling approach addressed the challenging topic of sustainable agriculture through a model linking a biophysical model to a bio-economic model. The difference in terms of methodology, compared with the previous models is the stochastic dimension of this model. Concretely, the bio-economic farm model has a moving time horizon of 10 years, assuming that longterm decisions are taken according to rainfall probability.

A crop growth simulation model was used to build a database to determine the relationships between agricultural practices, crop yields and environmental effects with respect to salt accumulation in soil and leaching of nitrates in a context of high climatic variability. A reduced "meta model" was estimated based on the results of CropSyst simulations, to calculate the yield reduction for the given period of simulation according the crop pattern chosen by the model in the previous period.

According to Janssen and Van Ittersum (2007) while simulating animal production the number of animal units has been kept fixed for the whole simulation timeframe. When dealing with environmental problems in agriculture, time scale is very important because environmental issues are often characterized by long-term processes but using recursive models involves the construction of large matrices that makes the result assessment difficult. This model does not consider the dynamics of the herd stock animal since it is a considered as fixed unit. Prices of products and inputs are considered exogenous.

This approach proved that it is possible to represent the evolution of farm decisions within a given year and over a period of years by taking into account a wide range of biophysical conditions in terms of soil and rainfall, crop practices, land use or agro-management systems and types of production fodder and grain. This methodology could also be re-used to simulate different scenarios combining biophysical, crop diversity and socio-economic conditions with respect to price liberalization and water quotas, etc. as well as new techniques that may be released by industry and extension services relating to new varieties resistant to major diseases and soil salt accumulation, new cropping techniques such as conservation agriculture or organic farming promoted in a region etc.

THE INTEGRATED LAND USE MODEL

The Integrated Land use Model was developed by Schönhart *et al.,* (2011) to addresses the biodiversity effects, at farm and landscape levels, of land use intensity and landscape development. Integrated Land use Model is a static mixed integer linear programming farm model with spatial field contexts. It combines the crop rotation model.

The model covers all relevant crop and livestock production activities, management variants, and policy options as well as field attributes of the region. The livestock production component includes the type and amount of animals raised and the farming system in terms of organic versus conventional production taking into account coupled livestock subsidies for suckler cows, bulls, and calves. Farm optimization model includes interaction between livestock and crop production components through the Feed balances which guarantee animal specific nutrient demands that are supplied from internally produced or purchased forage and concentrates.

Land use intensity is considered by crop rotation choices, nutrient application rates with respect to nitrogen, phosphate and potassium as well as mowing frequencies. Four intensity levels can be tested in the model: high intensity, medium intensity, low intensity, and organic farming. The cost-effectiveness of different agri-environmental measure to achieve biodiversity targets is assessed by scenario analysis. Fields are the spatial decision units in farm optimization model. This structure allows introducing landscape metrics to quantify the spatial biodiversity impacts of landscape development scenarios. The Shannon's diversity index proposed by Weaver and Shannon, (1949) is used as indicator of landscape biodiversity.

As per the report by Schönhart et al., (2011), this modeling approach addresses several methodological challenges related to integrated land use optimization models at landscape levels such as "model evaluation, data availability, the trade-offs between model complexity, size and dynamics, and the linkages to disciplinary knowledge". This approach contributes to closing a methodological gap in the scientific literature by allowing for spatial modeling of landscape elements. However, it requires high resolution landscape data, which could be restrictive in some contexts.

This framework couples integrated and static approaches as the modules are structured in a sequential order, where the former two provide input data to the latter without feedbacks. Decisions in farm optimization model reflect actual producers' choices assuming efficient farm resource utilization. As such, it would be classified as a positive approach model. According to Zander and Kächele (1999) van Ittersum *et al.* (2008) and Wei *et al.* (2009), this typical procedure for integrated land use models reduces model complexity and solving time, as well as data demand on exogenous market conditions. As per the report by Weersink *et al.,* (2002) and Janssen and van Ittersum (2007), this model neglects issues such as land use transition processes or strategic decision making for investments. Furthermore, although operating at a larger scale than the farm level, interactions among farms are not considered. Interactions are determined only by exogenously given prices for inputs and outputs. Finally, the modeling approach didn't take into account the long-term structural developments of farms via land markets.

