Energy farming in multiple land use

An opportunity for energy crop introduction in the Netherlands

Energieteelt binnen meervoudig landgebruik

Een mogelijkheid voor de introductie
van energiegewassen in Nederland

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de Rector Magnificus, Prof. dr. W.H. Gispen, ingevolge het besluit van het College voor Promoties in het openbaar te verdedigen op maandag 6 mei 2002 des middags te 16.15 uur

door

Henri Marius Londo

Geboren op 8 december 1970 te Emmen.

Promotor: Prof. dr. H.A.M. de Kruijf
Sectie Natuurwetenschap en Samenleving,
Copernicus Instituut, Universiteit Utrecht

Copromotor: Dr. H.J. de Graaf
Sectie Milieubiologie, Instituut voor Evolutionaire
en Ecologische Wetenschappen, Universiteit Leiden

Beoordelingscommissie:
Prof. dr. N.D. van Egmond, Universiteit Utrecht
Prof. dr. J. Goudriaan, Wageningen Universiteit
Prof. dr. L. Hordijk, Wageningen Universiteit

Dit proefschrift is mogelijk gemaakt met financiële steun van het Nationaal Onderzoeksprogramma Mondiale Luchtverontreiniging en Klimaatverandering (NOP-MLK), Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)

ISBN: 90-73958-85-7

Druk: Krips, Meppel.
Ontwerp omslag: Jan den Boesterd, AV-Dienst Chemie.
Foto: Biesboschmuseum bij Werkendam. Onderhouden naast doorgeschoten griend.

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Chapter 1

General introduction

1. Bioenergy and global energy-related problems

One of the most impressive images people remember of man's landing on the moon may be the view of a small, blue-green planet floating in space, called earth. The picture from outer space made inexorably clear that we, 6 billions of people, have to live on a planet with a finite amount of earthly space and natural resources. Furthermore, the impression may have risen that this earth is a small, vulnerable planet amidst a vast, inhospitable universe.

Many environmental problems that occur on a global scale are related to this picture of planet earth. Only three years after the first moon expedition, the Club of Rome report 'The limits to growth' [1] marked the growing concerns about the exhaustion of finite resources such as fossil fuels and minerals. More recently, concerns about human-induced disturbance of the global climate system have entered the political agenda. In both problem areas, the introduction of renewable energy technologies has often been mentioned as part of the solution.

Regarding exhaustion of fossil supplies, the Club of Rome prospects have appeared to be relatively pessimistic [2]. Economically extractable fossil fuel reserves have proven to be sufficient for more than a century of growing energy demand, and given technological progress, potential reserves, and unconventional reserves such as gas hydrates, it is highly probable that fossil fuels will continue to be available at low costs for a much longer period of time [2].

However, concerns about climate change have become stronger in the last decade, and for a major part they have been attributed to fossil fuel CO_2 emissions. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concludes, after unprecedented scrutiny and review, that 'an increasing body of observations gives a collective picture of a warming world and other changes in the global climate system [3]. Furthermore, 'there is new and stronger evidence (compared to the Second Assessment Report, ML) that most of the warming observed over the last 50 years is attributable to human activities' [3]. The projected changes in climate and climate extremes could have major consequences for natural as well as human systems [4]. Given differences in vulnerability and in ability to cope with climate change, it seems that climate change would also increase the disparity between developed and developing countries [4]. While there are still considerable uncertainties in the cause-effect chain of climate change [5], the Kyoto protocol and its follow-up illustrate that there is global agreement that climate change, and its mitigation, is a major global policy issue. In short, the unsustainability of current fossil fuel use is not as much induced by the finiteness of the resource, but primarily by the increasing certainty about negative effects of related CO_2 emissions.

Strategies for mitigation of CO_2 energy-related emissions have been roughly discerned in the *trias energica* [6]:

- Increased energy efficiency: decreasing energy inputs per unit of product or service.
- Clean fossil energy: using of fossil fuels combined to CO_2 separation from the flue gases and injection into underground reservoirs.
- Renewable energy: developing CO_2-neutral energy resources such as wind energy, solar energy and energy from biomass (bioenergy).

Given CO_2 emission reduction targets that can be deduced from potentially ‘safe levels’ of CO_2 in the atmosphere, and potentials for reducing CO_2 emissions per strategy, it is probable that all three strategies will have to be employed in order to tackle the problem of climate change [7].

In the renewable energy field, all options, such as wind and solar energy, bioenergy, and hydropower, have their own sustainability merits in ecological, economic and social terms [8]. Bioenergy, for example, leads to deforestation and land degradation if woodlands are overexploited for energy wood. On the other hand, sustainable cultivation of energy crops may lead to improvement of degraded land, and the development of an energy cropping sector might lead to new local employment and substitute fossil fuel imports. On a global scale, all renewable energy options have potentials, and per region implementation will depend on specific environmental and social characteristics.

In many future global energy supply prospects, energy from biomass plays an important role. A recent review of future global bioenergy supply assessments [9, 10] gives an indication of the huge potential of this option, as well as the broad range in predictions (Figure 1.1). Forecast bioenergy shares vary from below the current traditional biomass energy consumption (ca 50 EJ/yr) to the current global energy supply (ca 400 EJ/yr). Differences between the studies are mainly determined by different assumptions in economic development and corresponding energy demand, and by differences in assumed land availability for energy crops. The latter issue strongly depends on the economics of energy crop cultivation compared to other types of land use, and on land suitability for different types of land use. Note that, in Figure 1.1, current biomass energy consumption is considerable (more than 10% of primary energy supply). However, the traditional biomass use is often problematic, resulting in e.g. deforestation, and indoor air problems (badly tuned cooking stoves).

For bioenergy, environmental and social characteristics such as climate, land quality, land use and land use intensity strongly influence regional potentials [11]. For example, opportunities in countries with little agriculture and a high proportion of under-utilised land will differ from countries with intensive land use and a well-developed agricultural sector. In this study, we focus on the potentials for bioenergy in the Netherlands, as an example of the latter category.

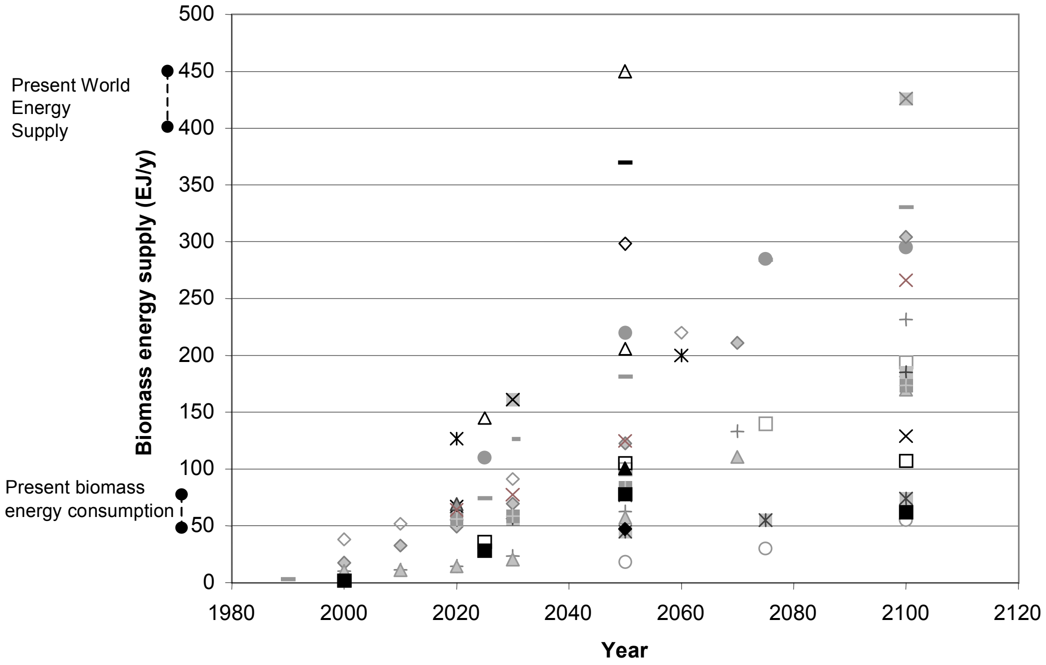

Figure 1.1: Global contribution of biomass energy over time to 2100 according to 29 scenarios in 17 studies on global energy prospects. Source: [9, 10].

2. Biomass energy in the Netherlands

In Dutch energy policy, an important landmark for bioenergy has been the 1996 3rd Policy Document on Energy [12]. In this document, the government proposed a target share of 10% of national energy demand to be fulfilled by renewable resources by the year 2020.

For bioenergy, the 2020 share was projected at a total supply of 120 PJ/yr [12, 13], ca 40% of the total renewable energy target. In recent ministerial documents, it is confirmed that bioenergy, together with offshore wind energy, will have to account for a major part of the renewable energy share in 2020 [8, 14]. Part of the bioenergy target will be fulfilled by electricity production in waste incinerators: the non-plastic part of household waste is allowed to count as renewable energy. Other bioenergy resources will be:

- Residual wood and other materials from agriculture, forestry and industry;
- Dedicated energy crops within the Netherlands, or energy farming;
- Biomass imports.

Within the period until 2020, most of these resources will be used for electricity generation, in specific biomass power plants or by co-firing in coal-fed installations.

For all resource options, indications of potentials vary widely. In several studies, for example, the currently available supply for energy from residues varies between 25 and 120 PJ/yr [15-17]. Figure 1.2 shows a number of area estimations for the contribution of dedicated energy crops (energy farming) by the year 2020. Again, the scenarios vary within a broad range, and claim up to ca 10% of the total rural area in the Netherlands. Most of the studies focusing on demands for biomass (D1 to D3) are unclear about the assumptions leading to their prospects, so it is hard to identify the determinants of this range. In studies on the availability of biomass as a resource (R1 to R4), key assumptions concern productivity improvement in common agriculture for food, changes in the EU

Common Agricultural Policy, and the resulting discharge of land from agriculture. However, the assumption that this land will become available for energy farming is disputable, given the low value added of energy crops compared to food crops.

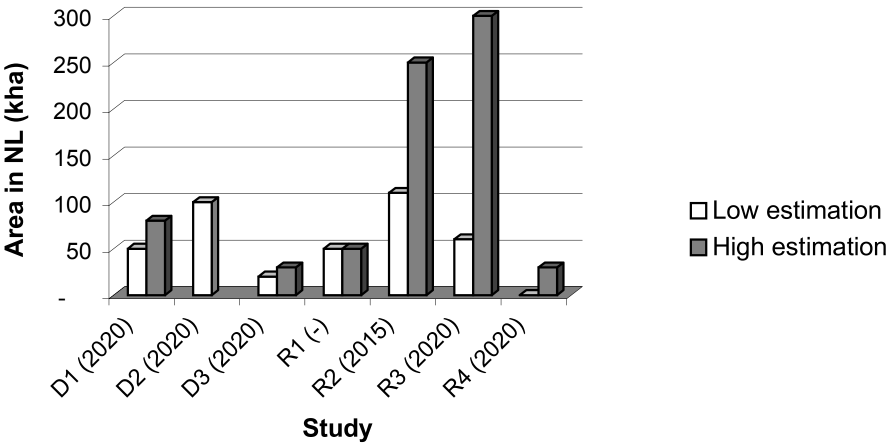

Figure 1.2: Future energy farming area in the Netherlands according to 7 studies. Sources: D1: [18]; D2: [19]; D3: [15]; R1: [20]; R2: [21]; R3: [22]; R4: [16]. D: focusing on bioenergy demand, R: focusing on biomass resources.

Currently, only residues are traded for bioenergy on a commercial basis to feed a number of power plants in the Netherlands. Prices for clean wood, collected from e.g. woodland management, vary between € 0 and € 25 per oven-dry tonne (odt) before transport. This price range can be considered an estimate of a range in which bioenergy can compete with fossil fuels such as coal, given the current incentive policy measures for renewable energy in the Netherlands.

3. Land use in the Netherlands and potentials for energy farming

The Netherlands has one of the highest population densities in the world (ca 500 inhabitants per km^2 of land), and a strong, export-oriented agricultural sector. Given the country's high degree of development, it is not surprising that land use is intensive. Cities are compact, and agricultural in- and outputs per ha are high. Therefore, the related problem of limited land availability for bioenergy is clearly present in the Netherlands.

In the 5th Policy Document on Physical Planning [23], the Dutch government has assessed all space claims from different policy sectors for the period up to 2030, based on a consistent set of demographic, economic and social determinants (see Table 1.1). This results in a quite alarming picture: on the total Dutch area of circa 4 million ha, a net additional area between 0.6 and 1 million ha would be needed to meet all demands, assuming that claims from different sectors can not be combined. While the Netherlands have an outstanding tradition in adapting their territory by e.g. land reclamation, such an area is currently not feasible. In response, the government proposes a strategy of combining functions: by fulfilling separate claims on the same tracts of land, the total area required may be reduced. For rural areas, such a strategy is also called multiple land use.

Table 1.1: Current areas and claims for space of different sectors in the Netherlands [23].

	Area in 1996	Extra space claim 2000-2030 (kha)	
		Minimum	Maximum
Housing	224	+ 39	+ 85
Employment[1]	96	+ 32	+ 54
Infrastructure	134	+ 35	+ 60
Recreation	83	+ 144	
Water[2]	765	+ 490	
Nature/woodland/landscape	461	+ 333	
Agriculture	2,351	- 475	- 170
TOTAL	4,150	+ 598	+ 996

[1]: Sum of claims for industry, services, and other space related to working activities.
[2]: Necessary for safety (inundation), extra open water, and 'spatial measures'.

Within this context, the accommodation of a new single-use space claim of tens of thousands of hectares for energy crops will be problematic. The low value added of energy farming, compared to common agriculture such as arable agriculture or dairy farming, aggravates this problem [16, 21, 24, 25]. Although a bioenergy feedstock market is still under development, and biomass prices are still hard to estimate, current prices paid for biomass for energy are by far insufficient to make dedicated energy crops competitive. Therefore, the introduction of energy farming as single land use will hardly have a chance. In order to improve financial competitiveness and therefore opportunities for energy crops, several strategies have been proposed. In multi-product cropping [26], new crops are used partly for high-value added applications, partly for energy. In cascading [27, 28], crops are first used for high-value applications, such as construction material, and afterwards as energy resource. Multiple land use is another interesting strategy: many of the proposed energy crops seem to offer good conditions for combination with other types of land use [29-31]. Compared to common agriculture, most energy crops require less intensive land use, and less external inputs [24], which suggests that they have better chances for combinations than common agriculture.

4. Multiple land use as a concept

In this thesis, we explore potentials for the introduction of energy farming in multiple land use systems. However, multiple land use as a concept is still relatively ill-defined and vague. While historically, land use was almost always aimed at the production of more than one product, developments after the second world war targeted at separation of functions like agriculture, nature conservation and recreation. In the latest decades, many concepts have been developed that are related to multiple land use, in sectors such as agriculture, nature management, and space planning (see Table 1.2). In all these concepts, functions interdepend on each other within certain spatial and temporal dimensions. These levels are different for each concept: a plot, a farm, or a region, and simultaneous or after each other.

For a successful application of multiple land use, this concept requires further operationalisation. First, Table 1.2 illustrates that many concepts are familiar to each other, but not identical. This indistinctness can lead to inflation of the concept: when every actor has activities related to it, it will loose its relevance. Second, discussions on the merits of multiple versus single land use are sometimes coloured by ideological differences. For example, in the agricultural sector, the multiple land use farming style is sometimes associated with outdated production technologies, and environmental problems such as nutrient and biocide outputs are often attributed to large-scale single land use. However, both types of land use can be sustainable, and given the situation of a land holder (in terms of e.g. his land characteristics, personal preferences and relevant policies), either of them can be most suited. Finally, continuation as well as changes in land use entail opportunities as well as risks for farmers, so a clear operationalisation of multiple land use may provide them with a more sound basis for their decisions on land use.

Table 1.2: A selection of concepts familiar to multiple land use. Based on Dekker [32].

Concept	Originating from:	Since	Spatial scale[1]	Mixed functions
Semi-natural landscapes	Nature management	1945	From plot to region	Nature management, agriculture, forestry, etc.
Nature development preceded by mining	Nature management	1990	From plot to region	Nature management, extraction of soil, gravel, etc
Multifunctional woodlands	Forestry	1950	From plot to holding	Forestry, recreation, nature management, etc.
Integrated agriculture	Agriculture	1980	Holding	Agriculture, nature managmt, environmental management
Multifunctional rural development	Spatial planning	1985	Region	Agriculture, transport, nature management, recreation, etc.

[1]: Holding indicates e.g. a farm or management unit of a conservation organisation.

Therefore, methodologies need to be formulated to help land holders systematically explore opportunities for multiple land use within their holdings, in order to obtain reliable information on the merits of multiple as well as single land use options. Such methods can explicitly take options with bioenergy farming into account, but also functions such as nature management on the farm, or water retention.

