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New Approaches to Support Development of Sustainable Land Use Systems

H. van Keulen[1,2], M.K. van Ittersum[1], R.P. Roetter[3,4], N. de Ridder[1], C.T. Hoanh[4]

[1]Group Plant Production Systems, Wageningen University, P.O. Box 430,
6700 AK Wageningen, The Netherlands
[2]Plant Research International, Wageningen University and Research Centre,
Wageningen, The Netherlands
[3]Alterra, Wageningen University and Research Centre, P.O. Box 47,
6700 AA Wageningen, The Netherlands
[4]International Rice Research Institute (IRRI), DAPO Box 7777,
Metro Manila, Philippines

1 Introduction

More than ever before in human history, the way in which land is being used has become a source of widespread concern. In 1999 the population of the world surpassed 6 billion, hence demand for safe and accessible food is higher than ever, while the negative environmental impact of food production, especially in the developing world, is increasingly recognised. In the developed world, the 'new economic order' has become a focal point, predicting continued economic growth. That view may appear too optimistic in view of recent developments, but income of especially the urban population will continue to increase, leading to higher demands for alternative land uses, such as nature, recreation and employment. These developments lead to a call for a basic redirection in the concepts of land use, in which the concept of multi-functionality will play an ever-increasing role (OECD, 2001). In that situation, where many different (groups of) stakeholders have an active interest in the way the land is (being, or going to be) used, new methodologies for land use studies are required, as a basis for formulation of land use policies. In these methodologies, the aims and aspirations of the different stakeholders have to be taken into account, but they should be based on thorough knowledge of the agro-technical possibilities and socio-economic boundary conditions under which land use has to take place.

In land use studies, two main directions can be distinguished, i.e. explorative studies that aim at defining the envelope of development possibilities and have their main focus on 'what would be possible?' These studies emphasise the bio-physical possibilities, in the belief that, at least in the long run, most human-related factors and attitudes can be adapted (or can be forced in a desired direction), whereas the biophysical conditions can hardly be modified (van Ittersum et al., 1998). The second type may be characterised by the term predictive, and focuses on the questions ‘what can be changed?' and 'how can desired changes be realised?' These studies, therefore, emphasise current and foreseeable future situations in terms of the (socio-)economic environment and land use pattern, and consider these as the main constraints to modification (Kruseman & Bade, 1998). Explorative and predictive land use studies have distinct and different roles within the process of land use planning and policy formulation. Thus, each phase or step within a so-called land use planning cycle requires different types of information and thus distinct land use studies.

In this paper, the land use planning cycle is introduced and some recent efforts at developing appropriate methodologies for supporting some of its distinct phases are illustrated. The examples still largely bear an academic character, but since there is increasing demand by policy makers for integrated land use analysis studies, they may serve as building blocks for development of operational methodologies for land use policy formulation and analysis. Their potential impacts on planning procedures and achievement of land use objectives are high, particularly when they are further developed and operationalized in settings that allow participation and involvement of the various user groups (Hoefsloot & van den Berg, 1998).