THE GINCHI BIO-ECONOMIC MODEL

Okumu *et al.,* (2000) developed the Ginchi Bio-Economic Model. It uses a watershed-level dynamic non-linear mathematical programming model to optimize a weighted utility function wherein three goals are incorporated in terms of cash income, leisure and basic food production. It is used to identify the economic environmental trade-offs among various possible technologies and policies. The model takes into account crop and livestock constraints, rising household food requirements, and forestry activities, as well as the biophysical aspects of soil erosion and soil nutrient balances arising from these activities. Data for input and output coefficients to be collected by structured questionnaire. The dynamic model addresses the issue of the long-term effects (12-year time horizon) of soil erosion on income and food self-sufficiency. It incorporates a dynamic relationship among soil loss, productivity and community welfare. It also considers soil nutrient balances for N, P and K. Cumulative soil losses are computed for each year and these determine crop yields in the following year after accounting for the effects of chemical fertilizer and dung manure applications.

This approach considers a single decision-maker and thus doesn't consider the heterogeneity of farmers' decision making. Furthermore, the model does not include a component for risk analysis. However, it does endogenize the effects of land degradation. Assessment of environmental concerns at a watershed level better addresses the natural delineation of the landscape, and hence the biophysical scale of environmental issues. The model considers resource multi-functionality and the multidimensional trade-offs that emerge from this. It also integrates the feedback to productivity through use of modified Universal Soil Loss Equation to change yield potential and takes into account the seasonality of land and labor use as well as labor type.

NATIONAL AND REGIONAL MODELS

It is evident from the works of Stoorvogel (1995) and Knowler, D *et al.,* (2002) that bio-economic models aim to optimize the total production of a specified region in relation to its technical options and economic and social aspirations. Regional scale analysis provides the possibility of integrating the interactions and competitions between farms in the region when considering the possibilities of resources transfer between farms with respect to labor and land. This type of model is generally complex because it takes into account the diversity of production systems in the region. At the regional scale, the application of bioeconomic approaches usually involves a classification of farms in order to define a typology able to represent the diversity of farming systems and extrapolate the results of a sub-set of farms to the whole region studied. The use of representative farms is still an approximation of reality and depends on the available data, which leads to an aggregation bias that must be minimized. But any modeling exercise implies some level of simplification of the real system, as in all cases, what is important is to choose this simplification according to the objectives of the study and to understand what kind of bias this simplification may produce.

THE SUSTAINABLE OPTIONS FOR LAND USE MODEL

Bouman *et al.,* (1998) and Bouman *et al.,* (1999) developed the Sustainable Options for Land Use model. It explores sustainable land use options at the regional level by quantifying trade-offs between socioeconomic and biophysical sustainability objectives.

At the heart of Sustainable Options for Land Use model is the agricultural sector model in terms of Regional Economic and Agricultural Land-use Model. This linear programming model identifies the optimal combination of production systems by maximizing the economic surplus at sector level. Coupled with technical coefficient generators for cropping and livestock activities, and integrated with geographic information system, Sustainable Options for Land Use model explores the long-term policy impacts on economic and environmental sustainability objectives. Sustainability is addressed in terms of economic surplus; labor employment; and in terms of environmental indicators N, P and K balance in terms of nitrogen, phosphate and potassium N losses through (de)nitrification, volatilisation and leaching, use of pesticide active ingredients; biocide index. The Sustainable Options for Land Use model model incorporates endogenous output prices and wages at the regional level. At the same time, it takes into account the heterogeneity in land use options and land unit characteristics at the local level; i.e. it incorporates heterogeneity of technologies, resource endowments and constraints in terms of land use options and land unit characteristics. This model allows also farmer decision making to import labor from outside the region. The link to external market supply and demand is made through elasticity of product and labor supply and demand.