5. Researching opportunities for energy crops in multiple land use: overview of this thesis

Given the context outlined in the preceding sections, the central research question of this thesis is whether, and to what extent, multiple land use can improve opportunities for energy crops in the Netherlands, in comparison with single land use energy cropping.

We specify this central question into three criteria for improvement of opportunities for energy crops. First, in multiple land use combinations, with energy farming as one of the functions should be *biophysically feasible*, i.e. all combined functions can generate their products and/or services. Second, multiple land use should lead to a *lower supply price* for energy crops compared to single land use, preferably comparable to prices of other bioenergy resources such as residues. Finally, multiple land use energy farming should be introduced on an *area scale significant to the national renewable energy targets*, not only on a marginally small area.

In order to answer the research question, we selected a number of research topics.

- As stated in Section 4, methods for (biophysical) exploration and evaluation of multiple land use are needed. In Chapter 2, we define multiple land use, and develop a procedure for the design and evaluation of multiple land use systems within the context of a land holding or group of land holdings. Potentials for combinations are assessed at two levels: in a qualitative or semi-quantitative rapid appraisal, and in a more detailed modelling phase. This chapter also contains a discussion on optimisation strategies for multiple land use systems.
- In Chapter 3, four combinations of energy farming and another function are assessed in a 'rapid appraisal' phase of the Chapter 2 procedure, intended to create an indicative picture of the potentials of the combinations, and of the applicability of the proposed methods. Co-functions in this chapter are protection of groundwater resources in groundwater protection areas, protection of drinking water in groundwater extraction areas, the conservation of the specific flora and fauna of traditional willow coppice, and an ecological corridor co-function. Potentials of each combination are expressed in biophysical feasibility, financial competitiveness compared to single land use, and potential area.
- As applications of the detailed input-output modelling phase, two other combination options are further elaborated. In one study (Chapter 4), we quantified the performance of a combined system of energy farming and hydrological buffering of a nature reserve susceptible to desiccation. In another study (Chapter 5), we systematically explored the possibilities for steering and optimising an energy farming system for productivity as well as breeding bird diversity.

In Chapter 6, we answer the central research question and draw general conclusions.

Some general delineations of this thesis deserve attention here:

- The bioenergy chain, as a type of renewable energy includes, apart from energy crop cultivation, logistics (transport, storage, handling), and conversion into electricity or another energy carrier such as a liquid fuel. For this thesis, only the crop cultivation phase is relevant cultivation. Therefore, we do not consider this integrated chain: our system boundary is the harvested material, ready to be taken further into the logistics and conversion system.
- Proposed energy crops can broadly be classified in woody crops (e.g. willow, poplar, eucalyptus) and grasses (e.g. miscanthus, switchgrass, reed canary grass). In this thesis, we concentrate on willow in short rotation coppice (SRC). This crop has been assessed to be one of the most interesting energy crops for the climatic region of the Netherlands, in terms of productivity and cultivation sustainability [24, 33]. Furthermore, given the low inputs in its cultivation, the crop seems to offer good opportunities for combination, in particular with environmental functions. Finally, willow SRC has a long history of cultivation in the Netherlands [34, 35], so several aspects, such as the occurring flora and fauna in the cropping system have been studied relatively well compared to other proposed energy crops [24, 36].

- Many co-functions with energy farming have been proposed. Heineman et al. [29] made an extensive longlist of options, and polled a large number of involved researchers, policy makers and other relevant actors on the options' potentials. However, the idea of combining was relatively new at the moment, and there had hardly been any research on it. Therefore, this ranking of potentials has limited significance for this study. Our selection of co-functions has mainly been done on our impressions of feasibility and availability of data. The selection for this thesis is not fully consistent with the ranking of potentials in Heineman et al.
- Four selected combinations are related to nature conservation. This because attention for nature management related to cultivation systems has gained increasing attention in the latest decade, in the Agenda 2000 revision of the EU Common Agricultural Policy [37], and in the framework of the further elaboration of the 1992 UNCED convention on Biodiversity [38, 39].
- This study focuses on multiple land use in the Netherlands. However, this strategy may be also useful in other countries with intensive land use.

References

1. Meadows, D. and F. Franken. *The limits to growth: a report for the Club of Rome on the predicament of mankind.* New York: Universe, 1972.
2. Rogner, H.H. (ed.). *Energy resources.* In: Goldemberg (chief ed.). *World Energy Assessment: Energy and the challenge of sustainability.* New York: UNDP / UNDESA / WEC, 2000.
3. IPCC. *Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press, 2001.
4. IPCC. *Climate change 2001: Impacts, Adaptation, and Vulnerability. A report of working group II of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press, 2001.
5. Council, National Research. *Climate Change Science; an analysis of some key questions.* Washington: National Academy Press, 2001.
6. Lysen, E. *The Trias Energica: Solar strategies for developing countries.* In: Goetzberger, A. and J. Luther. *Proceedings Eurosun '96.* München: DGS-Sonnenenergie-Verlag, 1996. 51-56.
7. Soest, J.P. van (ed.). *Climate change: Solution in Sight , a Dutch Perspective.* Delft: Energy Policy Platform, 2000.
8. Cleijne, H., W. Ruijgrok, and P. Juffermans. *Duurzame energie in de race naar 2050; winnende paarden en talenten in prijs, aanbod en duurzaamheid (Renewable energy in the race to 2050; winning horses and talents in price, supply and sustainability).* The Hague: Ministry of Housing, Spatial Planning and Environment, 1999.
9. Hoogwijk, M., G. Berndes, R. van den Broek, L. Bouwman, and A. Faaij. *A review of assessments on the future global contribution of biomass energy.* Utrecht: Utrecht University, Dept. of Science, Technology and Society, 2000.
10. Berndes, G., M. Hoogwijk, and R. van den Broek. *The contribution of biomass in the future global energy system.* Submitted to Biomass and Bioenergy
11. Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods. *Biomass for energy: Supply prospects.* In: T.B. Johanson, H. Kelly, A.K.N. Reddy and R.H Williams, Burnham, L., (eds.). *Renewable Energy, Sources for Fuels and Electricity.* Washington: Island Press, 1993. 593-651.
12. Ministry of EZ. *Derde energienota (Third policy document on energy).* The Hague: Ministry of Economic Affairs, 1996.
13. Ministry of EZ. *Duurzame energie in opmars. Actieprogramma 1997-2000 (renewable energy in advancement. Action programme 1997-2000).* The Hague: Ministry of Economic Affairs, 1997.

14. Ministry of EZ. *Vaststelling van de begroting van de uitgaven en de ontvangsten van het Ministerie van Economische Zaken (XIII) voor het jaar 2002 (Budget of the Ministry of economic Affairs for the year 2002).* The Hague: Ministry of Economic Affairs, 2001.
15. Heuvel, E.J.M.T. van den and J.K. Gigler. *Is er grond voor biomassaproductie in Nederland? (Is there ground for biomass in the Netherlands?).* Utrecht: NOVEM, 1998.
16. Zeevalking, J.A. and J. Koppejan. *EWAB marsroutes, Taak 1; Beschikbaarheid van biomassa en afval (EWAB Marching routes, task 1; Availability of biomass and waste).* Utrecht: NOVEM, 2000.
17. Faaij, A., J. van Doorn, T. Curvers, E. Olsson, A. van Wijk, and C. Daey-Ouwens. *Characteristics and availability of biomass waste and residues in the Netherlands for gasification.* Biomass & Bioenergy 1997, 12 (4): 225-240.
18. Ruijgrok, W. and M.C. Kalf. *Bouwstenen bio-energie 2020 (Building blocks bio-energy 2020).* Anhem: KEMA, 1998.
19. Ree, R. van, T. Gerlagh, B. Groenendaal, L. Dinkelbach, J. van Doorn, and K. Hemmes. *Kritische succesfactoren biomassa (critical succes factors biomass).* Petten: ECN, 2000.
20. Bestebroer, S. *Energiewinning uit Biomassa; plan van Aanpak (energy production from biomass; action plan).* Arnhem: KEMA, 1995.
21. Faaij, A., I. Steetskamp, A. van Wijk, and W. Turkenburg. *Exploration of the land potential for the production of biomass for energy in the Netherlands.* Biomass and Bioenergy 1998, 14 (5/6): 439-456.
22. Ybema, J.R., P. Kroon, T.J. de Lange, and G.J. Ruijg. *De bijdrage van duurzame energie in Nederland tot 2020 (Renewable energy contrubution in the Netherlands up to 2020).* Petten: ECN, 1999.
23. Ministry of VROM. *Ruimte maken, ruimte delen; Vijfde nota ruimtelijke ordening (Making space, sharing space; fifth policy document on spatial planning).* The Hague: Ministry of Public Housing, Spatial Planning and Environment, 2000.
24. Biewinga, E.E. and G. van der Bijl. *Sustainability of energy crops in Europe; a methodology developed and applied.* Utrecht: CLM, 1996.
25. Dinkelbach, L., J. van Doorn, and R. Jansma. *Mogelijkheden voor kostenreductie bij energieteelt (potentials for cost reduction in energy farming).* Petten: Novem, 1998.
26. Anonymous. *Biocascade; geïntegreerde plantconversie met gecombineerde winning van producten en energie (Biocascade; integrated plant conversion with combined extraction of products and energy).* S.l.: DCO, ATO-DLO, BTG, Cebeco, CPRO-DLO, LEI-DLO, LUW-Agronomie, LUW-Organische Chemie, TNO-MEP, Uniqema, 1999.
27. Fraanje, P.J. *Cascading of renewable resources hemp and reed.* Industrial Crops and Products 1997, 6 201-212.
28. Sirkin, T. and M. ten Houten. *The cascade chain.* Resources, Conservation and Recycling 1994, 11 215-277.
29. Heineman, A., G. Saaltink, and L. Kuiper. *Energie uit biomassa in combinatieteelt (Energy from biomass in combination farming).* Wageningen: CPV/SBH, 1999.
30. Börjesson, P. *Environmental effects of energy crop cultivation in Sweden - I: Identification and quantification.* Biomass & Bioenergy 1999, 16 137-154.
31. Eker, M., W. Elbersen, B. de Klerk, R. de Koning, N. van der Windt, and A. Wintjes. *Switch on! First prize winning entry for the 'Living Energy' design competition to introduce energy crop cultivation in the landscape.* Wageningen: SC-DLO, 1999.
32. Dekker, J.N.M. *Het multifuncitonaliteitsprinicipe in het beheer van de natuur (the multifunctionality principle in nature management).* In: Dekker, J.N.M. *De strategische dynamiek van de particuliere natuurbescherming in Nederland (Dynamics in strategy of private nature conservation in the Netherlands).* Utrecht: Utrecht University (thesis), in prep.
33. Gigler, J.K., M.J.G. Meeusen - van Onna, and E. Annevelink (eds.). *Kansen voor energie uit biomassa! Resultaten van een 4-jarig DLO-onderzoekprogramma (Opportunities for energy from biomass! results of a 4-year DLO research programme).* Wageningen: Dienst Landbouwkundig Onderzoek, 1999.
34. Tuinzing, W.D.J. *Gegevens betreffende de griendcultuur in Nederland (Data concerning osier bed culture in the Netherlands).* The Hague: Ministry of Agriculture, Fisheries and Food, 1956.
35. Schepers, J.A.M., A.A.M. van Haperen, and J.L. van der Jagt (ed.). *Grienden: hakken of laten groeien; inventarisatie van het hakgriendenarsenaal en mogelijkheden voor ontwikkeling (Traditional willow coppice: coppicing or letting grow; an inventory of the arsenal of traditional willow coppice and potentials for development).* Utrecht: IKC-NBLF, 1992.
36. Jagt, W. van der. *Overzicht van literatuur aanwezig bij IKC-Natuurbeheer over grienden (tm 1987) (Survey of literature present at IKC-Natuurbeheer on tradiational willow coppice (until 1987)).* Wageningen: IKC-Natuurbeheer, 1996.

37. Berkhout, P. *Agenda 2000: Structuurfondsen en plattelandsbeleid. Notitie (Agenda 2000: Structural funds and rural policy. Note).* The Hague: Ministry of Agriculture, Nature Management and Fisheries, 1998.
38. CBD. *Agricultural biodiversity; Progress report on the implementation of the programme of work, including development of the International Pollinators Initiative.* Montréal: Subsidiary Body on Scientific, Technical and Technological Advice, 2001.
39. UNEP. *Convention on Biological Diversity.* Rio de Janeiro: United Nations Environmental Programme, 1992.

Chapter 2

Multiple land use on land unit level in rural areas: Towards operationalisation[*]

Abstract

The increasing demand for land urges for efficient use of this resource. Multiple land use may contribute to efficiency improvement. In this study, a number of elements for operationalisation of the multiple land use concept are elaborated. We define multiple land use as land use aimed at the generation of more than one type of product and/or service, and compare it to several related concepts. A procedure to explore potentials for multiple land use types at land unit level within a land holding is presented, primarily to be used by groups of land holders. We shortly elaborate and graphically illustrate four types of optimisation strategies to evaluate the performance of multiple land use systems, classified by types of steering strategy and basis for rewarding. Finally, we discuss some applications of the methods.

Keywords: multiple land use, methodology, functions, biomass for energy.

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[*]: Co-authors: Jos Dekker, Pita Verweij (both Dept. of Science, Technology and Society, Copernicus Institute, Utrecht University) and Hans de Graaf (Section Environmental Biology, Institute of Evolutionary and Ecological Sciences, Leiden University). Submitted to Land Use Policy.

1. Introduction

In the past decades, land has become an increasingly scarce resource, particularly in densely populated countries [1, 2]. Growing land demands for housing, infrastructure, recreation, and nature conservation, combined with the existing share of agriculture, have led to this problem. In rural as well as in urban areas, opportunities are searched for to combine the generation of different goods or services on the same land or within the same region [1-5].

This trend can be observed in different sectors in the Netherlands, such as agriculture, forestry, and spatial planning [6-9]: sometimes in order to gain better revenues from land, sometimes aimed at more efficient use of space, both within the limitations of land use sustainability. Common terms in this context are *multiple land use* (related to use) and land multifunctionality (related to qualities). Multiple land use (MLU) may offer opportunities to expand types of land use that are financially less profitable. For example, economically 'weak' types, such as nature conservation and recreation, may have better chances when combined with other types of land use such as housing or agriculture.

The growing need for renewable energy will also put extra claims on areas. The need for biomass production for energy purposes will probably generate a significant extra demand for rural land [10, 11]. Since the value added of energy crops is generally lower than that of food crops (e.g. [12]), biomass production for energy will be a function that needs to be combined with others [13] to stand a chance in the competition for land.

Multiple land use is not an entirely new concept. A definition was formulated in FAO studies in the eighties [14], and in the fields of forestry, nature conservation, rural development and city planning it has a long history [6, 15, 16]. However, MLU has been used in various contexts and disciplines as a strategic concept, therefore often ill-defined. On one hand, this can have the advantage of a so-called boundary object: leaving its exact meaning relatively vague, it can motivate a range of actors with different perspectives to develop varying new initiatives related to the issue [6]. However, when we leave the term multiple land use too fuzzy, almost any kind of land use may qualify for it. This may lead to inflation of the concept, which is not desirable in case government organisations intend to stimulate and subsidise MLU projects [6].

The objective of this study is to clarify and operationalise the concept of multiple land use as a tool for land use improvement. MLU methodologies at the regional level are relatively well worked out [15, 17-19], recent methodological elaboration of MLU at more detailed spatial levels is still relatively scarce [20, 21]. Because this is a logical level for energy farming, we focus on the land unit level within the context of a land holding or group of land holdings, and develop tools for land managers for the introduction of MLU within their holdings. MLU sustainability in biophysical and socio-economic terms should also be guaranteed, at the land unit as well as the land holding level [22]. Therefore, not only biophysical aspects of MLU deserve attention, but also the socio-economic consequences of MLU for the land holding. Because this study concentrates on the opportunities to make the concept useful for the production of biomass for energy in MLU systems, we focus on rural non-built-up land.

Definitions of multiple land use and other terms relevant to this study are first presented in Section 2. An essential element of our definition is that MLU combines different functions. To this purpose, a classification of functions is needed, which is discussed in Section 3. Section 4 contains a procedure for the introduction of MLU systems in existing land holdings. Section 5 deals with the problem of optimisation of a land use system with more than one target, a typical characteristic of MLU systems. Section 6 contains two illustrations how the formulated concepts can be applied, and in Section 7, some conclusions are drawn.

2. Multiple land use: definitions

Our definition of multiple land use is *land use aimed at the generation of more than one type of product and/or service*. It is a way of combining functions, in which a function is defined as the relation between land resources and human activities, providing goods and services for the satisfaction of human needs (derived from [23]). The term 'function' is almost equivalent to 'land use'. However, 'land use' and related terms as 'land utilisation type' have a more technical and biophysical character, whereas 'function' is a more general term often used in policy documents. Some further delineations of the multiple land use concept are the following.

Multiple land use concerns a combination of *activities* aimed at more than one *type* of product and/or service. This implies that e.g. the cultivation of wheat for both flour and straw, is *not* multiple land use, but multiple crop use. A major difference between MLU and multiple crop use is that in multiple crop use, a single crop with specific land use requirements yields different products, which can not be varied by shifts in land use requirements, only by variety choice and post-harvest processing. In MLU, changes in land management lead to changing ratios in generated products or services.

