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Exploring sustainable technical alternatives for Dutch dairy systems by integrating agro-economic modelling and public preferences assessment

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Abstract— **Theoretical discussions on the joint consideration of multiple (economic, social and environmental) functions when assessing the sustainability of human actions are increasing. However few studies exist that integrate the social demand for multifunctional agriculture in the evaluation of the sustainability and the global welfare of society. This paper presents a methodology to answer to these questions: Which are the social demands for the multiple functions of agriculture and how can they be quantified?; Which are the feasible technical alternatives of land management to satisfy these demands?; What is the value of the land use alternatives according to social preferences and which alternatives optimally satisfy the social preferences?. The net utility of alternatives for society, and therefore their sustainability, will be measured as the sum of market and non-market net changes compared to the current situation. The proposed methodology combines economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation. In particular, different multi-criteria methods (QFD/ANP) and agro-economic modelling and optimizing tools (Landscape IMAGES) were used. The methodology will be fully illustrated through the case study of dairy farming landscapes in the Northern Friesian Woodlands, The Netherlands. Results show that for the case study it is possible to change current farming techniques and achieve more sustainable farming systems. The more sustainable alternatives are beneficial for farmers, obtaining higher gross margin, and for government, decreasing the current levels of subsidies in agri-environmental programs. Even current environmental restrictions can be slightly relaxed without compromising social demands to the analysed Dutch dairy farming systems.**

Keywords— **Land-use planning, public preferences, agro-economic models.**

I. INTRODUCTION

New demands of society to agriculture increased from the 1980s onwards, related to concepts such as sustainable agriculture, environmentally friendly agricultural practices and responsible management of natural resources. These ideas refer to the ecological, technological and socioeconomic dimensions of the broader concept of sustainable development [1], and implicitly allude to the multifunctional nature of agriculture. Awareness among rural and urban citizens of the multifunctional role of agriculture is growing and governments are increasingly looking for ways to ensure that its non-commodity outputs correspond in quantity, composition and quality to those demanded by society [2]. Delivering to growing public demands raises two main questions for farmers and policy makers: (a) what might the public actually want [3]; (b) how to integrate preferences of citizens in the evaluation of the multifunctional performance and the sustainability of alternative land use options. [4] suggested that integrating key elements in an approach that combines economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation can provide complementary insights into sustainable and welfare-optimizing management and policy. In this paper we investigate these suggestions.

The main objective of this paper is to investigate these suggestions by applying a methodological framework to integrate the social demand for multifunctionality of agriculture in the exploration of more sustainable farming systems. The methodology will be illustrated in a case study of intensively managed, ecologically and historically valuable agro-landscapes in the Northern Friesian Woodlands (The Netherlands).

This paper strongly leans on the work of Parra-López et al. [5] representing an effort of summarization of some of its findings. For a complete explanation of the analysis including other aspects and results not considered here, the reader is referred to the original work.

II. DAIRY LANDSCAPES IN NORTHERN FRIESIAN WOODLANDS, THE NETHERLANDS

Northern Friesian Woodlands (The Netherlands) is a region characterized by a small scale landscape on predominantly sandy soils with dairy farming as the prevailing land-use activity. Most of the area of farms is occupied by permanent grassland, rotationally grazed and mown. The fields with an average size of 2 ha are often surrounded by hedgerows and frequently border on ponds. In the 1990s, the farmers were confronted with strict regulations to reduce emissions of ammonia and nitrate to the environment. Environmental cooperatives emerged as a response to predominantly generic and means-oriented policy interventions. The cooperatives developed activities to reach the aims of the proposed policies with context-specific measures that were acceptable for farmers. In addition the farmers committed themselves to maintaining the historical landscape which is the basis for a strong local identity of its inhabitants and the cooperatives organized activities related to nature and landscape management by farmers ([6], [7]).