This framework allows exploring, at the aggregate level of the region or sector, the possibilities and impact of policy measures, such as environmental taxes/subsidies, on economic surplus and environmental indicators. However, it does not account directly for the farm level where actual land use decisions are made. In a normative approach, the model optimizes societal economic welfare rather than models individual decisions based on their individual priorities and constraints. Also, biological processes are fixed for a particular period.

THE MALI BIO-ECONOMIC FARM HOUSEHOLD MODEL

Kuyvenhoven *et al.*, (1995), Kruseman and Bade (1998) and Ruben *et al.*, (2000) developed the Mali Bio-Economic Farm Household model to assess farmers' responses to agrarian policies, and their effectiveness to improve farm income and soil fertility. It consists of a linear farm household optimization model, integrating different resource endowments as well as bio-physical processes. The model is an extension of traditional farm household models developed by Barnum and Squire (1979) and Ferraris M and Paleari S (1986). It assumes non-separability between production and consumption decisions. In some countries, production and consumption decisions are more likely to be linked because the deciding entity is both a producer and a consumer. As long as markets are perfect for all goods, including labor, households are indifferent between consuming own-produced and market-purchased goods and allocate indifferently production between consumption and market sales.

In other words, consumption decisions do not affect production decisions and production is independent of household preferences and income. However, if there are market failures, nonseparability regarding production and consumption decisions has to be assumed and a household approach might be necessary depending on whether the good for which market fails is important in production.

Sadoulet and De Janvry (1995) provide a comprehensive review of household models. Formally, the production, consumption and labor decisions can be integrated into a single household problem, which maximizes a consumer utility function defined over a vector of commodities. While following this household approach, in practice, Kruseman and Bade (1998) consider multiple objectives to account for consumer preferences in terms of consumption utility and producer decisions. Farm household decisions on allocation of land, labor and capital resources for crop and production technique choice are simulated in a linear programming framework with consumption levels and farm income, adjusted for the monetized loss of soil fertility, as the objective variables optimized subject to budget and resource constraints and to a production function. Available resources, specific production activities for arable cropping, livestock and pasture management are taken into account. The production activity module describes the agro-ecological processes that determine production options for cropping, pasture, livestock and forestry activities. Different technical coefficients are defined for currently applied farming practices generally based on soil mining, as well as for alternative practices that guarantee more sustainable resource use in terms of non-negative nutrient and organic matter balances. The biophysical data are integrated as discrete variables in the economic model.

The farm households are then aggregated to the regional level to assess the supply response and the potential price effects as they interact with demand. This partial equilibrium analysis allows capturing the interactions between different types of households and between farm households and local markets. Regional aggregation allows prices to be determined endogenously on regional markets. The relations with the non-agricultural sector and with other regions are considered through the opportunity costs of labor (migration).

These procedures are applied to evaluate the impact at farm household and regional level of technology improvement and a variety of policy instruments: improvement of infrastructure, price support, land, policy and credit schemes. The major advantage of the modeling approach lies in the simultaneous estimation of welfare and sustainability effects of crop and technology choice at farm household and regional level. As such, the modeling approach lies somewhere between a positive describing approach and a normative prescribing approach. According to Brown (2000) the model offers important information about the required incentives to bridge the gap between actual practices and more sustainable land use.

THE DAIRY FARMING MODEL

van de Ven (1996) Ten Berge *et al.,* (2000) van de Ven et van Keulen (2006) developed the dairy farming model. It explores dairy farming systems that meet the environmental policy objectives and analyses the perspectives for development. According to Hengsdijk and van Ittersum (2003) this model is a static approach where multiple goals linear programming is used as optimization technique. The model reconciles economic objectives maximizing income per ha with ecological objectives minimizing nutrient leakages and maximizing landscape values.