Multiple land use can occur at different spatial levels. For example, a meadow managed for providing roughage for cattle and habitat for meadow birds is MLU at the land unit level [24]. And a dairy farm providing small campsites is an example at the land holding level [8]. A regional groundwater system managed for two or more spatially separated but hydrologically interrelated functions, can be regarded MLU at a regional level [15]. As argued in the introduction, we focus on the land unit level within the context of a land holding or group of land holdings.

Whether a specific land use is considered multiple or not may be a matter of perspective. For example, a low-input farming practice that co-generates specific nature qualities may be considered MLU by a nature conservation organisation, while the farmer involved may not have the explicit target to produce those nature values. Particularly for policy purposes, there may be a need to guarantee that all functions are significant. This will be the case when the generated products or services are not only specified, but also valued. Especially for public goods, this implies a valuation process in which 'consumers' are involved [25].

Multiple land use goes beyond agriculture meeting compulsory, general standards of environmental protection and sustainability. Also, it surpasses approaches in which environmental criteria such as nutrient leaching or impacts on biodiversity are included to evaluate agricultural practice [26-29]. Often, these standards and criteria do not necessarily include the total set of requirements associated to the generated product or service, making it difficult to assess the consequences for this product/service when objectives are not met. In multiple land use, generated products and services are defined, including all corresponding land use requirements. The effects of compromises between different targets on products or services can be made explicit.

Some other definitions: a land holding includes complexes of land units managed by one actor. The land holding can be a farm, a system of nature areas managed by a nature conservation organisation, etc. We use the term land manager to identify any person or agency managing a land holding or a part of it.

3. Classification of functions

An MLU system should combine functions that differ in their type of product or service as well as in their land use requirements. Therefore, a classification of functions is needed based on this criterion. Kolk and Dekker [23] give an overview of function classifications, mainly based on Dutch literature. For the purpose of MLU, a classification should meet the following criteria:

- The classification consists of functions of rural, non-built-up land. Housing, transport infrastructure and industry are not included, nor non-terrestrial functions.
- It distinguishes local functions; i.e. the land use can be described for a land unit or a land holding. Functions that are only fulfilled at a regional level, e.g. storage of drinking water in a regional groundwater system, must be translated into local targets or requirements.
- The classification distinguishes functions at a proper aggregation level. This is a policy relevant choice: an authority willing to subsidise MLU may need a classification that reflects its view on what is MLU and what not. For example, in agricultural policy the mixed farm, producing dairy products as well as food crops in one holding, may be classified as MLU. In spatial planning the mixed farm may not be classified as such.
- Within these limitations the classification should be homologous, distinctive and exhaustive[1].

Table 2.1 gives an illustrative classification for functions in multiple land use systems, based on MLU combinations found in literature and practice [7, 30-33].

4. A procedure for the design of multiple land use systems

We developed a procedure for a systematic design of MLU systems at land unit level in the land holding context. It contains many definitions and concepts developed in FAO land evaluation and land use planning procedures [14, 34]. Furthermore, FAO and related procedures pay attention to biophysical sustainability, by matching of Land Use Requirements (LURs) to available Land qualities (LQs) [35], as well as sustainability in the farm's socio-economic setting [36]. However, the FAO work lacks explicit attention for MLU development. The procedure also contains elements from studies on MLU on a regional scale [19] and on environmental utilisation space operationalisation [37].

---

[1]: According to Kolk and Dekker (1999) a function classification should meet the general criteria of homology, exhaustiveness, distinctiveness, richness and universality. The first three criteria are relevant to this study.

Table 2.1: Example of a function classification for multiple land use at local (subregional) level, on non-built-up rural land.

Main group	Function	Examples
Goods	Production of biomass	*Food crop production, diary farming* *Biomass production for energy* *Forestry*
	Extraction of abiotic renewable resources	*Storage and extraction of drinking water*
	Extraction of non-renewable resources	*Quarrying of sand or other soil materials*
	Waste treatment	*Waste water purification* *Soil decontamination*
	Waste disposal	*Waste landfilling*
Services	Recreation facilitation	*Providing facilities for recreation*
	Protection	*Diking* *Creating buffer space for excessive water supply*
	Nature management and conservation	*Preserving or developing nature areas, small habitats, or ecological corridors*
	Conservation of culture and landscape	*Preserving or managing (historico-)cultural objects or landscape elements*

The procedure can be used in regions with a need for land use improvement, e.g. to change single-use agriculture that is not sufficiently profitable. It should help land managers, or groups of land managers, to explore the potentials to better reach their targets using MLU systems within their holdings. Such a process could be stimulated by governments, e.g. by facilitation, subsidies for research, or by valuing services of public interest.

The procedure is given in Figure 2.1. It starts with an inventory of the land holding's setting, including exogenous factors such as regional and national policies, regulations and subsidies. In this step, targets and constraints regarding available land and land qualities, capital and labour are also made clear. These serve as preconditions for the further process. The total setting is translated into targets, options and constraints for management at land holding and land unit level. For example, when a regional policy target is to increase the water retention capacity in the catchment, agreements between authorities and land managers can translate this policy into targets at land holding and unit level.

On the basis of this step, the potential for MLU is explored in three phases, with increasing complexity. These phases contain steps in which strategic choices are made, and steps in which these choices are worked out by applied research or information gathering. In complex projects the research can be executed by researchers or consultants. Discerning these two different types of steps should enable to make a separation between a manager's preferences and (information) tools for decision making, keeping the key responsibility for management choices where it belongs.

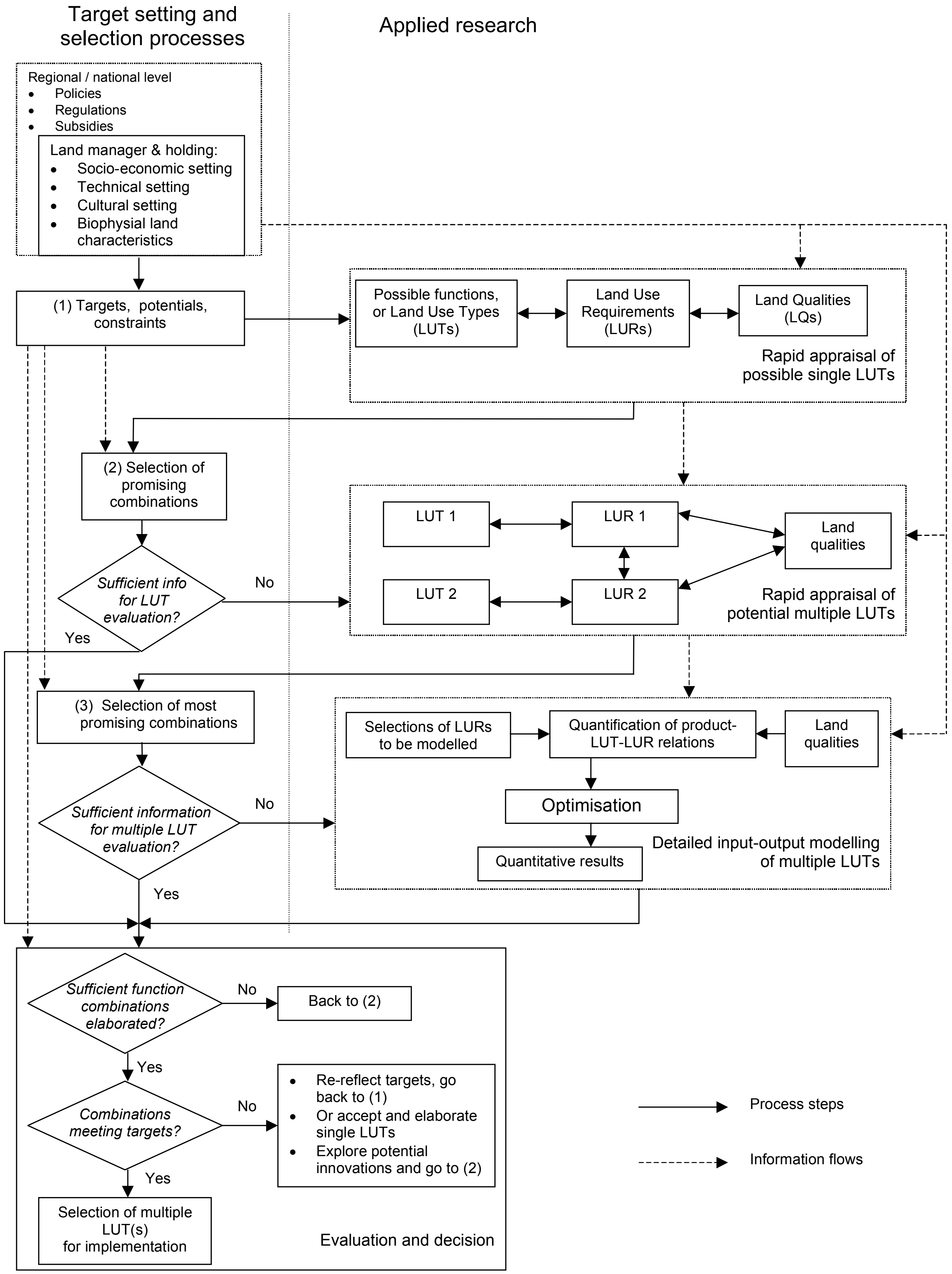

Figure 2.1: Procedure for the design of MLU systems at land unit level within a land holding.

The three exploration phases are as follows:

- First, a rapid appraisal of possible single Land Use Types (LUTs), 1 in Figure 2.1. This entails the identification of relevant (new) single-use LUTs related to goods and services to be (potentially) produced, and a rough comparison of their Land Use Requirements (LURs) to the land qualities (LQs) of the available plots. In this stage, requirements applying to other plots within the land holding should also be identified. For example, the need to re-use animal manure produced in dairy farming may entail targets for fertilisation of land units other than meadows.
- After this single LUT rapid appraisal, a first selection of promising function combinations takes place, 2 in Figure 2.1. In the second applied research stage, a rapid appraisal of multiple LUTs, single LUTs that may be combined are assessed in qualitative or semi-quantitative terms according to the compatibility of their LURs. Different LUTs should preferable be elaborated at the same level of detail. For this assessment, the sets of LURs of the different LUTs are compared to each other. For each single land use type may need to be completed with LURs of the other LUT with which it is to be combined. This to provide the information, necessary for assessment of the combination, but easily overlooked in a single LUT assessment. When, for example, agricultural land will be co-used for recreational purposes, accessibility may be a requirement. Then, it should be evaluated to what extent threading represents negative impacts to the agricultural function.
- The multiple LUT rapid appraisal leads to a second selection of the combinations that are most promising. If more detail is considered necessary, these combinations are elaborated in more detail: input-output relations are modelled, leading to an elaborate design for such a combination (3 in Figure 2.1). Trade-offs between conflicting LURs of different LUTs can then be analysed more quantitatively, and the system as a whole can be optimised.

After every phase the land holder (or group of holders) evaluates whether proposed (multiple) LUTs can be integrated in the holding, given its potentials and constraints in technical and socio-economic terms. The land holder (or group) can decide when to stop the process and move forward to the evaluation and decision phase. This in case he has a sufficient impression of MLU potentials for his situation, and either concludes that the proposed options are not sufficiently contributing to his targets, or that he has sufficient information to start introducing MLU systems. Only when more detailed information is needed, the next applied research step follows.

The biophysical sustainability of MLU systems is guaranteed by matching the combined system’s LURs to the available land qualities, as in the FAO methodology. If the total set of LURs exceeds the available land qualities, either targets have to be tuned down, or the combination is unfeasible. Furthermore, the land manager judges whether proposed multiple LUTs meet his constraints and targets in terms of e.g. available labour, capital, knowledge, and financial benefits, thereby assessing socio-economic sustainability.

Technological innovations can lead to changes in trade-offs between functions. When two functions compete on a certain land quality, such innovations may alter the relation between a LUT and its LURs, and therefore its dependency on the land qualities. Consequently, balances and trade-offs may change, and a formerly not accepted combination may become attractive. This option is included in the final decision making process.

Research work done in a certain context can be transformed to ready-made 'building blocks' of multiple LUTs, and offered to any manager as scientific input [5]. Such a prepared multiple land use type can be designed as a 'fixed' unit: a clearly defined multiple land use type designed to deliver a fixed amount of two or more products or services. One could also try to make a function combination more flexible, and let the optimisation (and possible trade-offs) depend on the specific context of the management system (Section 5).

The proposed procedure may seem complex and data-intensive. Therefore, it will primarily be suited for groups or associations of farmers, who can initiate a project of certain significance. A single land holder may use it in a very simple form, or may benefit from newly developed multiple LUTs from such projects [38].

5. Optimisation of combined land use types

In the detailed modelling step of the procedure in Section 4, multiple land use systems need to be optimised for the total set of involved functions. There will be cases in which functions have conflicting LURs, and trade-off must be made. This is particularly difficult when one of the function outputs (e.g. nature or landscape qualities) can not be directly valued in terms of a market price or otherwise quantified. In such a situation, a government may facilitate an optimisation. In this context, we can classify such a facilitation on two axes (see Table 2.2), resulting in four ideal types:

- Steering by command and control versus economic instruments. These are the two main types of instruments in environmental policy (next to other instruments like education and voluntary approaches, [39]). Economic instruments, such as levies and subsidies, are tools to value function outputs that can not be directly valued by a market price. Command and control measures such as regulations and standards circumvent this problem.
- Rewarding on results, e.g. the output in terms of a product or service, versus rewarding behaviour e.g. adapted inputs in terms of materials or activities. This distinction is made in agency theory, a commonly used organisation theory [40], and is applicable to e.g. types of governmental support.

We shortly illustrate the resulting four types of optimisation for a combination of two LUTs. In the examples, both LUTs have a land use requirement (LUR) on the same resource. The management to meet this requirement (the x-axis) can vary, thereby changing the balance between the two LUT performances. Note that, in each different situation on the x-axis, we assume that further activities are optimised for that situation. When, for example, changing fertilisation inputs on grassland, mowing intensity is adapted to resulting productivity. This also implies that the curves in the Figures are not by definition applicable to single-use situations.

Table 2.2: Four types of optimisation, depending on the type of government steering .

	Rewarding result (output)	Rewarding behaviour (input)
Economic instruments: steering via subsidies, levies, etc.	1. For all functions, the relation between management and result is quantitatively known Outputs of all functions are valued in financial terms	3. For some functions (I), the management-output relation is known quantitatively, for others (II) only qualitatively For (I), output is valued financially, for (II), specific management is valued financially
Command and control: steering via standards and regulations (possibly combined with a sanction)	2. For all functions, the relation between management and result is quantitatively known For outputs of one or all functions, standards are set	4. For some functions (I), the management-output relation is known quantitatively, for others (II) only qualitatively For (I), standards are set on output, for (II), a standard is set on management

1. Economic instruments for result rewarding are possible when the relation between LUR and output is known quantitatively for both functions, and their results are translated into a financial performance. Optimal MLU is then simply defined as that state of management in which total performance of all LUTs is as large as possible (see Figure 2.3). This optimum, however, may be reached when both individual LUTs perform sub-maximally. This strategy is used in e.g. nature production payment (see Box 1).

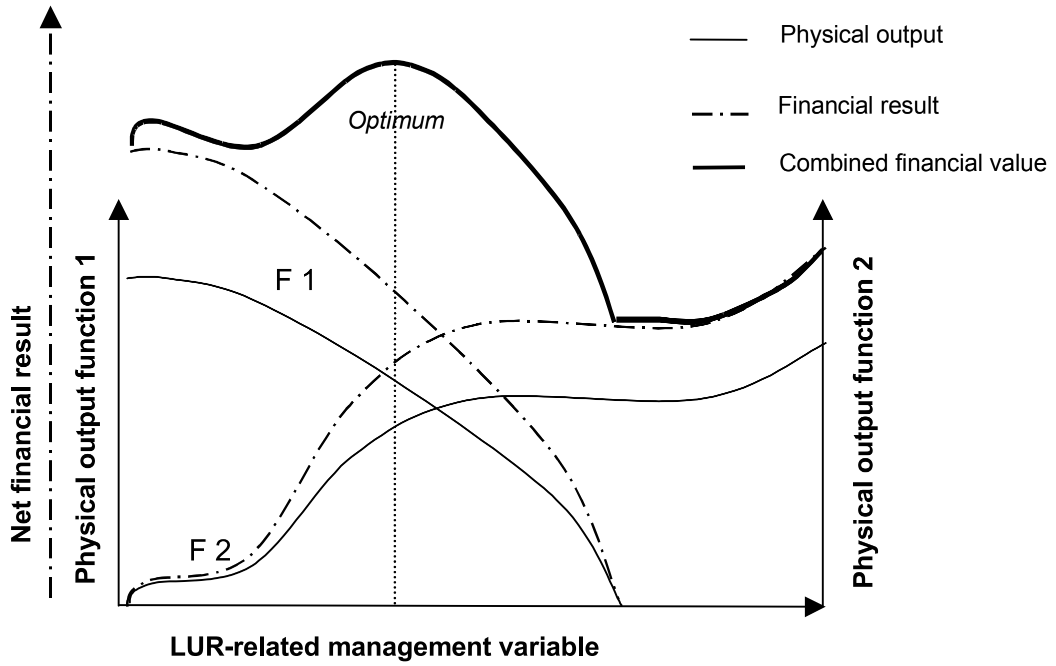

Figure 2.2: Optimisation by economic instruments rewarding outputs

Box 1: Meadow birds as a farm product [41, 42]

Since the beginning of the 1990's, several experiments have been carried out in the Netherlands to stimulate dairy farmers in protection of meadow birds by granting output-dependent rewards in stead of restricting the farmer's agricultural activities. In most cases, the payment depends on the number of incubated clutches. Payments per clutch vary from ca € 15 for common meadow birds such as Oystercatcher *Haematopus ostralegus* and Lapwing *Vanellus vanellus* to ca € 100 for rare species such as Garganey *Anas querquedula* and Ruff *Philomachus pugnax.*

The philosophy behind this strategy is that each individual farmer fine-tunes his management, dependent on yearly and local circumstances, in order to enhance breeding success and minimise production losses. A small-scale evaluation of system effectiveness indicated that breeding success was significantly higher when farmers were paid than when they were not. Product losses were relatively low compared to other bird protection policies. A significant cost item was the time farmers spent spotting clutches.