In this paper we will explore opportunities to satisfy both the non-market and the market functions of agricultural systems by adapting agricultural land use and land management in an area of 232 ha, comprising three farms. As indicator of the market function we use landscape gross margin (GM), which is defined as the total revenues minus all variable costs, at the landscape scale. Three key non-market functions that are supported by the activities of the environmental cooperatives are analysed in this paper:

F1. *Landscape quality (LQ)*: It refers to variation in number of plant species in pasture and to irregularity in the hedgerow pattern, referred to as half-openness of the landscape, and thus pertains to the spatial scales of field and landscape.

F2. *Nature value (NV)*: This function refers to species diversity in the grass swards and hedgerows (number of species per ha). It is relevant at the field scale.

F3. *Environmental health (EH)*: Low nitrogen loss from agriculture, here also interpreted at the field scale.

III. PREFERENCES OF SOCIETY FOR NON-MARKET FUNCTIONS OF AGRO-LANDSCAPES: QFD/ANP METHODOLOGIES

Market outputs are valued by consumers in the market. Their impact on economic agents will be described in the next section. Non-market outputs have not a market but may affect potentially all citizens of the world. We focus here on the Dutch national population, since the impact of the non-market functions of the small analysed region at the international level is supposed to be negligible. Dutch citizens' preferences for non-market functions of agriculture were derived from a Special Eurobarometer [8] that deals with perceptions and opinions of citizens toward agricultural policy (Table 1). These preferences have been translated into priorities of the non-market functions of agriculture by using QFD and ANP methodologies.

Table 1 Preferences of Dutch citizens towards agriculture

Aspect	Original priorities	Normalised priorities
P1. Ensure stable and adequate incomes for farmers	36	0.1417
P2. Ensure that agricultural products are healthy and safe	31	0.1220
P3. Promote the respect of environment	24	0.0945
P4. Favour and improve life in the countryside	16	0.0630
P5. Make European agriculture more competitive on world markets	22	0.0866
P6. Protect small or medium sized farms	20	0.0787
P7. Help farmers to adapt their production to consumer's expectations	17	0.0669
P8. Favour methods of organic production	27	0.1063
P9. Reduce development gaps between regions	15	0.0591
P10. Protect the welfare of farm animals	23	0.0906
P11. Encourage the diversification of agricultural products and activities	15	0.0591
P12. Protect the specificity and taste of European agricultural products	8	0.0315
Total	*254*	*1.0000*

Source: Special Eurobarometer [8]

QFD -Quality Function Deployment- is an analytical tool for strategic planning ([9], [10]). The aim is to translate what a customer needs, or the WHATs, equivalent with the social preferences for agro-landscapes in our application, into strategic or technical requirements or HOWs, i.e. how can these needs be satisfied, equivalent with the relative priorities of the non-market functions of agriculture in our case study. This is calculated on the basis of the relative importance of the Dutch citizens' preferences (vector $\mathbf{w_P}$ in Table 2) and the relationship matrix ($\mathbf{W_{F,P}}$ in Table 2) between non-market functions and social preferences. Inner relationships among preferences and among functions ($\mathbf{W_{P,P}}$ and $\mathbf{W_{F,F}}$ in Table 2) may be incorporated in the analysis to fine-tune the results [11].

Table 2 Super matrix for the proposed QFD/ANP model

	Goal	WHATs (Preferences)	HOWs (Functions)
Goal	0	0	0
WHATs (Preferences)	$\mathbf{w_P}$	$\mathbf{W_{P,P}}$	0
HOWs (Functions)	0	$\mathbf{W_{F,P}}$	$\mathbf{W_{F,F}}$

ANP -Analytic Network Process- [12] is a multi-criteria decision-making methodology. ANP has been used to overcome some limitations of the traditional application of QFD (e.g. [13], [14], [11]) related to the scale of measurement of relationships and the treatment of inner relationships. A QFD/ANP network can be represented by a *super matrix* (Table 2). Each cell of this matrix describes the contribution of element *i* to the achievement of element *j*. To specify the magnitude of the relationships ($w_{i,j}$), elements are evaluated by pairs through *pairwise comparisons* of their relative contributions (or priorities) to each of the other elements ([15], [16]), usually on the basis of judgement of experts or stakeholders.