2 Land Use Planning Cycle

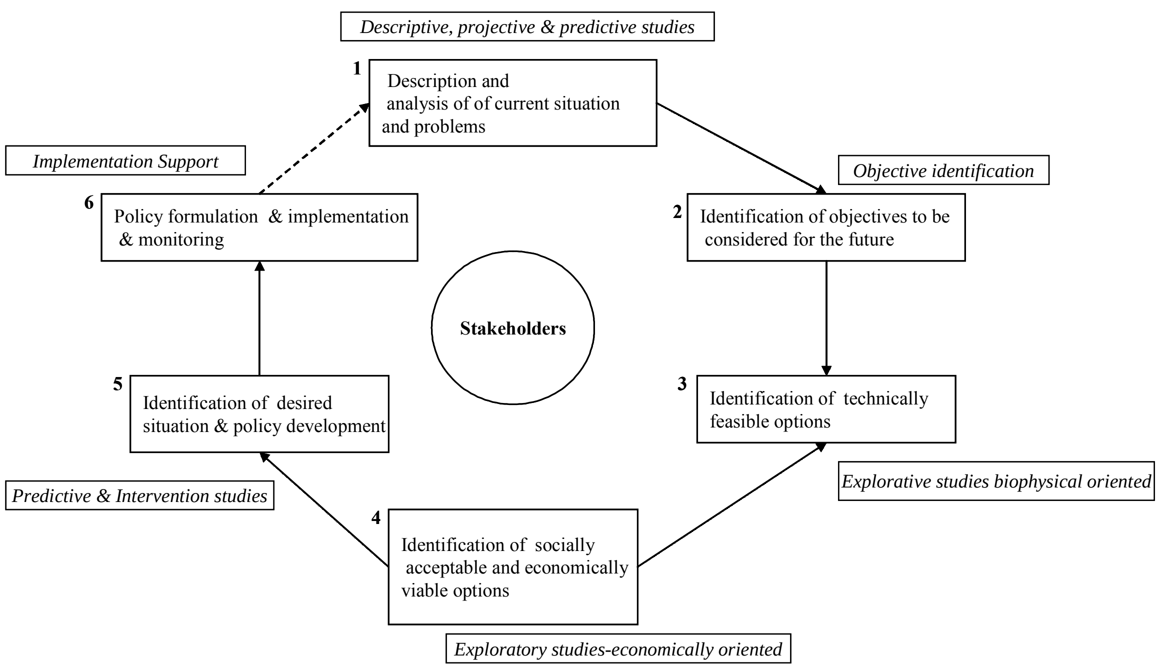
Development of sustainable land use systems and land use policy formulation can be considered as part of agricultural sector and/or regional planning, where the effects of economic policies on patterns of and changes in land use are studied (Thorbecke & Hall, 1982). In that approach, changes in land use are considered the result of the interaction between policy variables (like infrastructure, investments, prices, credit facilities) and exogenous parameters (resource endowments) that lead to realisation of a number of well-defined goals (welfare, equity) and possible (undesired) side effects (e.g. environmental pollution).

A land use planning procedure may be represented, highly schematised, as a land use planning cycle (Fig. 1), in which the stakeholders (should) occupy a central position, and constituting various distinct steps: (1) description and analysis of the current situation as a basis for problem analysis; (2) identification of objectives for future developments; (3) identification of technically feasible land use options; (4) identification of economically viable and socially acceptable options, within the set identified in (3); (5) discussion of the possible options with stakeholders, policy makers and disciplinary specialists, to identify the desired future situation, select the appropriate land use options and assess the policies necessary to initiate the required developments: 'how can the desired changes be realised?'; (6) policy formulation, implementation of sustainable land use systems, introduction of supportive programmes and monitoring of systems performance.

In theory, these steps should be executed iteratively, where at almost each step, the results can call for repetition of the preceding step(s), while in practice, the different steps are often implemented (at least partly) parallelly, or some are omitted completely. Consequently, many land use planning efforts have failed in promoting sustainable land use.

Over the last decade several quantitative or empirical land use analysis approaches have been developed in and with Wageningen. The various approaches support distinct phases of the land use planning cycle. In the remainder of this paper, examples are presented of those approaches, partly developed and/or (to be) applied in Southeast Asian projects, with emphasis on the complementarity of these approaches.

Figure 1 Land Planning Cycle



3 Approaches to Support the Various Phases of the Cycle

3.1 Model-Based Explorations

3.1.1 Methodology

This method plays its major role in steps 2 and 3 of the planning cycle, i.e. identification of objectives and targets for future developments and of agronomically-technically feasible options. It comprises a scientific-technical method to explore land use options using models and expert systems, following an exploratory methodology as described by e.g. Rabbinge et al. (1994) and van Ittersum et al. (1998). A typical example of its application was the eco-regional project Systems Research Network for Tropical Asia (SysNet), operating at sub-national scales in Southeast Asia (Roetter et al., 2000a;b). Land use options were analysed for four case study regions in India, Malaysia, Philippines and Vietnam, using the Land Use Planning and Analysis System (LUPAS). Such analyses serve the purpose of synthesising fragmented agricultural knowledge in support of development of land use policies. The SysNet project primarily focused on exploration of land use options, particularly addressing the phase of identifying policy objectives. When formulating objectives for future land use, there is currently always consensus on the aim of developing 'sustainable land use systems', but upon operationalisation, there will probably be as many perceptions of its meaning and implications as there are stakeholders. The explorative analysis methodology applied in SysNet provides an opportunity to explicitly express the consequences of such differences in perceptions, among others by the use of multi-objective linear programming. It yields a set of pictures of the envelope of land use possibilities at regional level, each associated with a specific development objective, identified in close interaction with stakeholders.