2. Steering by standard setting on results is an option when the relation between LUR and output is known quantitatively, but function outputs cannot be determined in a shared (financial) unit. For example, products such as managed nature or recreation are still hard to monetarise. In this case minimum output standards for the functions concerned are defined. These performances can be expressed in economic terms, e.g. a minimum profit for biomass production, or in (ecological) standard setting, e.g. a minimum biodiversity quality standard. Note that this is a normative step, which can be set by the land manager, or be given by an authority. Such a minimum performance for a certain function also defines the maximum performance of the other function. The range of LURs in which all minimum function performances are met can be regarded as an actual multiple land use space. The actual MLU space delineates a freedom of movement for management activities to produce an MLU system. If this MLU space does not exist, the combination is impossible, given the applied standards. The strategy is illustrated in Figure 2.3. An example can be found in multifunctional woodland management by the Dutch State Forestry Service (see Box 2).

Box 2: Standard setting on biodiversity output in multiple woodland management [9, 43]

The Dutch nature policy tends towards result rewarding in nature management. In woodland management, this has enhanced the development of methods to make nature qualities of multiple use woodlands more concrete. In these methods, biodiversity is specified in terms of (ecological) groups of birds, mammals, and other fauna and flora. Per group, relevant field characteristics are identified, and related to management activities. Thus, variables that are also relevant for wood productivity can be identified.

Currently, these methods merely serve as a tool for woodland managers to gain insights in the balance between productivity and specific nature qualities. However, the government can use such a method to set standards on the biodiversity results, on productivity, or on both.

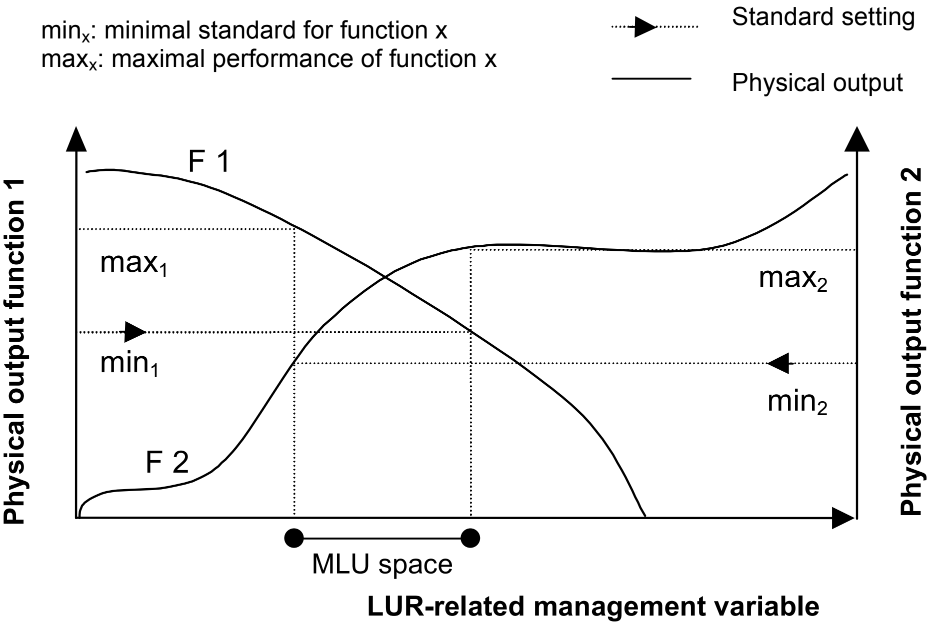

Figure 2.3:Optimisation by command and control on outputs.

3. Sometimes, functions cannot be quantified in terms of clear outputs or quantitative input-output relations. In such cases, rewarding on management (input) is more appropriate than rewarding outputs [44]. Economic instruments, in such cases, can reward specific management adaptations, on the basis of a qualitatively estimated relation between management and function output (see Figure 2.4, in which this is done for one of the two functions). In conventional nature conservation policies in the Netherlands, this has been common practice (see Box 3).

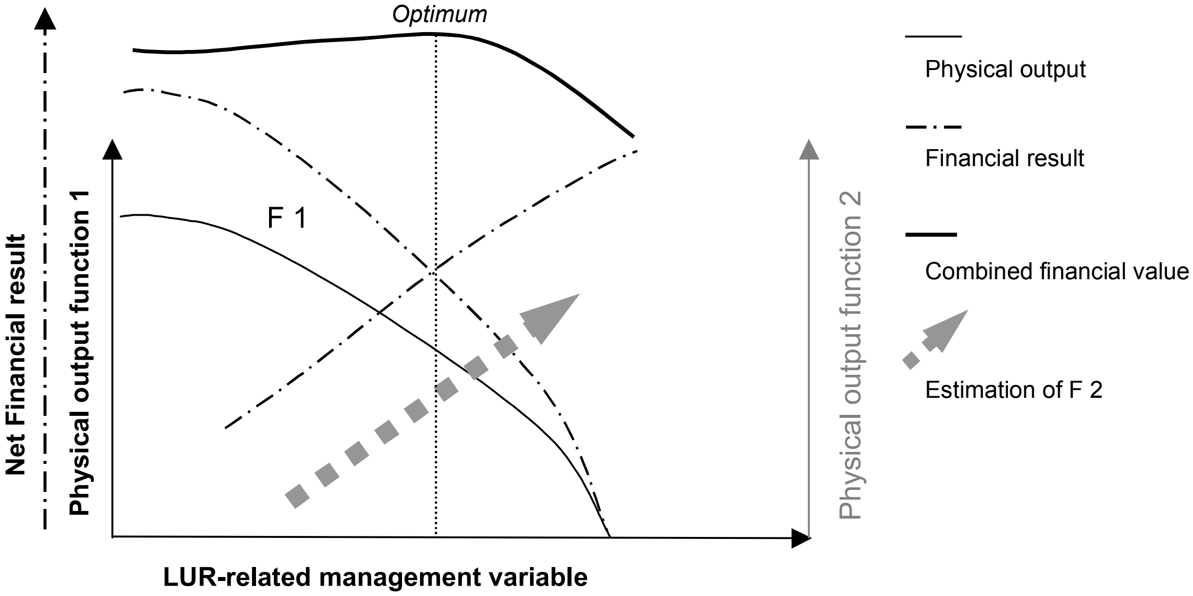

Figure 2.4:Optimisation by economic instruments rewarding input of one of the LUTs.

Box 3: Steering on input in Dutch nature management on the farm [45, 46].

Traditional Dutch subsidy regulations for nature management on the farm are input-orientated. This policy, which started in 1975 with the Policy Document on Agriculture and Nature Conservation, does not contain targets in terms of species diversity: it grants compensating subsidies for farmers who adopt measures considered beneficial for nature but restricting productivity. For example, the management packages for meadow bird protection restrict mowing, pasturing, fertilising and other activities during the breeding season. The corresponding subsidy depends on meeting these restrictions. Whether taken measures actually enhance meadow bird densities, is not checked per land unit or holding, only in regional studies [47].

4. Rewarding input is also possible in a standard setting approach. In such a case, a limitation is set on management inputs, again deduced from a qualitative insight in the corresponding function input-output relation (see Figure 2.5). In conventional multiple use woodland management, this has been a common approach (see Box 4).

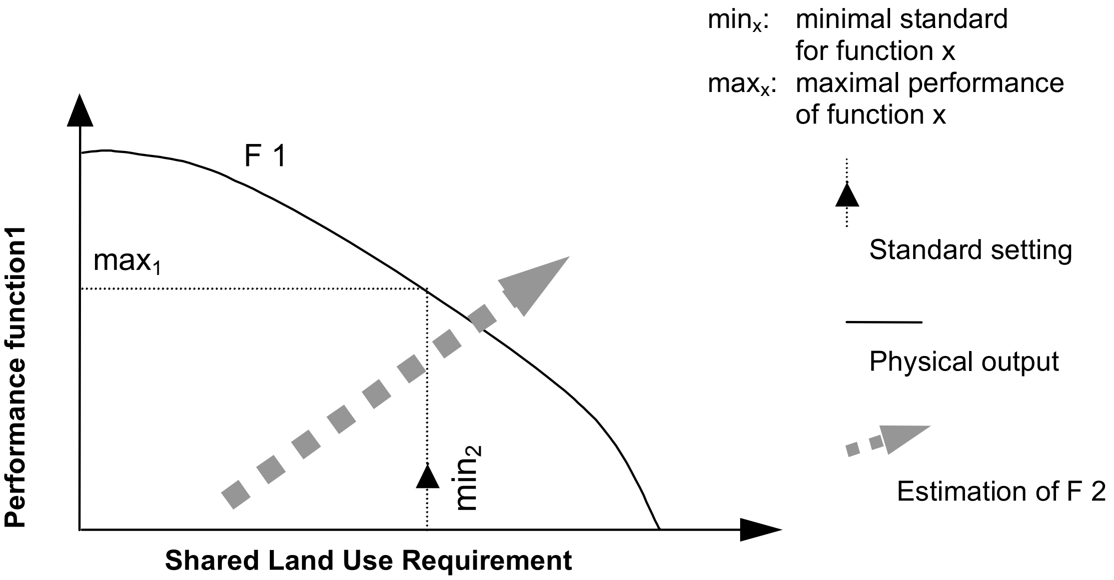

Figure 2.5: Optimisation by command and control on management input of one of the LUTs.

Box 4: Conventional nature and multiple use woodland management

In conventional nature and multiple use woodland management, authorities granted multi-annual subsidies and other facilities to nature management organisations on the basis of management plans that were mainly defined in management activities, not in targets on resulting flora and/or fauna. In recent years, there is a shift towards evaluation on output.

Obviously, the four strategies are ideal types within a spectrum. For example, in a case with command and control standard setting and a financial fine on standard exceedance, this fine can serve as an indirect pricing of the concerned function, and thereby come close to an economic instrument. And on the other axis, the line between inputs and outputs is sometimes hard to draw. While e.g. fertiliser application and biomass yield are clear examples of input and output, respectively, field characteristics like planting density or vegetation structure can be considered either input (e.g. for related fauna) or output (e.g. as characteristic of landscape quality).

6. Applications [2]

The procedure, as proposed in section 4, has not yet been applied fully. In several other studies, we have elaborated elements of it, in particular the rapid appraisal and detailed modelling of multiple LUTs, combining the production of biomass for energy with other functions [32, 48, 49] (chapters 3-5). Two examples are shortly dealt with here.

An example of a 'rapid appraisal' of a multiple land use type is presented in Table 2.3. Logically, '1/0' and '0/1' LURs can be combined. Potential conflicts are indicated as LURs with a '1/1' combination. As shown, the LUTs biomass energy production and groundwater extraction for drinking water can be combined according to most LURs. Four of them require further attention, viz. fertilisation, weed and pest/disease control, and ploughing activities. A further analysis [49] showed that, also on the basis of these LURs, the two LUTs could be integrated.

In a more detailed, quantitative modelling study on a specific LUR we concentrated on potentials to introduce willow energy farming on lands with poor drainage, that serve as buffer areas between vulnerable groundwater-dependent nature reserves and well-drained agricultural lands [32].

Figure 2.6 (next page) shows that, with decreasing groundwater table class and corresponding increasing soil humidity, relative willow yields decrease. In this case, the other land use type (the buffering of a nature reserve) can only be made explicit in terms of the input parameter groundwater table class. For this LUT, rewarding input is therefore more opportune than rewarding results. For comparison, relative yields of grassland (currently the dominant crop on lands with poor drainage) are also depicted in Figure 2.6; these appear to decrease stronger than those of willow, indicating that willow is better adapted to wet conditions than grass. Financial calculations indicate that, as a result, the biomass price paid to a farmer to make willow cultivation equally competitive to grassland decreases with increasing soil humidity.

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[2] : In order to make this chapter suitable for publication as an article, we included some application examples. Obviously, more details about the applications can be found in Chapters 3 to 5.

Table 2.3: Example of a rapid appraisal of a multiple LUT: biomass for energy combined with groundwater extraction. Source: [49] (Chapter 3)..

Product/service:	Biomass for energy [1]	Clean groundwater suitable for consumption [1]
LUT:	Willow plantation	Groundwater layer
Land use type characteristics	High productivity per ha Mechanical management	Water is extractable Water is and remains clean
LURs: land use requirements		
Land characteristics:		
1. Area size	1	1
Specification:	10 – 100’s ha	10 – 100’s ha
2. Edge-to-area	0	0
3. Soil type	0	0
3a Soil type drillability	0	1
4. Groundwater table	1	0
5. Extractable groundwater volume	1 see text	1 see text
Land design/arrangement		
6. Willow species	1	0
7. Planting density	1	0
8. Planting structure	1	0
Land management		
9. Fertilisation	1	1
Specification:	see text	see text
10. Weed control	1	1
Specification:	see text	see text
11. Pest/disease control	1	1
Specification:	see text	see text
12. Rotation	1	0
13. Ploughing of soil	1	1
Specification	max. ca 1 m	<2.5 m

[1]: The digit 1 indicates that the LUT sets a (positive or negative) demand on this requirement, a 0 indicates indifference. A combination 1-1 is a potential conflict

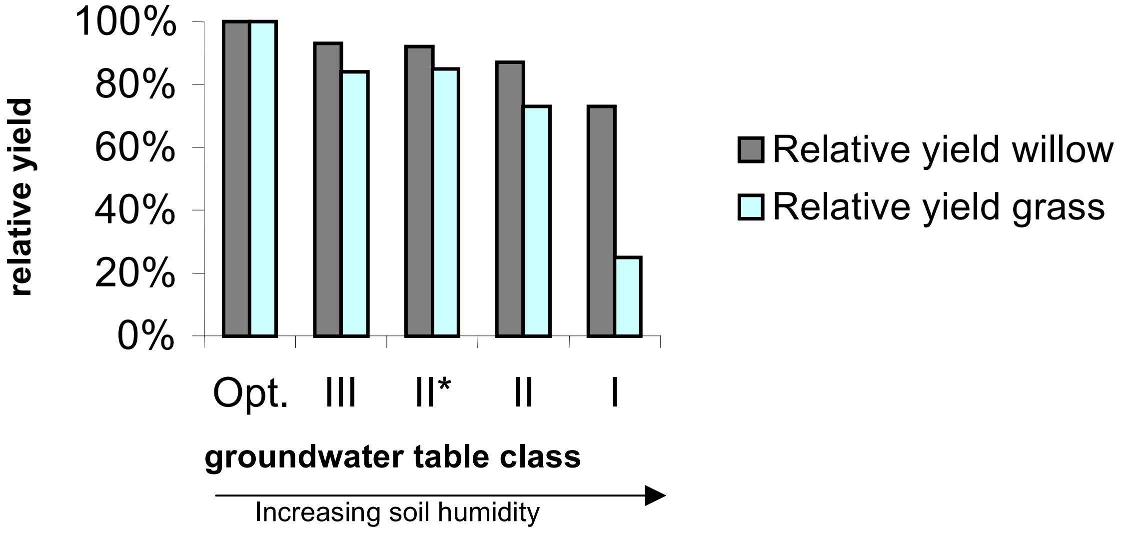

Figure 2.6: Relative willow and grass yields as a function of groundwater table class for a peat-on-sand soil in the Netherlands. Source: [32].

7. Conclusions

Multiple land use has been an ill-operationalised term, particularly at land unit level. The set of definitions and procedures in this study can make the concept more useful for land holders in the specific context of their holdings.

We define multiple land use as land use aimed at the generation of more than one type of product and/or service. It can be a tool to combine functions, where a function is the relation between land resources and human activities, providing goods and services for the satisfaction of human needs. Part of the operationalisation should be a classification of functions, for which some essential criteria have been discussed.