Ten experts on sustainable farming systems and with knowledge of the case study situation were individually interviewed. Each of them filled out all correlation matrices, resulting in one super matrix for each expert. Sub-matrices $\mathbf{W_{F,P}}$ and $\mathbf{W_{F,F}}$ were defined according to the pair-wise procedure. $\mathbf{W_{P,P}}$ was elicited by 'direct rating' assessment [17], since the number of elements to compare is high as for the social preferences (usually 7-9 is recommended as maximum in ANP). The used rating scale ranged from 1 (very weak relationship) to 9 (very strong relationship).

A matrix manipulation procedure allowed calculating the priorities of the non-market functions for each expert [14]. A vector of priorities of the social preferences is calculated considering the inner dependencies according to $\mathbf{w_P}^{\mathbf{int}}=\mathbf{W_{P,P}}.\mathbf{w_P}$. A matrix of priorities of the non-market functions as determined by the social preferences is calculated considering the inner dependences among the non-market functions: $\mathbf{W_{F,P}}^{\mathbf{int}}=\mathbf{W_{F,F}}.\mathbf{W_{F,P}}$. Finally, priorities of the functions considering all the interdependencies are calculated: $\mathbf{w_F}=\mathbf{W_{F,P}}^{\mathbf{int}}.\mathbf{w_P}^{\mathbf{int}}$. Therefore a vector $\mathbf{w_F}$ can be obtained for each expert or decision agent (thus we can call it as $\mathbf{w_{F(e)}}$, to refer to the specific expert *e*). Individual priorities were aggregated to the group by *Aggregation of Individual Priorities (AIP)* [18]:

$$\mathbf{w}_{\mathrm{F(group)}} = \sum_{e=1}^{G} \mathbf{w}_{\mathbf{F}(e)} / \mathrm{G}$$

where *e* is the expert e, and *G* is the number of experts.

IV. SOCIAL NET BENEFITS OF AGRO-LANDSCAPES

Social benefits derived from a change in land management from the current situation are of both market and non-market nature.

A. Market net benefit

Market net benefit (ΔU_M) is defined as a change in utility for society as result of a change in the equilibrium point in the market of agricultural products. Utility is assumed equivalent to the neoclassical concept of surplus, and can be measured in monetary units. Assumptions in our case study are: 1) Alternatives are based on the same fixed inputs as in the current situation, but may require different amounts of variable inputs; 2) Prices of inputs and outputs are assumed constant over the considered short-time horizon.

Market net benefit is composed of ($\Delta U_M = \Delta U_{M,FARM} + \Delta U_{M,CONS} + \Delta U_{M,GOV}$):

- *Market net benefit for farmers* ($\Delta U_{M,FARM}$): Surplus of farmers is gross margin. A change in GM is equivalent to a change in utility for farmers, and, since fixed costs are assumed constant, to a change in their profit as producers[1]. Therefore: $\Delta U_{M,FARM} = \Delta GM$; *GM*=*R*+*S*-*VC*, where *GM* is gross margin, *R* revenue, *S* subsidies and *VC* variable costs. In our case study, the market function of agriculture is production of milk.

- *Market net benefit for consumers* ($\Delta U_{M,CONS}$): An approximation of the surplus of consumers for small changes in supply at constant demand curve is (P2-P1)*(Q2+Q1)/2, where *1* and *2* indicate two equilibrium points, and *P* and *Q* price and quantity of the product in the market. In our application price of the output (milk) is assumed constant. Therefore: $\Delta U_{M,CONS} = 0$.
- *Market net benefit for government* ($\Delta U_{M,GOV}$): Utility for the government increases if financial support for agriculture decreases. We assume the relation to be: $\Delta U_{M,GOV} = -\Delta S$, where *S* is the public support.