The model describes options of different intensities for producing feed in the field, for processing or buying feed and for converting feed into milk. The combinations of different intensities result in different types of income levels, different nutrient emissions into the ecosystem and different abilities to manage the landscape. Inputs and outputs of “all possible” combinations are quantified systematically by technical coefficient generators for grass, maize, fodder beet and milk, based on experiments, the literature and expert judgment. The interactions between forage i.e maize and fodder beet and animal activities are considered through a feed balance.

The dairy farming model can easily be used to explore the scope of new technologies or alternative policies within a normative perspective. However, this approach represents a regional model in which farmer’s behavior has not been taken into account. According to the authors, the model could be applied at farm scale if we assume the homogeneity of farm characteristics; which is unrealistic. Furthermore, there is no interaction between farmers and market. Farmers’ degree of risk aversion is also not addressed in this modeling exercise.

This model was initially developed by van de Ven (1996) in the context of his PhD thesis. Deybe and Flichman (1991) note that a regional agricultural model using a plant growth simulation program as activities generator is a static regional model, using linear programming. It represents the agricultural system of the northern part of Argentine Pampa region. This model is one of the first using information from a biophysical model in order to simulate the vectors of activities considering simultaneously yields, costs and erosion levels. A market for land, machinery and labor inside the region is taken into account, allowing exchanges of these production factors between the different farm types that are represented. Simulations are performed for analyzing the impacts of changes in prices on production levels, farmers’ income and erosion levels.

THE MULTILEVEL ANALYSIS TOOL FOR AGRICULTURAL POLICY MODEL

Deybe and Gerard (1994) Gerard *et al.,* (1994) and Deybe (1998) developed the Multilevel Analysis

Tool for Agricultural Policy model. It is a dynamic-recursive model using non-linear mathematical programming. It allows ex ante simulation of the impacts of agricultural policies - as well as external shocks - on economic welfare and agricultural sector performances at aggregate levels.

It consists of a set of modules, namely: (i) a macro-economic module, (ii) a production or farming system module, and (iii) a commodity chain module. The macroeconomic module describes the general context, both in macro-economic terms and institutionally. Multilevel Analysis Tool for Agricultural Policy model is essentially a sectorial model, macroeconomic variables enter the model as exogenous variables in terms of input prices, import prices, etc. and can also be set to allow simulation scenarios. The production module represents farming activities for several types of representative farms. Production opportunities and constraints faced by farmer are determined by agro-climatic and socio-economic conditions for each farm type. Regional agricultural production results from the aggregation of individual productions. The model assumes that farmer's decisions are taken on the basis of expectations of gross margins and potential. The commodity chain module represents processing industry and consumer behavior. It evaluates consumer welfare and nutrient intakes, indicates employment and level of activity in agro-processing industries, and calculates endogenous prices for the products.

The Multilevel Analysis Tool for Agricultural Policy model was originally developed by researchers at CIRAD (France). It is a flexible tool, combining a micro-macro modeling approach with a dynamic and recursive structure. Risk measures of agricultural activities are also taken into account.

THE TUNISIAN DYNAMIC REGIONAL MODEL

Louhichi *et al.,* (1999) Louhichi *et al.,* (2010) developed the Tunisian dynamic regional model. It analyses the impact of soil and water conservation policies in a Tunisian region. A multi-objective modeling approach is used. In addition to the maximization of revenue, objectives in terms of impact on the environment are added. The bio-economic model is a primal-based approach that combines the biophysical model to an economic mathematical programming model. The bio physical model aims to estimate discrete production and externality functions. The economic model seeks to assess the economic and ecological impacts of erosion control policies at farm and regional levels.

The bio-economic model consists on a non-linear multi-period recursive programming farm model. The multi-period dimension means that each year, the income of three years is optimized. On the basis of the initial situation, production plans for the coming years are determined, taking into account all available information about the future, namely the expectations on prices and yields. The recursive dimension enters the optimization program by considering explicitly dynamic interactions across periods. More specifically, results of period t affect the baseline in period t +1, i.e. for each period the starting values are the end values of the last period. The application of such models can take into account various types of "recursive equations", other than those used for the transfer from one horizon to another, namely the investment equation. Based on the results of the previous horizon, the model provides insight into investment decisions.