The procedure presented can be helpful for land managers to explore the biophysical and socio-economic potentials of multiple land use systems within their land holdings, and to steer the (technical) development of such systems. Since it starts with an inventory of policies and targets on national and regional levels, it leads to multiple land use systems that are socially relevant. In the procedure, the well-known FAO analytical framework (from products, via Land Use Type to Land Use Requirements to be matched to Land Qualities) is applied to explore the compatibility of functions. Depending on the complexity of the system, scientific input can be an important element of the procedure in terms of applied research and information gathering, whereas land managers obviously make the decisions themselves.

Attention to the sustainability of multiple land use is paid in two ways. Biophysical sustainability is evaluated by matching of the multiple LUTs to the available land qualities. Socio-economic sustainability within the land holding is evaluated by checking whether the proposed multiple LUT can be integrated in the holding, given its potentials and constraints in technical and socio-economic terms.

Optimisation of multiple land use systems with functions competing for a shared land use requirement can use at least four strategies, specified in economic instruments vs. command and control, and in rewarding results or management inputs. For these four strategies we developed tools for optimisation of the system as a whole. The applicability of the four strategies mainly depends on choice to quantify or qualify function outputs and input-output relations, and the possibility to express them either in a monetary or non-monetary parameter.

Acknowledgements

The authors would like to thank Drs. Wim ter Keurs (Leiden University, Environmental Biology) and Prof. Dr. Hans de Kruijf (Utrecht University, Department of Science, Technology and Society) for their useful comments.

References

1. RMNO. *Meerjarenvisie 1996: Ruimte voor ecologische modernisering. Samenvatting. (Multi-year vision 1996: Space for ecological modernisation. Summary).* Rijswijk: RMNO, 1996.
2. Anonymous. *Ruimte maken, ruimte delen; Vijfde nota ruimtelijke ordening (Making space, sharing space; fifth policy document on spatial planning).* The Hague: Ministry of Public Housing, Spatial Planning and Environment, 2000.
3. Janssen, E. and I. Südmeier. *Het gelaagde landschap; meervoudig ruimtegebruik in perspectief (The layered landscape: multiple space use in perspective).* Gouda: Expertisenetwerk Meervoudig Ruimtegebruik i.o., 2000.
4. Ministries of LNV, VROM, V&W, and OS. *Natuur voor mensen, mensen voor natuur; nota natuur, bos en landschap in de 21e eeuw (nature for people, people for nature; policy document on nature, woodlands and landscape in the 21st century).* The Hague: Ministries of Agriculture, Nature Management and Fisheries, of Public Housing, Spatial Planning and Environment, of Transport, Public Works and Water Management, and of Development Cooperation, 2000.
5. Graaf, H.J. de and C.J.M. Musters. *Exploration of the potential regional benefits of multiple land-use.* In: Graaf, H.J. de, C.J.M. Musters, and W.J. ter Keurs. *Regional opportunities for sustainable development; theory, methods, and applications.* Dordrecht: Kluwer Academic Publishers, 1999.
6. Dekker, J. *Het multifunctionaliteitsprincipe in het beheer van de natuur (The principle of multifunctionality in management of nature).* In prep.
7. Luttik, J. and J.T.C.M. Sprangers. *Combineren met natuur; Economische, sociale en ecologische duurzaamheid van functiecombinaties (Combining with nature: Economic, social and social sustainability of function combinations).* Wageningen: SC-DLO, 1999.
8. Broekhuizen, R. van, L. Klep, H. Oostindie, and J.D. van der Ploeg. *Atlas van het vernieuwend platteland (Atlas of the renewing countryside).* Doetinchem: Misset, 1997.
9. Boersma, F. and G. Kuipers. *Sturen op resultaat in multifunctioneel bos bij Staatsbosbeheer (Steering on results in multifunctional woodland at the State Forestry Service).* Nederlands Bosbouwtijdschrift 1998, 70 (6): 262-268.
10. Hall, D.O. and J.I. House. *Biomass energy in Western Europe to 2050.* Land Use Policy 1995, 12 (1): 37-48.
11. Heuvel, E.J.M.T. van den and J.K. Gigler. *Is er grond voor biomassaproductie in Nederland? (Is there ground for biomass in the Netherlands?).* Utrecht: NOVEM, 1998.
12. Biewinga, E.E. and G. van der Bijl. *Sustainability of energy crops in Europe; a methodology developed and applied.* Utrecht: CLM, 1996.
13. Heineman, A., G. Saaltink, and L. Kuiper. *Energie uit biomassa in combinatieteelt (Energy from biomass in combination farming).* Wageningen: CPV/SBH, 1999.
14. FAO. *A framework for land evaluation.* Rome/Wageningen: FAO/ILRI, 1984.
15. Lier, H.N. van. *Meervoudig grondgebruik : syllabus colleges landinrichtingswetenschappen (Multiple land use: lecture notes course rural development sciences).* Wageningen: Wageningen Agricultural University, 1991.
16. Guttenberg, A.Z. *A multiple land use classification system.* Journal of the American Institute of Planners 1959, 25 (3): 143-150.
17. CMLI. *Perspectieven voor landinrichting; toekomst voor een multifunctionele landinrichting (Perspectives for rural development; future for a multifunctional rural development).* 's Graveland: Commissie Multifunctionaliteit Landinrichting, 1990.
18. Ministry of LNV. *Landinrichting in de jaren negentig (Rural development in the nineties).* The Hague: Ministry of Agriculture, Nature Management and Fisheries, 1992.
19. Arnold, G.E., T. Kroon, and R. van Eck. *Gewenste grondwatersituatie Noord-Brabant (Desired groundwater situation Noord-Brabant).* Lelystad: RIZA, 1998.
20. Graaf, H.J. de and C.J.M. Musters. *Resultaten project Duurzaam Landgebruik, fase B/C (Results project sustainable land use, phase B/C).* Delft: DTO, 1997.
21. DTO. *DTO sleutel 1, Voeden; spectrum van een duurzame voedselvoorziening.* Delft: DTO, 1997.
22. Kruseman, G., R. Ruben, A. Kuyvenhoven, H. Hengsdijk, and H. van Keulen. *Analytical framework for disentangling the concept of sustainable land use.* Agricultural Systems 1996, 50 191-207.
23. Kolk, A.J. van der and J.N.M. Dekker. *Functions in integrated region-oriented environmental policy: a classification system.* Land Use Policy 1999, 16 107-119.

24. Kruk, M. *Meadow bird conservation on modern commercial dairy farms in the western peat district of the Netherlands; Possibilities and limitations.* Leiden: Leiden University, Environmental Biology (thesis), 1994.
25. Graaf, H. J. de, C.J.M. Musters, W.J. ter Keurs, and M.A.W. Noordervliet. *In search of an Instrument for setting Development Goals of a Socio-Environmental System.* in prep.,
26. Berge, H.F.M. ten, M.K. van Ittersum, W.A.H. Rossing, G.W.J. van de Ven, J. Schans, and P.A.C.M. van de Sanden. *Farming options for The Netherlands explored by multi-objective modelling.* European Journal of Agronomy 2000, 13 263-277.
27. Tozer, P.R. and J.R. Stokes. *A multi-objective programming approach to feed ration balancing and nutrient management.* Agricultural Systems 2001, 67 201-215.
28. Meyer-Aurich, A., P. Zander, A. Werner, and R. Roth. *Developing agricultural land use strategies appropriate to nature conservation goals and environmental protection.* Landscape and Urban Planning 1998, 41 119-127.
29. Tiwari, D.N., R. Loof, and G.N. Paudyal. *Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques.* Agricultural Systems 1999, 60 (1999): 99-112.
30. Graaf, H.J. de, M.J.D. Hack, and O.C.H. de Kuijer. *Stimuleren van Meervoudig Duurzaam Landgebruik in de praktijk: toegankelijk maken en uitdragen van kennis, inzichten en methoden (Stimulating multiple sustainable land use in practice: making knowledge, insights and methods accessible and carrying them out).* Leiden / Wageningen / Amsterdam: Environmental Biology / SC-DLO / KDO Consultancy, 1999.
31. Roose, M. *Energieteelt in Multifunctioneel Landgebruik; evaluatie van een aantal mogelijkheden om de teelt van biomassa te combineren met andere functies (Energy farming in multi-purpose land use; evaluation of a number of options to combine biomass cultivation with other functions).* Utrecht: Utrecht University, Dept. of Science, Technology and Society, 1999.
32. Londo, M., L. Vleeshouwers, J. Dekker, and H. de Graaf. *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation.* Biomass and Bioenergy 2001, 20 (5): 337-350.
33. Vissers, J. (ed.), N. Hazendonk, W. de Haas, H. van Engen, and G.F.P. IJkelenstam. *Verweving van nutsfuncties en natuurfuncties; ideeën en voorbeelden van verweving van nutsfuncties en natuurfuncties voor ruimtelijke planvorming op lokale en regionale schaal (Interweaving of public interest and nature functions; ideas and examples of interweaving of public interest and nature functions for spatial planning on a local and regional scale).* Wageningen: IKC-Natuurbeheer, 1995.
34. FAO. *Land evaluation for forestry.* Rome: FAO, 1984.
35. Beek, K.J., K. de Bie, and P. Driessen. *Land evaluation for Sustainable Land Management.* Enschede: ITC, 1997.
36. Sharifi, M.A. and H. van Keulen. *A decision support system for land use planning at farm enterprise level.* Agricultural Systems 1994, 45 239-257.
37. Musters, C.J.M., H.J. de Graaf, M.A.W. Noordervliet, and W.J. ter Keurs. *Measuring environmental utilisation space: Can it be done?* Milieu 1994, 9 (5): 213-220.
38. Visser, A.J. and G. Migchels. *PPO/PV Onderzoeksprogramma Multifunctionele Bedrijfssystemen (PPO/PV research programme Multifunctional Farm Systems).* Lelystad: PPO, PV, 2001.
39. Barde, J.P. *Environmental policy and policy instruments.* In: Folmer, H. and H. Landis Gabel. *Principles of Envionmental and Resource Economics.* Cheltenham: Edward Elgar, 2000. 157-201.
40. Hendrikse, G.W.J. *Moderne organisatietheorieën (modern organisation theories).* Schoonhoven: Academic Service, 1998.
41. Musters, C.J.M., M. Kruk, H.J. de Graaf, and W.J. ter Keurs. *Breeding birds as a farm product.* Conservation Biology 2001, 15 (2): 363-369.
42. Mugge, F.L.T., W. van Harmelen, M.Kruk, H.J. de Graaf, and W.J. ter Keurs. *Natuurproduktiebetaling; een bruikbaar instrument voor het agrarisch natuurbeheer? Een evaluatie van de experimenten en een vergelijking met andere systemen van agrarisch weidevogel- en slootkantbeheer (Nature production payment, a useful instrument for nature management on the farm? An evaluation of the experiments and comparison to other systems of meadow bird and ditch bank management on the farm).* Leiden: Leiden University, Environmental Biology, 1996.
43. Hekhuis, H.J., J.G. de Molenaar, and D.A. Jonkers. *Het sturen van natuurwaarden door bosbedrijven (Steering of nature values in forestry).* Wageningen: IBN-DLO, 1994.
44. Eisenhardt, K.M. *Agency theory: An Assessment and Review.* Academy of Management Review 1989, 14 (1): 57-74.

45. Ministries of L&V, CRM, and VRO. *Nota betreffende de relatie landbouw en natuur- en landschapsbehoud (Policy document on agriculture and nature conservation).* Tweede Kamer 1975, 1974-1975 (13 285, nrs 1-2):
46. Anonymous. *Subsidieregeling Agrarisch Natuurbeheer (subsidy regulation nature management on the farm).* Den Haag: Ministry of Agriculture, Nature Management and Fisheries, 2000.
47. Graaf, K. de. *Een evaluatie van studies naar de effectiviteit van agrarisch natuurbeheer.* Utrecht: NW&S, 2001.
48. Londo, M., W. ter Keurs, and J. Dekker. *Willow Short Rotation Coppice for energy and breeding birds: An exploration of potentialsin relation to management.* Submitted to Biomass and Bioenergy.
49. Londo, M., M.E. Roose, J. Dekker, and H. de Graaf. *Willow short rotation coppice in multiple land use systems: evaluation of four combination options in the Dutch context. Submitted to Biomass and Bioenergy*.

Chapter 3

Willow short rotation coppice in multiple land use systems: Evaluation of four combination options in the Dutch context[*]

Abstract

Introduction of energy crops in multiple land use might be an opportunity to increase overall land use efficiency, improve energy crop competitiveness and thereby enhance their introduction in regions with intensive land use in all sectors, such as Northwest Europe. In this study, we assessed biophysical feasibility, effects on financial competitiveness, and potential area of four land use combinations for willow short rotation coppice in the Netherlands: with groundwater quality protection, drinking water production, conservation of traditional willow coppice flora and fauna, and an ecological corridor function.

Biophysically, almost all combination options are feasible, although some have sub-optimal willow yields. Technical innovations can improve chances for the non-feasible option. The willow SRC option in groundwater extraction areas gives improved competitiveness compared to single land use, expressed in a lower willow break-even price. For the other options, this is hardly the case. The total of potential area for all biophysically feasible combinations could significantly contribute to the Dutch renewable energy targets, but the area with improved competitiveness is only a minor share of this.

Keywords: Willow short-rotation coppice, groundwater protection, drinking water production, traditional willow coppice, ecological corridors, multiple land use.

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[*] Co-authors: Michelle Roose, Jos Dekker (both Dept. of Science, Technology and Society, Copernicus Institute, Utrecht University) and Hans de Graaf (Section Environmental Biology, Institute of Evolutionary and Ecological Sciences, Leiden University). Submitted to Biomass and Bioenergy.

1. Introduction

Land, as a resource to fulfil human needs, has become increasingly scarce in a densely populated country like the Netherlands [1]. This can be observed in rising land prices and increasing land use efficiency and intensity, in agriculture as well as other sectors. In this context, the introduction of energy crop cultivation (energy farming) as a new type of single land use will be difficult, especially since the value added of energy crops, compared to e.g. food crops, is relatively low.

The general urge for overall efficient land use can be an incentive for multiple land use: producing more than one type of product or service on the same tract of land [2]. Since the cultivation of energy crops like willow is generally described as low-input and environmentally friendly compared to common agriculture (e.g. [3]), combination with other functions may be an option. A wide range of combination options for energy farming has already been suggested [4-8]. Obviously, the assumption is that such combinations will be more efficient in a multiple land use system than in separated systems of single-use land.

In this study we apply the method developed in Chapter 2 [2] to explore the potentials of four options to combine willow in short rotation coppice (SRC) cultivation with another function. We evaluate the biophysical feasibility of each combination, i.e. whether both functions can be biophysically fulfilled together. Furthermore, we estimate whether combination of both functions is financially more attractive than separated fulfilment, or combination with other functions. We also estimate a potential land area for which each combination may be of interest. Apart from potential assessment the purpose of this work is also to evaluate usefulness of the proposed method.

Relevant methods are shortly described in Section 2. From a longlist of combination options [4] we selected four options for this study. This selection was based on our initial estimate of feasibility, and on data availability. The studied combinations are willow SRC with groundwater protection (Section 3), with drinking water production (Section 4), with conservation of the traditional willow coppice natural features (Section 5), and with an ecological corridor function (Section 6). We end with discussion and conclusions on the proposed methods as well as the application results.

2. Methods and general assumptions

Feasibility of a function can be evaluated in a broad range of terms, such as biophysical, financial, social and cultural criteria. In this study, we concentrate on a biophysical and financial analysis, leaving out e.g. individual preferences of land holders.

2.1 Biophysical feasibility

In Londo et al. [2] (Chapter 2) we have proposed a method for exploration of multiple land use options within a land holding (farm or comparable). After orientation and target setting, this method contains a ‘rapid appraisal’ phase for qualitative or semi-quantitative feasibility estimation of multiple land use types. For two functions, this phase can be schematised as in Figure 3.1. First, for each product or service to be combined, the Land Use Type (LUT) is specified: a general description of the land use delivering the product or service, such as ‘arable agriculture’, or ‘nature conservation’. These types are specified in their Land Use Requirements (LURs); i.e. the physical or other inputs or land characteristics necessary for the LUT. Examples of LURs are ‘a minimum fertilisation level of x kg N /ha.yr’, or ‘an average groundwater table of y cm below ground level’. Subsequently, the LURs are compared, to see whether they conflict or compete for a shared resource. If the requirements do not exclude each other, the combination is (biophysically) feasible. When applying a combination on a specific parcel (or in a region), the available land qualities should meet the combined set of LURs.

One can set the land use requirements of a LUT as fixed, inflexible demands related to optimal output, but it may be better to define them as variables: the range in which the corresponding LUT is still possible. This is because a combination in which both LUTs perform sub-optimally can still be interesting if the result as a whole is better than fulfilment in single use on the same area of land.