The main determinants of results of such model-based explorations are the availability and quality of the natural resources: soil, climate and water, the genetic properties of the crops and animals used in the agricultural production process, and the available technologies. The results provide a yardstick to judge current achievements and to indicate the scope for policy formulation and implementation (Rabbinge et al., 1994; Van Ittersum et al., 1998).

3.1.2 An Illustration: Land Use Analysis for Sustainable Food Security in Haryana, India

Regional stakeholders of Haryana State, India are interested in finding optimal agricultural land use options that can meet explicitly defined food production goals, as well as maximise employment and income from agriculture, while minimising pesticide residues, nutrient losses and groundwater withdrawal. A multiple goal linear programming (MGLP) model was developed to explore the possibilities for combining the various objectives (Aggarwal et al., 2001). Haryana is located in a semi-arid, sub-tropical environment between 27.4 and 30.6° N latitude and 74.3 and 77.4° E. longitude, occupies an area of 4, 421, 000 ha and has contributed strongly to the success of the Green Revolution in India. The agricultural area, of which 47% is sown more than once a year, comprises 81% of the total area. Rice and wheat, commonly grown in double cropping rotation, are the major food crops of the region, with a current total production of 10.5 Mt.

A typical example of the type of results generated with the MGLP model is illustrated in Table 1, where six goals have been considered, that in the so-called 'first round' of optimisations have been optimised successively, each without restriction on any of the other goals

Table 1 Goal attainment in the zero-round of optimizations for land use (land only resource constraint) in Haryana, India.

Goal optimized (Goal Value)	Food* Mt	Income* GRp1	Land used- %	Irrigation water-Gm3	Employment* Mlabor-days	Biocide index
Food	**39.1**	13.5	14.3	10.5	34.3	10.5
Income	109.9	**236.7**	74.6	58.5	88.4	52.7
Land used	100	100	**36.9**	100	100	100
Irrigation water	56.4	41.7	21.9	**9.9**	56.1	14.8
Employment	666	663	283	236	**752**	274
Biocide index	95	739	85	31	108	**24**

1109 Rupees; * goal maximized; - goal minimized (In each column the value of the goal optimized is given in bold. Each row illustrates the feasible range for each objective).

The set of results defines the feasible area, for each of the goals identifying the 'best' value attainable, as well as the 'worst' value that has to be accepted (Veeneklaas, 1990). The results illustrate the wide range in possible combinations of goal values: food production can reach a value of 39.1 Mt, or virtually four times the current value, however at the 'expense' of the use of almost six times the quantity of irrigation water. Realisation of that production level would require therefore, extensive irrigation water development. Similarly, a strong trade-off exists between food production and income, which is generated through production of cash crops at the expense of food crops.

3.2 Model-Based Predictive Studies

3.2.1 Methodology

Following identification of policy objectives, and technically feasible options, two important questions arise: what type of policies should be promoted to stimulate development of land use towards sustainable options, and which type of farming systems best meet sets of specific objectives (steps 4 and 5 of the planning cycle).

These questions can be addressed through application of predictive land use analysis tools, such as Farm Household Modelling (FHM), in which the current situation, in both agro-technical and (socio-)economic sense is taken into account as determinant for the scope for agricultural development, and the associated requirements for changes in land use. Application of linear programming in these tools allows inclusion of alternative agricultural technologies, explicitly defined in accurate quantitative terms. These can then be combined in a meaningful way with economic considerations to analyse the scope for agricultural development under the prevailing economic conditions, taking into account the aims and aspirations of the farm households. Taking these objectives into account implies that in these tools behavioural aspects have to be considered.