B. Non-market net benefit

We define a change in the utility of an agro-landscape for society (dU_{NM}) as:

$$dU_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot dF_i / F_i$$

where *Fi* are the non-market functions (F1=LQ, landscape quality; F2=NV, nature value; F3=EH, environmental health); *dFi/Fi* is the change in the non-market function Fi relative to the current performance; ω_{Fi} is the relative importance that society attaches to such a change; and *n* is the number of non-market functions. We assume that preferences of society for the non-market functions as determined previously by QFP/ANP, $w_{F(group)}$, are equivalent to the relative importance of the functions, ω_{Fi}. This assumption is based on the observation that human beings generally perceive relative change in relation to the level from which the change starts [19].

Non-market net benefit (ΔU_{NM}) of a change from the present situation (0) to a given situation (s) can be obtained by integrating the previous equation, resulting in a Cobb-Douglas function:

$$\Delta U_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s) / F_i(0)\right]$$

C. Social net benefit

We define social net benefit (ΔUS) as:

$$\Delta U_S = \frac{\Delta U_M}{RU_M} + \frac{\Delta U_{NM}}{RU_{NM}}$$

where R_{UM} and R_{UNM} are the ranges of possible market and non-market net benefits, respectively, for the set of potential agro-landscapes. Similar relative changes of market and non-market (essentially environmental in our case study) benefits thus have the same influence on social welfare. This assumption is in agreement with social demand in Europe: 85% of people in the EU-25 and 75% in the Netherlands think that, on key issues, political decision-makers should pay the same degree of attention to environmental concerns as to economic and social factors [20].

V. EXPLORATION OF AGRO-LANDSCAPE ALTERNATIVES: THE LANDSCAPE IMAGES FRAMEWORK

Landscape IMAGES [21] is a static modelling and optimizing framework for exploration of the potential contribution of agricultural land-use and landscape management to the improvement of economic and environmental performances at field, farm and landscape levels. Performance is determined by the arrangement of two types of land-use activities. The first type concerns a field with pasture and its fertilizer and harvesting management regimes. The second concerns the field borders, each of which may or may not contain a hedgerow. Market and non-market performances may be affected by interaction between land-use activities on two or more spatial units.

The mathematical problem faced is a multi-objective problem with multiple functions that are simultaneously maximized, decision variables that represent land use activities allocated to n spatial units, and constraints, for instance limitations on the inputs or outputs related to the activities [21]. The evolutionary strategy of Differential Evolution [22] was applied to obtain approximations of the trade-off surfaces in a population of solutions.

1. Surplus of producers equals gross margin. Profit equals gross margin minus fixed costs.

The case study agro-landscape consists of an area of 232 ha enclosed by roads, comprising three farms with an average area of 42 ha and buffer fields belonging to other land users. An agro-ecological engineering approach was used to design land use activities, which are defined as the cultivation of a crop or vegetation and/or management of a herd in a particular physical environment, completely specified by its inputs and outputs [23]. Grassland activities including their fertilizer and harvest regimes were allocated to the fields, and field borders could be occupied by a hedgerow or remain unoccupied. The inputs (soil fertility, fertilization level and harvesting regime) and outputs (production of net energy for lactation, species diversity and nutrient emissions) of the land use activities were calculated from established empirical agro-ecological relations ([24], [6]).

VI. RESULTS

The priorities of the non-market functions of the farming systems in Northern Friesian Woodlands according to Dutch preferences are: $\omega_{F1(Landscape\ quality)}=0.3228$; $\omega_{F2(Nature\ value)}=0.2894$; $\omega_{F3(Environmental\ health)}=0.3879$. These priorities determine the non-market benefit that society may obtain from a change of land use.

Feasible technical alternatives of land management for analysed agro-landscape are shown in Figure 1. Points above the line $\Delta U_S=0$, represent social gains, and points below this line entail social losses. Optimum alternatives according to social preferences were selected that could serve as prototypes of desired situations of the agro-landscape (Figure 1). In Table 3, the main land use characteristics and the performance of the selected landscape alternatives are summarised.