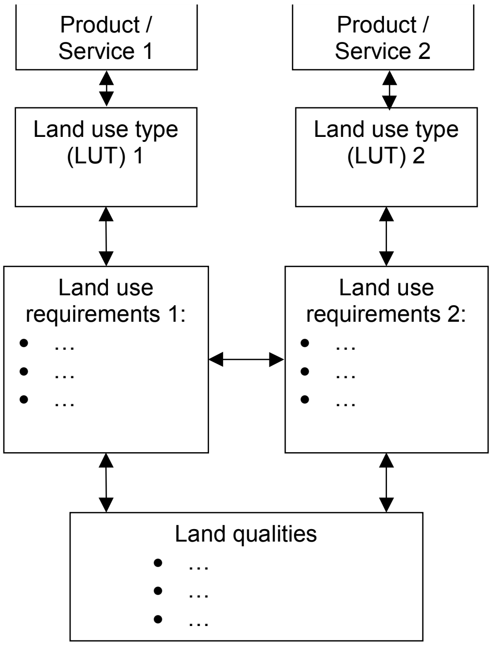

Figure 3.1: A rapid appraisal for potential multiple land use types [2].

In some cases, the question is not whether willow SRC combined with a specific function is biophysically feasible, but whether this combination is better feasible than the existing combination of e.g. common agriculture for food with that function. For example, Dutch lands surrounding drinking water extraction wells, on which special regulations apply for the use of fertiliser, are currently in use for common (arable and dairy) farming, and the question might be whether willow SRC can more easily deal with these regulations. In such cases, the procedure described above must be carried out for both combinations under study, and the feasibility of the two combinations should be compared.

2.2 Financial evaluation

Financial performance of multiple land use systems can be evaluated by a substitution costs method: Costs and benefits of the combined land use system are compared to those of two separated systems, both fulfilling one function [9]. This should be a comparison on an identical area basis, in which a combined land unit is compared to two single use units of the same area size in total. If the net balance of the combined system is better than that of separated systems, the combined option is simply more attractive (type I in Table 3.1). The comparison is easiest when, in both situations, one of the goods or services is generated in the same quantity.

An adapted version of the latter method should be applied when two multiple use systems are compared: Then the net balance of combination {1+2} should be compared to that of combination {1+3} (type II in Table 3.1). Again, this comparison should be made on areas of identical size, and comparison is easiest when the generated quantities of the shared function 1 are identical.

A disadvantage of the latter method is that two systems are compared that do not deliver identical sets of products and/or services. A large-scale shift from combination {1+2} to {1+3} may cause macro-economic effects such as changes in market prices, thereby changing inputs for the comparison. In this study, we do not deal with this effect: we assume that a shift to willow SRC systems, in whatever form, will develop at first on a relatively small scale, thereby having a negligible effect on market prices.

Table 3.1: Financial comparison of different land use types.

Type I: Comparison combined system (MLU) vs. separated systems (single LU)			
Land resource	Land unit (A+B)	Land unit A	Land unit B
Generated products	Product {1 + 2}	Product 1	Product 2
(partial balances)		$B_1 - C_1$	$B_2 - C_2$
Net balance[1]	$B_{1+2} - C_{1+2}$	$(B_1 - C_1) + (B_2 - C_2)$	
Type II: Comparison combined system (MLU) vs. other combined system (MLU)			
Land resource	Land unit (A+B)	Land unit (A+B)	
Generated products	Product {1+2}	Product {1+3}	
Net balance[1]	$B_{1+2} - C_{1+2}$	$B_{1+3} - C_{1+3}$	

[1]: *B:* benefits; *C:* Costs.

In type II comparisons, it is possible to calculate a willow *break-even price*: the price a farmer should be paid to make the option with willow financially equally competitive to the other option. When, for example, combinations {1+willow} and {1+common agriculture} deliver the same amount of product 1, and when the benefits of willow production are (physical) harvest times price, this break-even price $p_w^{e,mlu}$ can be calculated as in Equation I:

$$p_w^{e,mlu} = \frac{(B_{c.a.}^{mlu} - C_{1+c.a.}^{mlu}) + C_{1+w}^{mlu}}{y_w^{mlu}} \qquad \text{I}$$

y_w^{mlu} being the willow yield, $B_{c.a.}^{mlu}$ being the benefits of common agriculture, $C_{1+c.a.}^{mlu}$ being the management costs of the system {1+ common agriculture} and C_{1+w}^{mlu} the management costs of the system {1+willow}, all for the multiple land use systems (all quantities per ha.year).

Such a break-even price, indicating the competition between the two combined systems, should be compared to the break-even price when willow SRC in single land use competes with common agriculture in single land use ($p_w^{e,slu}$), which can be calculated by Equation II:

$$p_w^{e,slu} = \frac{(B_{c.a.}^{slu} - C_{c.a.}^{slu}) + C_w^{slu}}{y_w^{slu}} \qquad \text{II}$$

In which y_w^{slu} is the willow yield, $B_{c.a.}^{slu}$ the common agriculture benefits, $C_{c.a.}^{slu}$ is the management costs of common agriculture, C_w^{slu} the management costs of willow SRC, all for the single use systems.

If the break-even price in multiple land use ($p_w^{e,mlu}$) is lower than the break-even price in single land use ($p_w^{e,slu}$), willow SRC in MLU will be cheaper than willow SRC in SLU, and vice versa. In short, this ratio indicates the effect of the multiple land use option on willow SRC financial competitiveness.

In this kind of calculations, assumptions on the valuation of the farmer’s capital and labour are always subject to discussion [10]. These assumptions strongly influence the calculated break-even prices. However, for an indication of competitiveness improvement of energy crops we are merely interested in break-even price *differences* between the multiple and single land use options, which are hardly affected by the assumptions.

2.3 Assumptions on willow SRC

In the following sections, willow SRC as a land use type (LUT) is compared to other LUTs. Here, we shortly give the main land use requirements of willow SRC, as input for this comparison. For each LUR we estimate a range within which willow SRC is possible, and a value optimal for the cultivation.

Furthermore, we assume that, in the Dutch situation and with proper management, average yields of 10 odt/ha.yr are feasible [11]. When management is sub-optimal, yields will be lower. However, current knowledge is insufficient to predict exactly what yield a specific sub-optimal management set will give: in such cases, a yield reduction is estimated based on literature or expert guess. Costs of willow management activities were derived from Coelman et al. [12].

Table 3.2: Willow cultivation in SRC as a Land Use Type in the Netherlands: summary of Land Use Requirements, corresponding ranges and optima.

Variable	Range of tolerance[1]	Optimum	Ref.
Plantation area	10 – 100's ha	-	
Edge-to-area ratio	Perfectly square – irregular	Square	
Soil type	Practically any soil	-	
Groundwater table	'Moist-dry' (Dutch Groundwater tables I-V[2])	Gt III	[13]
Willow species and variety	S. viminalis, alba, diverse varieties	-	[14, 15] etc.
Planting density	5,000 – 30,000 cuttings/ha	Depends on variety and situation	[12, 14, 15]
Fertilisation	From absent to intensive	N: 60-120 kg/ha P: 20-50 kg/ha Dependent on e.g. soil type	[11, 13, 16]
Protection against weeds	From absent to intensive Chemically, mechanically	Intensive management in year of establishment. Thereafter willow outcompetes most weeds.	[17, 18]
Prevention/abatement pests/diseases	From prevention: Mixing varieties, using resistant varieties to (chemical) abatement	Prevention of severe outbreaks by variety choice and mixing	[14, 19, 20]
Rotation time	2-5 years	3-4 years	[11, 13, 16]

[1]: Within these ranges yield reduction may occur: this need not be problematic if the total performance of the combined LUT is better than that of separated single LUTs on the same amount of land (see 2.1).

[2]: In Dutch agro-hydrology, soil wetness is often expressed in groundwater table classes (Gt's). The lower the Roman number, the wetter the soil. Gt I: groundwater level in winter < 20 cm, in summer < 50 cm. Gt V: winter < 40 cm, summer > 120 cm.

3. Groundwater protection: groundwater protection areas

Circa 60% of total Dutch drinking water is produced from groundwater [21]. Furthermore, many nature reserves in the Netherlands depend on clean, nutrient-poor groundwater. In order to protect the quality of this resource, the regional governmental authorities (provinces) are obliged to assign *groundwater protection areas* (GPAs), relatively broad zones (>10 ha) around extraction wells or reserves, in which they can apply special regulations [22]. In total, there is circa 140,000 ha of GPAs in the Netherlands [23], mainly surrounding drinking water extraction wells. Several types of land use are still possible in these areas, including agriculture. However, the regulations can be a limiting factor, for example when fertilisation is restricted. This may generate a competitive advantage for willow SRC with its low inputs. In this section we compare willow SRC within the restrictions of GPAs to common agriculture within the same restrictions.

3.1 Biophysical feasibility

A comparison of land use requirements for willow SRC and groundwater protection is given in Table 2.3. The land use requirements of common agriculture are (qualitatively) identical to those of willow SRC, and are therefore not included in an extra column. Some shared requirements of willow SRC and groundwater protection, i.e. area size and ploughing depth, do not cause potential conflict. The extractable groundwater volume, fertilisation, and weed, pest and disease control need more attention.

Table 3.3: LUR comparison of biomass for energy and groundwater protection. The digit 1 indicates that the LUT sets a (positive or negative) demand on this requirement, a 0 indicates indifference. A combination 1-1 is a potential conflict.

Product/service:	Biomass for energy	Clean groundwater suitable for consumption [1]
LUT:	Willow plantation	Groundwater layer
Land use type characteristics	High productivity per ha Mechanical management	Water is extractable Water is and remains clean
LURs: land use requirements		
Land characteristics:		
1. Area size	1	1
Specification:	10 – 100's ha	10 – 100's ha
2. Edge-to-area	0	0
3. Soil type	0	0
3a Soil type drillability	0	1
4. Groundwater table	1	0
5. Extractable groundwater volume	1 see text	1 see text
Land design/arrangement		
6. Willow species	1	0
7. Planting density	1	0
8. Planting structure	1	0
Land management		
9. Fertilisation	1	1
Specification:	see text	see text
10. Weed control	1	1
Specification:	see text	see text
11. Pest/disease control	1	1
Specification:	see text	see text
12. Rotation	1	0
13. Ploughing of soil	1	1
Specification	max. ca 1 m	<2.5 m

[1]: Here, we mainly consider GPA for drinking water, not for groundwater-dependent reserves. Regulations in these areas are determined by provinces (regional authorities) and vary slightly per province. This table is based on the province Zuid-Holland 's regulations [24]. In these regulations, some specific types of land use are also banned (such as industrial activities, waste dumping, and graveyard establishment). These are not relevant in the case of combination with energy farming.

Extractable groundwater volume

Willow SRC as well as drinking water production extract groundwater from the soil. However, they do so from different soil layers; willow SRC uses shallow groundwater, while drinking water is mostly extracted from deeper aquifers, which makes them only indirectly competing. Furthermore, willow SRC water use is comparable to that of grassland, winter wheat, sugar beet and maize [3] which are common crops in GPAs. Considering the general precipitation surplus in the Netherlands, we assume that the LUTs are not conflicting on this requirement.

Fertilisation

Currently, each province has different standards for fertilisation in GPAs, mostly consisting of limitations on animal manure application in terms of a maximum amount of phosphate [25]. However, the Dutch government has introduced a new national nutrient policy, setting standards on ‘mineral losses’ [26]. This means that the net emission into soil and groundwater, i.e. the difference between mineral inputs (fertilisation) and outputs (yields), is limited. In general, these mineral loss standards will actually be more stringent than the current standards for GPAs [25, 27, 28]. Therefore we concentrate on loss standards in their currently proposed form. These standards apply nationally, not only on GPAs. However, meeting the standards will be of priority in these areas; therefore we use them as an illustration, although there is still discussion going on between the Dutch government and the EU whether the current system will be effective to meet the EU nitrate directive’s groundwater standard of 50 mg N/l [29].

A mineral account system (Minas) has been developed for determining losses, which farmers should apply to their whole holding. The corresponding loss standards will become more stringent each year up to the year 2003. For this study, we will use the final 2003 standards. Table 3.4 gives an overview of mineral balances for willow, arable land and grassland, and compares them to their corresponding 2003 loss standards. For willow, the balances were calculated, for arable and grassland, they were found in different surveys.

Table 3.4: Mineral losses (calculated by the Minas method) for willow SRC, arable and grassland.

Type of land use	N (kg/ha)		P_2O_5 (kg/ha)	
	Average	Range	Average	Range
Willow SRC				
Input (via fertilisation)[1]	100	60 – 120	30	20 - 50
Output (via yield)[2]	50	35 – 65	21	14 - 27
Loss	50	-5[4] – 85	9	-7[4] - 36
Loss standard (2003)[3]	100	-	20	-
Arable land				
Average (1998)[7]	90	[5]	-14[6]	[5]
Project practice data (1998)[8]	122	[5]	41	-25 – 350
Farmers group in GPA (1994)[9]	81	60 – 120	4	-20 – 30
Loss standard (2003)	100	-	20	-
Grassland (dairy farming)				
Average (1998)[7]	271	[5]	18[6]	[5]
Project practice data (1998)[8]	214	50 – 400	37	[5]
Farmers group in GWP area (1993)[9]	283	150 – 400	48	0 – 80
Loss standard (2003)	180	-	20	-

[1] These values are advised fertilisation levels from [3, 11, 16, 30].

[2] Assumptions: average yield of 10 odt/ha.yr [11], bad yield 7 odt/ha.yr, good yield 13 odt/ha.yr. Nutrient contents of harvested parts: 0.5% for N, 0.09% for P (on weight basis, [31]).

[3] Loss standard for arable land applied [32].

[4] A negative value means that the nutrient stock in the soil decreases.

[5] Not given.

[6] Phosphate in artificial fertiliser not accounted for.

[7] Source: random check by the Dutch agri-economic institute [33];

[8] Source: information on a project with 233 farmers, who, with limited support from the ministry of agriculture, try to decrease their mineral outputs [34]

[9] Source: information on a project with 22 farmers in GPAs, who could get paid for diminishing mineral outputs [35].

It seems that willow SRC will relatively easily cope with the fertilisation standards: average losses are well below them (see Table 3.4). Only in cases with very intensive phosphate fertilisation and low harvest, mineral loss is higher than the corresponding standard. On arable land, the end loss standards also seem to be attainable, although the picture is complicated by one source's lack of information on phosphate from artificial fertiliser. However, the average losses for nitrate are higher than those calculated for willow SRC. For grassland, other end loss standards apply, which are not reached in practice at the moment. There is, however, a wide spread in mineral losses, on arable lands as well as on grassland, illustrating the broad variety of fertilisation practices between farmers. This complicates a straightforward judgement of differences between willow SRC and common agriculture, especially since the data on willow are still calculations.

Nevertheless, in GPAs, in which meeting the end loss standards will be of vital importance given the potential threat to drinking water production, willow SRC will more easily meet the protection requirements for fertilisation than common agriculture, especially considering grassland. Compared to arable agriculture, willow SRC does not make a very strong difference.

Weed, pest and disease control

Although successful experiments have been carried out in willow SRC with integrated pest management, and the selection of varieties and variety mixes to prevent disease outbreaks, limited amounts of biocides are commonly used, as well as weed controlling chemicals in the establishment phase of the crop [12, 14, 16]. In GPAs, national regulations on biocide use apply, aiming at a reduction of biocide use, and a long-term ban on the most polluting substances. For this study we constructed a hypothetical regime for willow SRC, and compare this regime to other types of agriculture (Table 3.5). Biocide use is evaluated in terms of kg active substance per ha.year, and in Groundwater Pollution Points (GPP) per ha per year. The latter unit is part of the Dutch environmental yardstick for biocides [36, 37], that takes specific substance mobility and persistence into account.

Table 3.5: Biocide use in willow SRC, grassland, and some arable crops, and their threat to groundwater quality expressed in Groundwater Pollution Points.

	Biocide use in kg/ha.yr		Biocide use in GPP/ha.yr [3]	
	Average	Range	Average	Range
Willow [1]	0.7	-	100	-
Grassland [2]	0.1	0 – 0.8	70	0 – 350
Winter Wheat [2]	3.0	-	1,000	200 – 1,500
Potatoes [2]	5.7	-	4,200	50 – 20,000
Sugar Beet [2]	3.4	-	1,300	100 – 3,500

[1]: Sources: [3, 38]. Constructed biocide regime for a 25-year plantation lifetime. General herbicide Roundup (glyphosate) every first year after planting or harvest; Starane (fluroxipyr) treatment against hedge bindweed (*Calystegia sepium*) every first year after planting or harvest; Tilt (propiconazool) treatment against rust (*Melampsora spp.*) total 3 times in 25 years, Decis (deltamethrin) treatment against *Phyllodecta vulgatissima/vitellinae* 7 times in 25 years. This is a relatively intensive biocide use regime.

[2]: Source: [39]. Data are examples of plausible biocide regimes for GPAs, generally lower than the national averages. Data on ranges in applied kilograms in arable crops are lacking in this study.