This modeling approach considers the interaction between crop practices and animal production activity. For livestock, two different animal activities for meat and milk production are modeled, namely bovine and ovine. The dynamic-recursive approach is also used for modeling herd demography. It reflects the demographic growth and the production process over time. Each animal category is analyzed separately but linked to other animal categories by explicit relations. Culling and fertility rates, which depend on farmers' strategies in terms of renewal and performance, are taken as exogenous parameters, whereas traded animals in terms of sold and purchased animals are determined endogenously. Animal feed requirements as well as quality characteristics of the available feed are quantified using the Tunisian feed evaluation and rationing system for protein and energy. The feed requirements of the herd in terms of fiber, energy and protein are covered by forage produced on farm (hay or silage), purchased forage or purchased concentrates.

The experience gained in this model allowed to demonstrate the importance of bio-economic approach to assess the effectiveness of specific policy measures designed for supporting the conservation of water and soil in a semi-arid region of Tunisia. The model was applied at a regional level in a semiarid region, based on the definition of a set of representative farm types. Prices were set exogenously.

THE LIMA BIO-ECONOMIC MICRO WATERSHED MODEL

Barbier and Bergeron (1999) developed the Lima bio-economic micro watershed model. It is a further development of the Burkina bio-economic village model developed by Barbier (1998). Using a primal-based approach, it assesses the impact of policy interventions on land management in Honduras. The objective function maximizes an aggregate community welfare function subject to constraints on level, quality and distribution of key production factors with respect to land area, soil fertility, labor and cash availability, as well as food consumption and market demand for foods. The method combines a recursive and dynamic linear programming model with a biophysical model of soil condition and plant growth that predicts yields and land degradation for different type of land, land use and cropping patterns. The model is both dynamic with a 5-year planning horizon and recursive over the 20-year period, 1975-1995. The first year results are used recursively as the initial resources of a new multi-period model for the following planning period and so on. The recursive nature of the model allows adjustments from year-to-year using real historical prices, which are introduced into the model between simulations. The resources carried over from year-to-year in the simulation are population, livestock, tree volume, soil depth, and soil conservation structures. The model was designed to account for the whole of the micro-watershed level but it allows the two social groups ranchers and small farmers to interact at the level of the local labor market. The integration of biophysical information in the economic model was done using input-output vectors obtained from the results of biophysical model. The natural resource management component of the model includes soil erosion equations, and interactions among livestock, crops and forest. This modeling approach allows for migration in and out, selection of crop, animal and perennial of pine groves and coffee production methods, allocation of output in terms of consumption, storage and sale.

This model is similar to the Burkina model developed by Barbier (1998) with the added advantage of overcoming the limitation it had of assuming all households were the same. In fact, this model allows for household heterogeneity within the watershed by specifying two different types of farmers. Moreover, compared to the previous version of the model, this model included an environmental component, which is erosion. However, it does not incorporate risk aversion into decision-making and links the years only through price changes. This model is used to address of medium and long-term viability of agrarian systems at the micro-watershed level as well as the differential impact on different social groups of farmers. This application illustrates the ability of such approach to compare the actual events with what might have occurred under different policy scenarios. Modeling at the village level is one way to deal with the fact that land degradation issues are only addressed to a limited extent by farm level or household level analysis especially when land is not privately held.

A DYNAMIC MODEL OF CALIFORNIA'S HARDWOOD RANGELANDS

Standiford and Howitt (1991) proposed a Dynamic Model of California's Hardwood Rangelands. The objective of this model is to assess the likely impacts of different biological and economic conditions on oak stands by developing a multiple resource management model for hardwood rangelands ». For achieving this purpose, engineering production functions are estimated representing the relationships between different activities and resources.