3.2.2 An Illustration: Impact of Policy Measures on Farm Household Performance

In a study on identification of the scope for sustainable agricultural development in Southern Mali, a region in the Soudan zone of West Africa (Sissoko, 1998), FHM was applied to analyse the effectiveness of various policy instruments (Table 2 Effects (%) of policy measures on farm household behaviour) in stimulating adoption of more sustainable land use systems. Two criteria were used, the effect on farm net revenue, and on the soil carbon balance as a proxy for sustainability. To take into account the variability in resource endowments among farm households in the region, three farm types were distinguished, A, well-endowed, B, moderately-endowed and C, poorly-endowed.

On the basis of the simulated effects of the various policy measures on farm net revenue and on the (ecological) sustainability indicator (carbon balance in the soil), the measures could be classified in four types (see Table 2):

- very effective measures: having a strong positive effect on both farm net revenue and on the level of sustainability (C-balance less negative or more positive). These measures include: increased cotton price (ii), reduced transaction costs (vi), reduced fertiliser price through subsidies (v), increased grain prices and reduced fertiliser price (x) and soil improvement policy (xi);
- effective measures: these have a moderately positive effect on farm net revenue and level of sustainability. They include: increased grain prices (i); improved credit availability (vii) and technology choice (xii);
- ambiguous measures: these have a moderately positive effect on farm net revenue, but a negative effect on level of sustainability. These include: increased prices of leguminous crops (iii) and increased prices of animal products (iv);
- ineffective measures: these have a negative effect on both farm net revenue and the level of sustainability; these include: head tax (viii) and land tax (ix). However, the indirect effects of these measures is positive, as they lead to a reduction in animal density and hence to reduced pressure on part of the natural resources, i.e. the agro-pastoral lands.

Table 2 Effects (%) of policy measures on farm household behaviour

		Very effective policy measures					Effective			Ambiguous		Ineffective	
Indicator	Household type	XI	II	VI	V	X	XII	I	VII	III	IV	VIII	IX
Net revenue	A	37	9	11	4	4	2	0	1	2	5	-1	-5
	B	49	13	14	5	7	7	1	1	2	3	-1	-3
	C	50	13	12	5	7	1	2	1	2	1	0	-3
Sustainability (C balance)	A	48	27	27	28	28	19	2	3	-16	0	-3	3
	B	34	13	11	11	12	59	6	9	-18	-1	0	-1
	C	34	29	14	27	26	33	2	3	-3	0	0	0

The results of the simulations with the FHM show that policy measures can strongly affect farm household behaviour, however, differentiated per farm household type (see

Table 3). For example, the maximum effect on net revenue is 37% for type A households (well-endowed) and 50% for type C households (less-endowed), while the maximum effect on sustainability (C balance) is 48 and 34% for the two types, respectively.

Table 3 Policy instruments to stimulate sustainable agricultural development

Type of policy measure	Change
Price policies	
I cereal prices	+ 10 %
II cotton price	+ 10 %
III legume prices	+ 10 %
IV meat/milk prices	+ 10 %
V fertilizer prices	- 10 %
Market development policy	
VI reduction in transaction costs	- 10 %
Credit policy	
VII increased credit availability	+ 10 %
Natural resource management policies	
VIII head tax	cattle (1000 FCFA/head)
IX land tax	small ruminants (250 FCFA/head)
	2500 FCFA/ha
General development policy	
X reduction in fertilizer price + increase in cereal price	- 10 % + 10 %
XI land improvement through strong fertiliser subsidies	- 70 %
XII technology policy	alternative intensive and semi-intensive technologies

Examination of technology choice (data not shown) shows, that despite the favourable conditions, created by the very effective and effective measures, farm households continue to select a combination of alternative, sustainable and current, non-sustainable production technologies, with a maximum adoption rate (expressed as percentage of the area under alternative technologies) of 40% by type A households. The rate of adoption of alternative production technologies is determined by their profitability, i.e. the ratio costs/benefits