[3]: For details on Groundwater Pollution Points calculations see [36]. This method is applied with increasing popularity to evaluate and compare chemical crop protection regimes. Roughly, a 100 GPP score of a substance will cause a concentration of 0.1 µg/l of that substance in the underlying groundwater layer between 1 and 2 meter depth. This 0.1 µg/l is the EU standard for any biocide in drinking water [40]. Calculated for a soil with 1,5-3% organic matter.

In willow SRC, biocide use (in kg/ha.yr) can be on average a factor four to five lower. Furthermore, according to the GPP calculations, the biocides used in willow SRC are relatively harmless to groundwater quality.

3.2 Financial competitiveness

The relatively low mineral losses and biocide use of willow SRC may lead to a financial competitive advantage compared to common agriculture. In recent years, several drinking water companies had set up agreements with farmers in GPAs for financial compensation if they would reduce their nutrient and biocide outputs [35, 41]. In a situation in which such reductions decrease productivity of common agricultural crops, willow SRC could gain a competitive advantage, being able to meet the reduction targets without productivity loss. This, obviously, only if the compensation by the drinking water company would be maintained when a farmer shifts to willow SRC.

For nutrients, however, the nationally applied Mineral Administration System (Minas) and its (end) loss standards have now mostly overhauled these initiatives [25, 27, 28]. This system has also been put forward by the Dutch government to meet the demands of the EU nitrate directive, for which the total Dutch land area has been assigned as vulnerable area. A key target of this directive is to keep nitrate levels in groundwater below the drinking water directive standard of 50 mg/l, and the Dutch measures to meet the nitrate directive should per definition be sufficient for GPAs to protect drinking water extraction wells. Therefore, the relative ease of willow SRC meeting the Minas loss standards may lead to a competitive advantage, but this will not be specific for GPAs. It is not probable that specific financial incentives for GPAs, potentially leading to a competitive advantage for willow SRC, will be set up.

For biocides, several drinking water companies have introduced financial incentives towards farmers for decreasing their biocide use. Illustrative are the agreements two drinking water companies made with farmers unions, in which individual farmers can obtain allowances of ca € 50 per ha per year, if they reduce their biocide emission in terms of GPP substantially [42, 43]. Assuming that such a premium would also apply to willow SRC with its low biocide inputs, this can give a positive effect on willow financial competitiveness. However, given that crop yields and management costs are in the order of magnitude of € 1000 per ha per year [44], such an allowance has a negligible effect on willow break-even prices. For example, we can use equations I and II for break-even price calculations in winter wheat, using data of Vlasblom [45]. The break-even price without subsidies would be € 137 /odt; in GPAs with a biocide subsidy it would be € 133 /odt, a minor decrease.

3.3 Conclusions and potential area

Biophysically, willow SRC in GPAs is well feasible: on shared land use requirements such as nutrient outputs and biocide use, willow SRC meets the criteria based on drinking water protection, and does so better than common agriculture.

Willow SRC obtains a negligible financial competitive benefit due to the nutrient and biocide restrictions: financial benefits resulting from limited nutrient losses and low biocide emissions will probably not be decisive in a farmer's choice between willow and common agriculture.

The potential area of this option is considerable: assuming that 55% of all protection areas is agricultural land (which is the national land use average [46]) this means a physical potential of 77,000 ha.

4. Production of drinking water: groundwater extraction areas

Groundwater extraction areas (GEAs) are located within the groundwater protection areas, in the zone directly surrounding the extraction wells. The total area of Dutch GEAs is ca 8,000 ha [47]. Regulations for land use in these areas are stricter than those for protection areas, but apply to the same LURs as in GPAs. As a consequence, common agriculture with fertilisation and biocide use is a rare phenomenon in extraction areas: most of the land is owned and managed by the drinking water companies themselves [47]. Relatively often, they choose for an ecological type of management, like (conversion into) woodland or other kinds of nature, or low-input cereal production [23]. In this section we consider these types of management the land use types competing with willow SRC.

4.1 Biophysical feasibility

The land use requirements for drinking water production in GEAs are of identical types as in GPAs (see Table 2.3). Regulations on shared requirements with willow SRC (fertilisation and biocide use for weed, pest and disease control) are stricter, and therefore again deserve attention.

Fertilisation

In most provincial regulations, fertilisation is forbidden in GEAs. This is one of the reasons why there is hardly any common agriculture. However, in some cases artificial fertiliser is allowed [48], and exemptions may be obtained, e.g. for compost or solid manure [24]. Given the relatively low mineral losses in willow SRC, we assume that two situations may occur:

- Fertilisation on willow SRC remains strictly forbidden. This will lead to decreased yields in the long term. However, since most Dutch lands are relatively nutrient-rich, this yield decrease will occur after a significant number of years. Based on Herder [49] we assume that in a 15-year period yields will drop to 50% and then remain constant.
- Limited fertilisation with artificial fertiliser or compost is allowed; fertilisation is no limiting growth factor.

Biocide use

In most GEAs, the use of biocides is forbidden [48], although exemptions may be obtained. Since many experiments exist in which willow SRC is successfully protected with non-chemical methods such as mechanical weed control and mixed planting of different (resistant) varieties [20, 50], we assume that willow SRC will not be severely hampered by this prohibition, and that yields will not substantially be diminished by it.

4.2. Financial competitiveness

A growing part of total GEAs is owned by the drinking water companies themselves. Their ecological management options include low-input (minerals and biocides) agriculture of cereals, and the development of natural systems like marshes, heathland, and woodland [47]. We compared the costs of several of these ecological management types [47] to that of willow SRC. We excluded management types that can only apply in specific (naturally valuable) situations such as bogs and open water. Costs were specified in establishment costs (such as removal of an over-fertile topsoil) and (yearly) management costs. Establishment costs were converted into annuity (7%) over 25 years. Figure 3.2 indicates that willow SRC is a relatively low-cost way of management of the land compared to the other options.

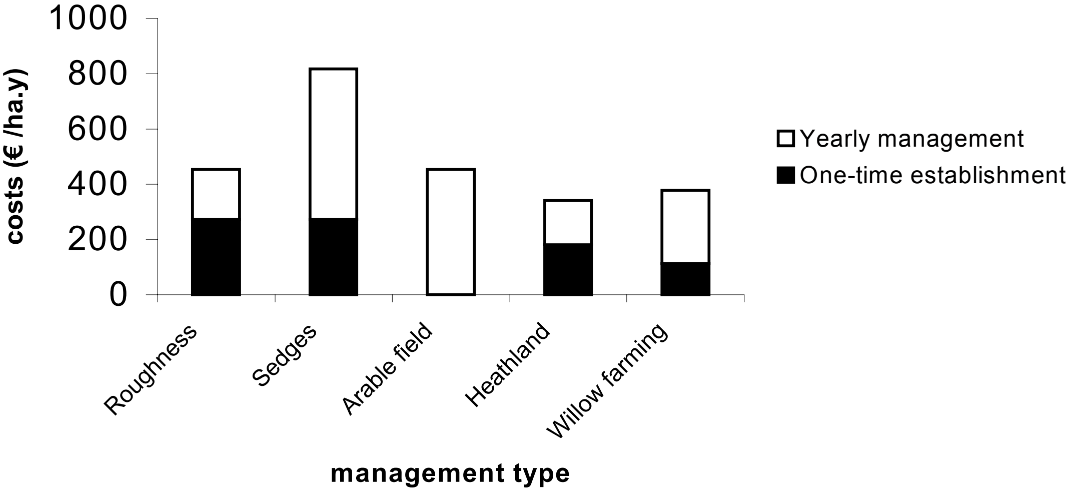

Figure 3.2: Comparison of management costs for different LUTs in groundwater extraction areas. Data from Jalink et al. [47] and Coelman et al [12].

However, willow SRC as well as low-input arable farming generates products. In this case, a comparison on costs alone is insufficient: break-even prices should be calculated according to Equations I and II, taking benefits of arable products into account. Since no data are available on arable crops under limited or non-fertilisation and non-biocide regimes, this can only serve as a (hypothetical) illustration. Assuming that willow SRC in GEAs competes with low-input winter wheat, we calculated corresponding willow break-even prices for a situation with limited fertilisation and with non-fertilisation (see Table 3.6). We assumed unequal yield reductions for wheat and willow (Table 3.6), because willow needs significantly less fertilisation than arable crops [3]. Compared to the situation in single land use outside GEAs, the willow break-even price is lower in GEAs, indicating improved competitiveness. However, given the uncertainties in the assumptions underlying these calculations, we consider this only an indication that willow SRC may be financially more attractive in GEAs compared to common, non-restricted areas, when it competes to arable land.

Table 3.6: Willow break-even prices in and outside groundwater extraction areas, with different fertilisation regimes and yield assumptions.

	GEA: Assuming no fertilisation		GEA: Assuming limited fertilisation[3]		Non-GEA: standard fertilisation[4]	
Item	Winter wheat	Willow SRC	Winter wheat	Willow SRC	Winter wheat	Willow SRC
Relative yield compared to normal fertilisation	50%	67%	67%	100%	100%	100%
Crop benefits (€/ha.yr)[1]	1100		1300		1800	
Crop management costs (€/ha.yr) [2]	450	380	540	430	620	490
Willow break-even price (€/odt)	150		120		160	

[1]: Benefits based on agricultural statistics [44]. Including a EU grant of €380 /ha.

[2]: Source: Jalink et al. [47], Spigt and Janssen [44].

[3]: Limited fertilisation defined as 50% of normal level.

[4]: Standard organic farming option, not comparable to the conventional winter wheat option in section 3. Currently, the margin on organic wheat is higher than the margin on conventional wheat in the Netherlands [44].

4.3 Conclusions and potential area

Willow SRC is biophysically feasible in GEAs: dependent on the specific situation, GEA requirements on (lack of) fertilisation may be a yield-limiting factor, the ban on biocide use will probably not lead to significant yield loss.

As a land management option, willow SRC has relatively low costs. Compared to another income-generating activity on these lands (low-input winter wheat cultivation), willow SRC may have better competitiveness as against non-restricted agricultural land.

The total area of GEAs is circa 8,000 ha. Approximately 5,000 ha of this is currently owned by the drinking water companies [47]. Especially these areas can be interesting for willow SRC. This number should be regarded an upper limit since part of this area may be nature reserve or open water.

5. Willow production for energy on traditional willow coppice

Traditional willow coppice has a long history producing wood for all kinds of purposes, e.g. baskets, barrel hoops and bean poles [51, 52]. Up till these days willow switches have also been much-used materials for the construction of dikes. However, due to material substitution most of these markets have declined, and many coppice plots have been converted into other types of land use. Only a limited area of commercial, intensively managed plots exist today, producing for infrastructure and some small niche markets. The major part of the remaining traditional coppice is maintained by governmental and private nature management organisations for landscape and conservation purposes. This because traditional willow coppice, especially in the river and tidal floodplains, has a characteristic flora and fauna [53], also acknowledged in Dutch nature policy [54]. However, given the poor market perspectives for willow twigs and the costs of traditional management, the traditional willow coppice land use is under pressure. While former outlets decline, wood for energy can be a new product, improving opportunities for conservation of the specific nature qualities. Two options can be identified in this context:

1. Energy wood as a new product for the traditionally managed coppice;
2. Introduction of modern techniques in willow coppice management in order to increase productivity and/or reduce management costs, while conserving the specific natural characteristics of the coppice.

5.1 Biophysical feasibility

In the first option, biophysical feasibility of the combination is proven: the current land use need not be altered, only the product use will change. More wood may be harvested for energy, since a minimal switch length is required for infrastructural use. We assume that a 10% yield increase is possible, compared to the current yield for infrastructural purposes.

In the second option, the question is whether the specific nature and landscape qualities of traditional willow coppice can be combined with modernised willow energy farming. Therefore, we translated the characteristics of traditional willow coppice relevant for its specific natural qualities into a set of LURs. The comparison with the modern willow SRC LURs is shown in Table 3.7. We shortly discuss all potential conflicts.

Area size

The remaining traditional willow coppice stands to be conserved are relatively small-scale. However, most of them are confined to the Dutch river delta, and are therefore located relatively close to each other. Therefore, a number of small-size plantations together will probably produce a sufficient scale for use in energy farming.

Willow species/varieties

Willow species Salix alba and S. triandra usually give better-developed stools than S. viminalis, and are therefore most popular in traditional willow coppice [56]. All three species are considered for willow for energy plantations, but most use S. viminalis varieties. Given the current tendency to mix species and varieties for pest and disease prevention, we assume that there will be no conflict in these LURs.

Planting density

Current traditional willow coppice usually has planting densities lower than 5,000 stems/ha. At such densities, well-developed stools can arise, which is a typical characteristic of traditional willow coppice. However, these plantations have all been planted once with densities around 10,000 stems/ha, and have experienced natural thinning and individual replanting at open spots [56]. Such processes are also conceivable in modern energy farming, provided that the willow stools are maintained well, to provide a lifetime longer than the currently assumed 25 years. This sets demands on harvesting, see below.

Table 3.7: LUR comparison of biomass for energy and specific traditional willow coppice natural vegetation. The digit 1 indicates that the LUT sets a (positive or negative) demand on this requirement, a 0 indicates indifference. A combination 1-1 is a potential conflict..

Product/service:	Biomass for energy	Specific natural vegetation of traditional willow coppice[1]
LUT:	Willow plantation	Willow plantation
Land use type characteristics	High productivity per ha Mechanical management	Dense undergrowth High densities of e.g. insects, birds Broad, well-established stools
LURs: land use requirements		
Land characteristics:		
1. Area size	1	1
Specification:	10 – 100's ha	ca 0.5 – 5 ha[2]
2. Edge-to-area	0	0
3. Soil type	0	0
4. Groundwater table	1	1
Specification:	Gt II – Gt V[2]	Gt I – Gt III[2]
Land design/arrangement		
5. Specific willow species	1	1
Specification:	S. viminalis, alba, mixt.	S. alba, S. triandra
6. Planting density	1	1
Specification:	5,000 – 30,000 st/ha	2,000 – 5,000 st/ha
7. Planting structure	1	1
Specification:	Regular, for mechanisation	Irregular, for 'natural' effect
Land management		
8. Fertilisation	1	1
Specification:	see text	see text
9. Weed control	1	1
Specification:	see text	see text
10. Pest/disease control	1	1
Specification:	see text	see text
11. Rotation	1	1
Specification	3 or 4 years	3 or 4 years
12. Plantation lifetime	1	1
Specification:	see text	see text
13. Harvest method	1	1
Specification:	see text	see text
14. Accessibility	0	1

[1]: Based on: [54, 55]

[2]: See Table 3.2 note 2. We assume that there is sufficient overlap between the two functions not to let this LUR be problematic.

Planting structure

Self-thinning and manual replanting in traditional willow coppice leads to an irregular planting structure, with small open spots throughout the plantation. This offers favourable conditions for local undergrowth and fauna. Again, this is also possible in modernised willow coppice, provided the stools are maintained well. Harvesting machinery not necessarily needs to drive in straight lines through the plantation [57].

Fertilisation

Traditional willow coppice fields are mostly located on relatively moist, clay soils. The ones in the river floodplains are regularly flooded and thereby obtain nutrients from water and sediments. Given the fact that the characteristic willow undergrowth is correlated to nutrient-rich soils, modest fertilisation will probably not drastically change its environmental conditions.

Weed control

Since undergrowth is an essential characteristic of traditional willow coppice flora and fauna, weed control is practically out of the question. This will inevitably lead to some yield reduction. However, it need not totally inhibit the combination.

Pest and disease management

Traditional willow coppice is also well known for its rich insect fauna. Therefore, use of chemical pesticides should also be avoided. However, given currently developed alternative methods, pest and diseases need not be an inhibiting factor.

Plantation lifetime and stool management

In order to obtain a well-developed ground vegetation, the plantation should not be ploughed for several decades. In modern plantations, lifetime is restricted to 20 to 25 years [12, 58], mostly because of increasing stool mortality. In order to keep vital stools for over 25 years, natural thinning should occur, and the remaining stools should be harvested with some care to keep a 'round', well-developed stool. Such broad, vigorous stools are another characteristic feature of traditional willow coppice. Modern machinery usually harvests in a flat surface, making the stools more broad and open (see Figure 3.3), and thereby more vulnerable to frost, diseases and tearing. Such harvesting entails poor stool development and a relatively short plantation lifetime. Therefore, technical innovations are needed to make more stool-friendly mechanical harvesting possible and reconcile these conflicting LURs.

Concluding, the only problem in combining the LURs of these LUTs remains the harvesting method, because of absence of a stool-sparing mechanical harvesting technology. For other LURs, the combination seems to be well feasible. That modern willow SRC for energy can offer good conditions for traditional coppice flora and fauna can be illustrated by a comparison of fauna in Dutch within-dike traditional willow coppice to fauna in British experimental willow-for-energy plantations, which indicated that species compositions are relatively similar [48]. Floral compositions differed significantly in this study, which may be caused by the relatively young age of the British plantations, which understorey was dominated by annual weeds characteristic for the former land use (grass- or cropland [48]).