This approach assumes that ranchers decide the level of oak tree retention and stock of cattle on the basis of cattle and firewood markets, taking into account the links between oak tree cover and forage production, the rate of growth of these resources, and the potential for alternative economic enterprises such as commercial hunting. The methodology applied, based on optimal control theory, is based on dynamic mathematical programming, optimizing actual revenue for a defined time horizon. Decisions are done year by year, based both on biological and economic factors. Price uncertainty is represented using a chance constraint method.

An interesting difference of this model respect most bio-economic models dealing with forestry is the use of a mathematical programming model instead of a dynamic programming approach. Blanco et al., (2011) note that from a mathematical point of view, the problem is the same, but from a practical perspective, the chosen method allows to deal with more complex issues as it is the case for this model. This model uses a normative approach, in the sense that the purpose is to assess optimal oak tree canopy and livestock stocking under different biological and economic conditions », taking also into account the hunting activity.

THE COST BENEFIT ANALYSIS FOR SUSTAINABILITY MODEL

Ulrich *et al.*, (2002) developed the Cost Benefit Analysis for Sustainability model. It simulates the effects of different management options on the stocks, fishers and regional economy. It is dynamic bio-economic model of fisheries that also encompasses the regional economy to assess industry and community led stock recovery plans. Accounting for the interactions between fish stocks, the size and effort of the fishing fleet and regional output, different management decisions are evaluated in terms of costs and benefits analysis. The Cost Benefit Analysis for Sustainability model was developed as part of the Invest in Fish South West project, with a focus on the English Channel and Celtic Sea. Key components of the model include commercial fishing sector further sub-divided in two different biological and economic components, recreational sector and regional economy. Model's components are interlinked with each other; output of one component enters the other components as input. Each endogenous variable is updated year by year.

The biological component aims to estimate the stocks dynamic. The levels of catches produced by the commercial and recreational fisheries have a direct impact on the stock surviving the year. Management options are simulated directly in the economic component of the commercial sector via effort, estimated in terms of days at sea, fleet in terms of number of vessels and commercial catch. The outputs of the economic component are directed to the biological component, and vice versa. Impacts of the fishing activities on the environment are also estimated through the economic component, by an ad hoc Environmental Impact Index. Results produce management advice in terms of both economic and biological indicators. Given the revenue and employment generated by commercial and recreational fishing, model's output on total production and employment, deriving also from fish processing, wholesale, retail, boat repair, etc., can be simulated by a multiplier process.

The model is to be used to assess a range of management options, such as days at sea limits including tie-ups; decommissioning schemes; limits/bans of particular gear types; restrictions on engine power, boat size, etc; changes in total allowable catches; levies management cost recovery, industry funded buyback; price intervention. Policy options can also be modeled, such as Mesh size restrictions and other technical measures; seasonal and area closures; permanent area closures, and post-harvest options traceability, ecolabelling. As reported above, the model has been used to simulate technical measures. However, results highlighted that the limited information on the effects of this types of management options do not allow the model to produce realistic outcomes. The complex structure of the model is very data demanding.

THE CARCHI INTEGRATED SIMULATION MODEL

Crissman *et al.*, (1998) developed the Carchi Integrated Simulation Model. It is unique among the integrated bioeconomic models in that it uses an econometric optimisation model at the farm level rather than some variation of a more-common linear programming model. Farmers' decisions are modelled through a sequential dynamic decision model which incorporates endogenous timing of input use in response to randomly generated field and environmental characteristics. The model avoids some of the problems inherent in the "representative farm" approach by allowing for heterogeneity in production and environmental variables over the landscape by classifying it into 4 different zones in proportion to the land area of each group. The 4 groups or zones are modelled within the overall framework and in so doing the differential impact of policy changes can be considered across each of the 4 zones. Rather than define sustainability explicitly, it is used to identify the trade-offs among different economic and environmental variables over a range of parameter values for different policy and technology alternatives at the watershed level. The model, however, is limited in the number of crops analysed and does not consider livestock activities apart from the pasture component.