The results indicate that the current state of the region is not very far from the social optimum prototype (Figure 1). Further approaching the social optimum would involve increasing the market net benefits but slightly decreasing the non-market net benefits of the system. Market net benefit could be increased by a higher gross margin for farmers of almost 2%, even with 83% lower subsidies from agri-environmental schemes. However, non-market net benefit would be decreased since ‘environmental health’, ‘landscape quality’ and ‘nature value’ performances of the current landscape are even slightly beyond social optimum. If we assume that a decrease in non-market net benefit would not be acceptable even when associated with an increase in market net benefit, the search for better alternatives than the current situation is limited to the upper right quadrant of Figure 1. The socially optimal landscape is then the ‘Win-win optimum’ alternative (Figure 1), increasing both the market and non-market net benefits of the system. This alternative would represent slightly lower ‘environmental health’ than the current situation and lead to 7% increase in nitrogen emission, and slightly lower ‘nature value’. However, these losses are compensated by the higher ‘landscape quality’ of the system resulting in a higher non-market value.

VII. CONCLUSIONS

This paper summarised a methodological framework to integrate the social demand for multifunctionality of agriculture in the evaluation and design of more sustainable agro-landscapes developed by Parra-López et al. [5]. It entails to answer to three questions: (1) Which are the social demands for the multiple functions of agro-landscapes; (2) Which are the technical alternatives of land management to satisfy these demands; (3) What is the value of the land use alternatives according to social preferences and which are the socially optimum alternatives.