3.3 On-Farm Prototyping

3.3.1 Methodology

Implementation of sustainable land use also requires on-farm development of sustainable farming systems (steps 5 and 6 in the planning cycle). Research and development may focus on important components of the farm system, e.g. integrated nutrient management or integrated pest management, but should also address whole-farm design. In the last decade, a promising empirically-based methodology for developing sustainable farming systems has been developed, i.e. prototyping (Vereijken, 1999; 1997), In close co-operation with commercial and/or experimental farms, farming systems are developed in an application-oriented fashion. Four phases can be distinguished: diagnosis, design, testing and improvement and dissemination (Vereijken, 1997; Rossing et al., 1997). In these successive steps, the shortcomings of current farming systems in a region are identified in view of established objectives, and a hierarchy of objectives for alternative farm systems is established. These objectives are transformed into a set of multi-objective indicators that can be quantified, and a set of multi-objective farming methods is established, such as multifunctional crop rotation, integrated nutrient management, or integrated crop protection. Subsequently, theoretical prototypes are designed by linking indicators to farming methods and adapting the methods until they are ready for testing. (Some of) the theoretical prototypes are implemented on pilot farms, to test and improve the prototype variants until the objectives have been achieved. Finally, the prototype variants are ready for dissemination within the region to other farms. Results of application of the method have been reported, by e.g. Vereijken (1997) and Van Keulen et al. (2000) and can be characterised as impressive.

3.3.2 An Illustration: Intensive Dairy Farming in the Netherlands

In the 1960s and 1970s, dairy farming systems in the Netherlands strongly specialised and intensified through increased inputs of chemical fertilisers and purchased concentrate feeds. This intensification has led to a serious imbalance between inputs of nutrients in atmospheric deposition and purchased fertilisers, concentrates and roughage and outputs in milk and meat, with the associated negative environmental impact. To assist in identifying options for agro-ecologically and economically sus-tainable land use in dairy farming systems, within the boundaries set by environmental conditions and government regulations, the prototyping methodology was applied to design, implement, test, adapt and further develop such a system. Objectives of the farming system in terms of environmental criteria have been identified, followed by establishment of input-output relations (technical coefficients) for the plant and animal components of the farm, applying existing, adapted and specially developed models. In this way, several farming systems have been designed that, in theory, meet the formulated objectives. From the theoretically acceptable set of systems, one of the technically and economically most attractive and, from a research point of view, most interesting was implemented at experimental farm 'De Marke' in the eastern, sandy part of the Netherlands in 1992. Monitoring of the performance of the system (see Table 4) shows that the realised average surpluses of N and P over the period 1994-97 (154 kg N and 3.1 kg P hã1) were significantly higher than expected (prognosis: 122 kg N and 0 kg P, respectively).

Table 4 N and P balances (kg ha^{-1}) of the average specialized dairy farm in the middle of the 1980s, prognoses at the start of 'De Marke' and values realized from 1994-1997.

Characteristic	'Average'		'De Marke'			
	1983/86		Prognoses		1994/97	
Input	N	P	N	P	N	P
Fertilizer	330	15.0	67	6.0	69	0.5
Feed	182	32.0	41	5.9	96	14.0
Deposition	49	1.0	49	0.9	49	0.9
N-fixation clover	0	0.0	30	0.0	12	0.0
Various	7	0.0	5	0.0	1	0.9
SUM	568	48.0	192	12.8	227	16.3
Output						
Milk	68	12.0	62	10.6	64	10.5
Meat	13	4.0	8	2.2	9	2.7
SUM	81	16.0	70	12.8	73	13.2
Input - Output*	487	32.0	122	0.0	154	3.1

* Accumulation in soil and losses to air and groundwater.

Source: van Keulen et al., 2000

The largest deviations originated in the component 'feed', most likely because the (animal) models applied to calculate the feed requirements were used outside the production range for which they had been calibrated/validated. On the basis of these results, the farming system has been adapted to more fully realise the (environmental) objectives (Aarts et al., 2001).