Crissman *et al.* (1998) also present a discussion of concepts related to model integration and the different levels thereof. Level I integration is defined as the independent simulation of economic and physical models and subsequent combination of the outputs to infer environmental impact. Their model exhibits Level I integration and they use this procedure to generate the joint distribution of output and environmental impact which is subsequently used to generate a trade-off frontier for policy analysis purposes. Level II integration occurs where the economic model is employed to simulate each policy or management scenario and the output is used as the input to the physical simulation model. There is, however, no feedback from the physical processes in one period to the economic decision-making component in subsequent periods. Level III integration occurs where an economic model is formally linked to a production model with the 2 being jointly simulated to allow for dynamic feedback from environmental conditions to production.

THE VIHIGA INTEGRATED FARM HOUSEHOLD MODEL

Shepherd and Soule, (1998) developed the Vihiga Integrated Farm Household Model. It is a dynamic simulation model that incorporates household needs, constraints and financial flows into the modelling framework. The model also considers households with different resource endowments and tracks their relative performance in different environmental contexts. Though it does not incorporate an economic optimisation component, it does succeed at integrating a dynamic economic simulation component alongside the biological simulation component at the household level. Within the household model there is also the possibility for off-farm employment. As a result, the model can assess both the economic and biological sustainability of households with different resource endowments under different environmental, technical and policy scenarios.

FOREST LAND ORIENTED RESOURCE ENVISIONING SYSTEM MODEL

Vanclay (2000) and Haggith (1999) developed the Forest Land Oriented Resource Envisioning System Model. It has the potential to perform an integrated simulation of biological processes at the landscape scale as a result of decisions at the household level. It incorporates some sort of prioritised household decision-making component – either a rule-based search routine or a form of economic optimisation model. It is unique in its extensive simulation of agroforestry at the village level while at the same time modelling households with various resource endowments, allowing interaction among the various households according to particular rules of conduct and including forest-related land use activities. It appears that it will model the livestock, plant, soil and nutrient cycling components, but no details were found in the available literature.

THE ZAMBIA HOUSEHOLD MODEL

Model Holden (1993) developed the Zambia Household Model. It simulates household decisions and impacts for households with various resource endowments in both "traditional" and "modernised" societies. While it is based on empirical data rather than a process model for the biological component and is not dynamic in nature in other words it is a static rather than a multi period model and does not have feedback between the economic and biological components, it is included under this category due to its potential as a decision making sub-model or component in a recursive simulation model. It successfully models what people actually do in various circumstances through a combination of lexicographic and weighted goal programming models.

CONCLUSION

It could be seen clearly from the above discussion that many bioeconomic models have been developed to explain the farming practices. This paper made a comprehensive discussion on joint products in bio-economic models, types of bio-economic models, farm design model, model of integrated dryland agriculture, the dairy cow model, the multi-objective decision support for agri-ecosystem management model, dynamic-recursive-stochastic bioeconomic model, the integrated land use model, the Ginchi bio-economic model, national and regional models, the multilevel analysis tool for agricultural policy model, the cost benefit analysis for sustainability model and forest land oriented resource envisioning system model. The farm households should make use of any one of the bioeconomic models to enhance their farm income and employment. In order to mitigate the impact of climate change on agriculture, the following policy measures can be considered towards developing climate resilient bioeconomic models.

1. The government should encourage the research on climate resilient bioeconomic models to improve the cropping system by the way of providing research grants.
2. Agriculture bioeconomic models to be developed to cope up with the changing climate scenario.
3. The government should promote integrated farming system by the way of providing subsidies and liberal agricultural credit.
4. Efforts should be made to encourage the researcher towards developing drought resistant cropping system in the context of drought and desertification
5. The government should give more research grants towards developing bioeconomic agriculture model to mitigate the impact of climate change on agriculture.

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