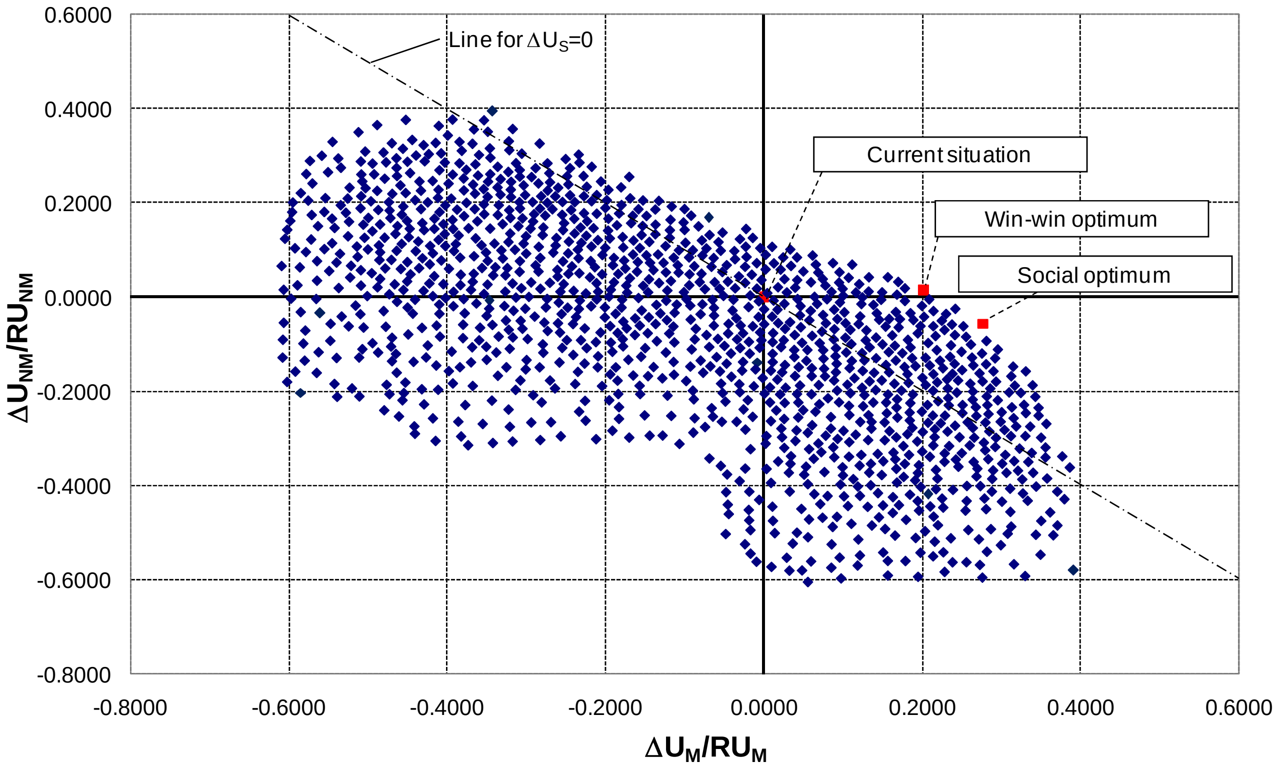

Fig. 1 Market and non-market net benefits for the feasible technical alternatives of land management and selected prototypes

Table 3 Socially optimum alternatives of land management

Characteristic	Alternative name		
	Social optimum	Win-win optimum	Current situation
Gross margin (€/ha/yr)	2969.08	2947.91	2917.43
Subsidies (€/ha/yr)	33.30	70.68	199.59
Landscape quality (-)	82.61	122.44	88.54
Nature value (-)	28.25	37.27	41.28
Environmental health (1/(kgN/ha/yr))	0.01	0.01	0.01
$\Delta U_{M,FARM}$ (€/ha/yr)	51.65	30.48	0.00
$\Delta U_{M,GOV}$ (€/ha/yr)	166.28	128.91	0.00
ΔU_{M} (€/ha/yr)	217.93	159.40	0.00
$\Delta U_{NM,LQ}$ (-)	-0.0224	0.1047	0.0000
$\Delta U_{NM,NV}$ (-)	-0.1097	-0.0295	0.0000
$\Delta U_{NM,EH}$ (-)	-0.0706	-0.0271	0.0000
ΔU_{NM} (-)	-0.2027	0.0480	0.0000
$\Delta U_M/RU_M$ (-)	0.2778	0.2032	0.0000
$\Delta U_{NM}/RU_{NM}$ (-)	-0.0554	0.0131	0.0000
ΔU_S (-)	0.2224	0.2163	0.0000
Species (per 25 m^2)	8.54	10.47	14.76
Emission (kgN/ha/yr)	170.00	155.23	144.96
N applied (kgN/ha/yr)	342.46	312.82	266.47
Grazing cuts (per yr)	2.07	2.02	2.44
Mowing cuts (per yr)	3.07	2.68	2.11
Occupied border (m/ha)	144.53	181.67	176.76

Social net benefit was introduced as the indicator which allowed linking the stated preferences of citizens to indicators that were evaluated for given agro-landscapes using the agro-ecological landscape model Landscape IMAGES. The methodology allows revealing trade-offs between market and non-market benefits of land use alternatives and detect utopian alternatives, including the 'social optimum', that is, the land use alternative that maximizes the social value of the landscape given the current technical and agronomic restriction at field and farm scales, and the economic and social environment. The methodology is broadly applicable and although involving expert opinion, transparent by drawing on the QFD/ANP approach, multi-attribute utility theory ad agro-ecological modelling.

The methodology was illustrated through the case study of dairy landscapes in Northern Friesian Woodlands, The Netherlands. The results indicate that there is only limited scope for improvement of the current situation in terms of social net benefit. It may be that the strict environmental policies of the last decade have been effective to reach low inputs and emissions. To satisfy public demand the new challenge appears to be a shift in policy focus to a more landscape-oriented emphasis. Following public demand apparently is not necessarily equivalent to pursuing long-term environmental policy goals. These severe implications of accommodating public opinion should be interpreted with care due to the small scale of the selected case study area as well as due to the choice of case study region where landscape is an important characteristic and farmers have developed high-profile activities to demonstrate their environmental engagement. Application to a larger part of the region and to different regions is desirable. The methodology was illustrated at landscape level but can also be applied at another level of analysis (field, farm, regional and national) and for other farming systems. The limits of application concern the availability of information on the performance of farming systems at the level and land use of interest.

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