4 Discussion

Land use is changing rapidly in all parts of the world under the influence of autonomous developments, such as increasing population pressure, increasing welfare and the associated changes in the aims and aspirations of people, and technological developments. A strong tendency exists towards 'liberalisation', and to leave developments to market forces. However, policy makers should retain a responsibility for the use of scarce and vital resources such as land, water and air, that directly affect the well-being of the population (food, health), and guarantee the quality of these resources in the long-run. Hence, policy measures aiming at influencing the use of land with its unavoidable consequences for its own quality and that of water and air appear appropriate. The type of measures to be taken depend on the one hand on the objectives of the various stakeholders in the long-run, and on the other hand on the expected impact of policy measures on the behaviour of farm households, that ultimately take the decisions on the use of the land. Hence, tools are required in which these factors can be taken into account.

Such instruments are being developed, tested and improved in land use analysis and applied in the process of land use policy formulation. In the framework of land use policy formulation, various steps each with its appropriate instruments can be distinguished (see Figure 1 on page 3).

For explorative analysis, IMGLP-type models at the regional level provide a picture of the envelope of land use possibilities as determined by biophysical factors. The results sketch a picture that has been defined as Utopia, a situation so far removed from reality that any attempt to reach it would be futile (de Zeeuw & van der Meer, 1992). However, it has rightly been argued that these results provide a yardstick to measure current achievements and to indicate the scope for policy formulation and implementation (Rabbinge et al., 1994; Van Ittersum et al., 1998). These types of results, therefore can serve as a platform for negotiation among the various stakeholders.

Complementary to these studies are predictive land use analysis tools, such as farm household modelling, that take into account the current situation, in both the agro-technical and (socio-)economic sense. This type of analysis has a strongly predictive character, where the major aim is to test the effectiveness of possible policy measures in inducing farmers to change their choices with respect to land use in the desired (in first instance often identified by 'society' represented by policy makers) direction. It results in identification of the most appropriate policy instrument(s) for realisation of the identified objectives, taking into account the aims and aspirations of the farm households. The relevance of these results for actual policy formulation strongly hinges on the accuracy with which technological options can be quantified. Therefore, this analysis also stimulates interactions between policy analysis and agricultural research and development. On the basis of explicitly defined 'proven' (on the shelf) technological options, considered ‘improved’ by agricultural scientists, the procedure can be used to explore the possibilities to induce adoption of these technologies through well-directed policy measures. Similarly, analysis of the policy impact may guide agricultural research in the development of ‘appropriate’ technologies that have a greater chance of adoption, because they more effectively address the aims, aspirations and constraints at the farm household level.

The implementation and monitoring steps in land use policy formulation, unfortunately, has received relatively little attention in land use analysis literature. The method of ‘prototyping’, described here at farm level, appears to be an effective intermediate step between exploratory land use studies at the regional level and attempts at large-scale implementation of technological innovations. The iterative framework of design, implementation, monitoring, identification of options and constraints and adaptation is especially effective for testing the technical feasibility of technological improvements. At the same time, issues such as economic viability and social acceptability form a spin-off of this methodology, as the presence of a prototype farm in situ induces close interaction with the sector and with policy makers on the techniques applied and the results obtained. Hence, within the framework of land use policy formulation and evaluation, prototyping should be advocated as a necessary step in regional development programmes. It may contribute to the formulation of more effective policy measures, and technological innovations can be tested in practice before being introduced at a large scale.

In conclusion, current developments in methodologies for land use studies, as a basis for land use policy formulation, appear to contribute to meeting the changing demands. It is evident that the intimate relation between agro-technical and (socio-economic conditions and considerations in land use decisions still presents a major bottleneck in model-based land use studies, but at the research level appreciable progress is being made. The tools developed and tested should be developed into a consistent and coherent framework that allows addressing the various aspects of relevance in land use policy formulation and implementation.

The probably biggest challenge is to transfer the methodologies developed in land use studies to the unruly practice of land use policy formulation and implementation. That requires close co-operation with the ultimate users of the methodologies, the various stakeholders, such as through the development of negotiating platforms.

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