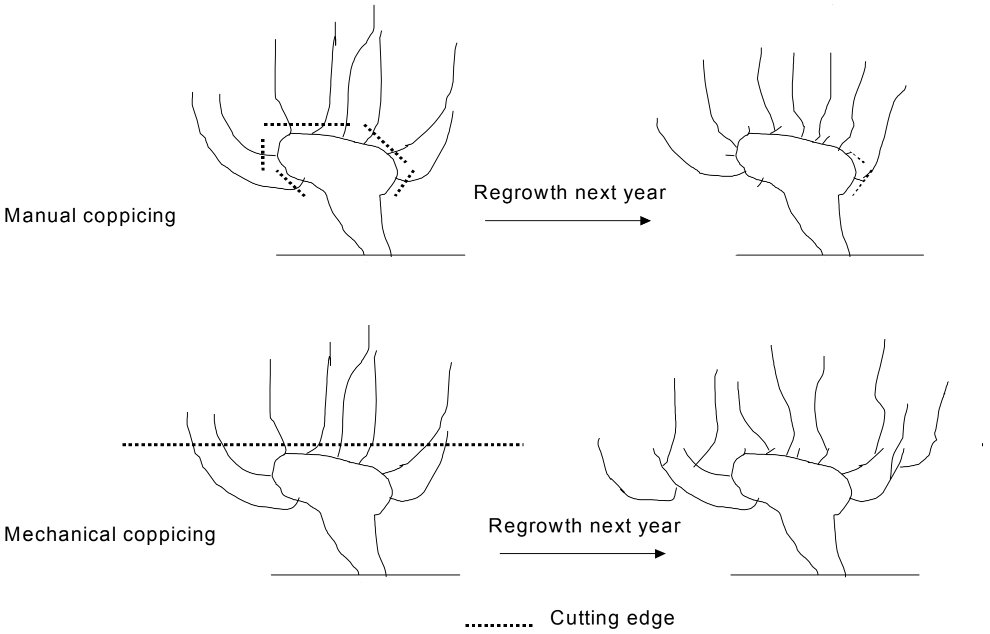

Figure 3.3: Effects of manual and mechanical harvesting on well-developed coppice stools.

5.2 Financial competitiveness

In the option with traditional coppice management, i.e. with manual harvesting, we can estimate the biomass price needed to make willow for energy competitive to traditional uses such as hydraulic engineering. This is not a break-even price as in Equation I, since the land use does not change, only product application. Nevertheless, such a price can be compared to break-even prices for energy wood in single land use on agricultural land, to indicate competitiveness of this type of production. In practice, willow coppice management organisations allow specialised workers to harvest the coppice for free and sell the wood by themselves. The price these workers can obtain, however, is not set on a transparent market, since willow switches are now only sold in bilateral contracts, not on an auction or similar. However, a coppice manager indicated this price around € 0.8 per bundle of 13 kg [59], corresponding to € 125 /odt (assuming a 50% moisture content). This is in the same order of magnitude of other willow producing systems, such as intensive culture on agricultural land (ca € 100-140 /odt, [7]), which implies that this energy wood production strategy in multiple land use is not significantly cheaper than energy wood production in single land use. Some comments should accompany this calculation. First, the € 0.8 per bundle price is currently below harvesting costs, assuming a reasonable hour's wage for the worker [59]. There is a fair chance that in the short term this activity may therefore be stopped if prices do not increase. Furthermore, an extra demand for willow for energy purposes will increase prices, even in an untransparent market. Therefore, the chance that traditionally managed coppice becomes a financially competitive energy wood resource is fairly small.

In the second option with mechanical harvest the same reasoning can be followed if the harvested material is also of sufficient quality for use in e.g. hydraulic engineering. However, if the quality would be lower, this competing use is eliminated, and simple production costs may be calculated. Assuming machinery costs as in Coelman et al. [12], standard agricultural hour's wages, and an average (relatively low) yield of 5 odt/ha.yr, gives a willow supply price of € 57/odt in a 3-year rotation, and € 42/odt in a 4-year rotation. This is a significantly lower price than other willow production systems [7], mainly due to the fact that in this reasoning, there is no competing land use or product application. Therefore, if it is possible to modernise traditional willow coppice by modern SRC techniques (especially in stool-friendly mechanical harvesting), maintaining nature and landscape features, this option can probably provide cheap energy wood.

5.3 Conclusions and potential area

The option with a simple product shift for currently produced willow switches is biophysically feasible. The option with management modernisation will meet difficulties in proper stool management, which need to be solved by technological innovations.

Financially, the first option with manual harvest leads to willow prices roughly comparable to those with intensive SRC on agricultural land, indicating unchanged financial competitiveness. In the second option with mechanical harvest, supply prices could become significantly lower. However, the material would only be sold at such a price if the harvested material is not applicable to the existing markets (with their higher market prices) or if they are satisfied.

Besides financial considerations, it should be borne in mind that willow SRC for energy on existing traditional coppice lands may be introduced more easily than willow SRC on common agricultural land. Adapting current product application or modernising existing coppice, provided the nature and landscape features are maintained, is a more logical shift than replacement of annual foods with perennial willow.

While in the past, large areas in the Dutch river areas were planted with willow, this area has decreased strongly in the last decades. Most recent coppice data on areas were found in Schepers and Haperen [53], and were derived from 1988 Dutch woodland statistics. These data indicate areas of 500 ha coppice in the floodplains, and 1000 ha in-dike coppice. These areas may still have decreased in recent years. However, traditional willow coppice might be re-introduced in some ecological restoration plans for Dutch floodplains and in more recent plans for floodplain draining capacity improvement.

6. Willow SRC as an ecological corridor

A major feature in current Dutch nature policy is the establishment of a National Ecological Network of nature conservation areas. This network, introduced in the first Nature Policy Plan [60], will consist of four types of areas. Apart from core areas, nature development areas and buffer zones, this network will also contain ecological corridors, enabling species to migrate from one core area to another. Current policy comprises the establishment of circa 50,000 ha of ecological corridor before the year 2020 [61].

For willow SRC, ecological corridors may be interesting since they are relatively open to combination with other functions [60, 61]. Therefore, we explored to what extent willow SRC can serve as a building block for an ecological corridor. It is relatively difficult to compare the corridor function of willow SRC to other land use types with that function, since currently ecological corridors are only roughly sketched in their vegetation structure (e.g. [62, 63]). Therefore we solely assess the suitability of willow SRC as a corridor, and do not compare it to other land use types. This also implies that we do not deal with other types of corridor that may generate energy wood as a by-product, such as common woodland.

6.1 Biophysical feasibility

Many of the 12 Dutch provinces responsible for ecological corridor policy [60], have developed a specific ecological corridor plan, and have selected guide species, animal species for which the corridor should function. Their assumption is that the guide species serve as indicators for many others. Most provinces already have selected their guide species, but the specific location and design of the corridors is still under discussion.

For the feasibility assessment, one should ideally identify all guide species and, given their habitat and other ecological characteristics, define corresponding corridor LUTs and accompanying LURs. However, such an approach would require extensive research. We simplified this approach in order to estimate the aptness of willow cultivations as an ecological corridor. This method, shortly summarised in Figure 3.4, tuurlijk Nico, ‘t is mijn schuld consists of two steps:

First, we identified different ecological corridor LUTs in a number of policy reports on the subject [62-68]. Such LUTs can roughly be described as either wet corridors (streams/canals and their banks), marsh-like corridors, meadow-like corridors, and woodland-like corridors. Since willow SRC most resembles (young) woodland, we limited ourselves to guide species identified for woodland-like corridors.

From several field surveys of fauna in willow SRC [69-71], we checked whether these guide species were observed (structurally or incidentally) in willow SRC plantations. If so, we assume that these plantations will or may be suited as an ecological corridor for this guide species. Since plantation survey data were only available on songbirds, butterflies and mammals (comprising approximately 75% of all guide species) we limited the comparison to these three species groups.

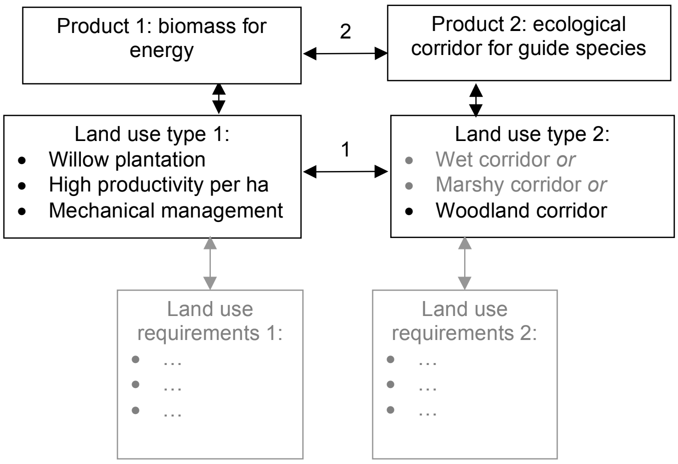

Figure 3.4: Simplified feasibility assessment method for willow SRC as an ecological corridor.

Table 3.8 summarises the total numbers of guide species per group, and the part of these numbers that can be expected to use willow plantations as a corridor. However, this comparison should be made with caution. A substantial part of the survey data on willow plantations was obtained in the United Kingdom, and there may be differences in species behaviour between the British and continental populations. Furthermore, the presence of a species in a willow plantation is not a real guarantee that it will use this land for migration. It may, for example, only use it for foraging or resting, while staying in the same habitat. However, given these precautions, Table 3.8 indicates that for circa 30 to 50% of the selected guide species, a willow plantation may be a useful part of an ecological corridor. This percentage applies to almost all provinces; for the province of Utrecht, it is significantly higher (75%); for Groningen it is lower (20%).

Table 3.8: Guide species for terrestrial ecological corridors with woody or shrubby elements, and their possible occurrence in willow plantations.

Species group	Total guide species[1]	Occurring in willow SRC[2] Surely[3]	 + Potentially[3]	Examples of shared species
Songbirds	24	2	11	Marsh warbler (*Acrocephalus palustris*) Whitethroat (*Sylvia communis)*
Butterflies	29	9	12	Speckled wood (*Pararge aegeria*) Ringlet (*Aphantopus hyperantus*)
Mammals	57	19	36	Badger (*Meles meles*) Roe deer (*Capreolus capreolus*)
Of which Mice	12	5	10	Bank vole (*Clethrionomys glareolus*) Common shrew (*Sorex araneus*)
Of which Bats	12	3	3	Noctule (*Nyctalus noctula*) Serotine (*Eptesicus serotinus*)
Total	110 (100%)	30 (27%)	59 (54%)	

[1]: Guide species for terrestrial corridors with woody or shrubby elements. From 8 policy documents on provincial ecological corridors [62-68]. Species that were found in more than one provincial document were counted for every mention.

[2]: Based on field surveys. For songbirds: see [69]; for butterflies: [70]; for mammals: [71].

[3]: Category 'surely' includes species that have been found regularly, category '+ Potentially' includes these plus species that have been found irregularly, or whose presence also depends on other (external) circumstances such as soil moisture content.

6.2 Financial competitiveness

There is no specific national financial instrument for the establishment and management of ecological corridors in the Netherlands. Some provinces have allocated own funding for this purpose, but in general, subsidy regulations for nature conservation or desiccation abatement are applied for [72]. And in order to find financial resources, the ecological corridor function is often combined with other, e.g. recreational or infrastructural functions [62, 67]. However, the new Dutch nature policy plan mentions this problem and the need for a specific (financial) instrument to be developed [61]. Currently, potential financial benefits from the implementation of willow SRC as an ecological corridor alone are still unclear. However, an allocation of tasks in which a willow cultivator leases a corridor plantation free of charge, complying to specific corridor management rules in return, is not inconceivable.

6.3 Conclusions and potential area

Biophysically, willow SRC can function as an ecological corridor, depending on the guide species at stake in a specific situation. Financial merits of this combination are still hard to estimate.

The recent national target area for ecological corridors amounts circa 50,000 ha of wet and dry ecological corridors [61]. Much of this area, e.g. the wet corridors, or corridors of marshes or open vegetations, will beforehand be unfit for willow SRC. Based on the eight provincial documents, a rough estimation could be made of the total area of terrestrial ecological corridors in the Netherlands containing woody or shrubby area or elements. Given information in these policy documents, approximately 1000 ha will be necessary for such corridors in the selected provinces, which implies that in the Netherlands as a whole this area will probably not exceed 2000 ha. This is a maximum estimate for willow SRC in ecological corridors: some corridors will need small-scale, patchy woodland, or will consist of a linking zone of less than 5 meters. Such dimensions will hardly be interesting for rational energy farming with willow.

In this context however, it is worth noting that there is persistent discussion on functioning and dimensions of ecological corridors [66, 73-75]. Especially ecological scientists argue that the currently designed ecological corridors will often be inadequate: mislocated, too narrow, too long, and without sufficient small biotopes or stepping-stones. Possibly, larger corridors will be necessary; some extended, ‘robust’ corridors have been announced in the latest national policy document on nature conservation [61]. These developments may also increase the potential area for willow SRC in these areas. However, in the current state of affairs any indication of area increase would be speculative.

7. Discussion and conclusions

On the applied method

The method introduced in section 2 had to be adapted in most option explorations. Regarding biophysical feasibility, only in the groundwater protection and extraction options the combined function could be clearly translated into land use requirements. In the traditional coppice and ecological corridor options, clear requirements were not available, and an evaluation was carried out on LUR derived from literature and field experience (in the traditional willow coppice case), or on extrapolated information (on the presence of corridor guide species in surveyed willow SRC). In the financial analyses, many data were also lacking. Therefore, some results should only be considered indicative. For example, of the competing land use types in groundwater extraction areas, only management costs were available, and no possible benefits. In general, it may still need a considerable research effort in order to elaborate functions related to nature and biodiversity on the same level of detail as functions related to physical production, such as agriculture or willow SRC.

These methodical limitations make that the conclusions from this study should be applied with prudence. The proposed rapid appraisal method, however, provides a clear and systematic framework for a qualitative or semi-quantitative indication of combination feasibility and financial competitiveness. Per combination, some creativity may be required to adapt the method to the available data.

On the combinations

In Table 3.9, the characteristics of the explored combinations are summarised, in terms of their biophysical feasibility, whether the combination leads to cost savings, and in their potential area. Almost all options are biophysically feasible, although policies and initiatives for ecological corridors are not sufficiently detailed for clear judgement. Especially introduction in groundwater extraction areas can create cost savings. In groundwater protection areas willow may also have a limited competitive advantage, but this will probably not be sufficient for a farmer’s switch. Biomass cultivation on traditional willow coppice lands may only create a cost saving if the management can be mechanised without decreasing stool lifetime. If manual harvest is maintained, this cultivation has roughly the same supply price as modern mechanical cultivation on agricultural lands. For ecological corridors, financial information was too scarce to draw a conclusion.

Table 3.9: The proposed functions to be combined with willow farming, their biophysical and financial feasibility and the potential land area.

	Biophysical feasibility		Effect on financial competitiveness		Potential area (ha)	
		certainty		certainty		certainty
Groundwater protection areas	yes	+	limited	+	77,000	+
Groundwater extraction areas	yes	+	positive	-	5,000	+
Traditional willow coppice case 1	yes	+	negligible	+	1,000	+
Traditional willow coppice case 2	no	+	positive	-		
Ecological corridors	yes	-	unknown	-	2,000	-

In terms of potential area, introduction of willow SRC on groundwater protection areas is the most interesting, and the option on traditional willow coppice the least. However, one should handle these data with care: for example, the financial advantage in groundwater protection areas is limited, while the traditional willow coppice has the advantage that already existing willow plantations can be used.

For the individual combinations, the potential areas are too small to generate sufficient biomass for a medium-scale conversion unit. The options are all fragmented over the country in sites of maximally tens of hectares [48, 53, 62-68], and for every MW (input) of a power plant, approximately 100 ha of willow SRC is needed. Therefore, these combinations can only make a limited contribution to a regional biomass supply: to a conversion unit it should be combined with e.g. forest or agricultural residues and other high caloric wastes.

The total of potential areas can significantly contribute to the Dutch renewable energy targets: their total could supply circa 0.5% of the current national energy demand, while the national target for 2020 is to generate 10% by renewables (including wind and solar). These numbers, however, include the GPA option, in which willow is hardly more competitive than elsewhere.

Acknowledgements

The authors would like to thank drs. Wim ter Keurs (Leiden University, Environmental Biology) and Prof. dr. Hans de Kruijf (Utrecht University, Department of Science, Technology and Society) for their useful comments on draft versions.

References

1. RMNO. *Meerjarenvisie 1996: Ruimte voor ecologische modernisering. Samenvatting. (Multi-year vision 1996: Space for ecological modernisation. Summary).* Rijswijk: RMNO, 1996.
2. Londo, M., J. Dekker, P. Verweij, and H. de Graaf. *Multiple land use on land unit level in rural areas: towards operationalisation.* Submitted to Land Use Policy.
3. Biewinga, E.E. and G. van der Bijl. *Sustainability of energy crops in Europe; a methodology developed and applied.* Utrecht: CLM, 1996.
4. Heineman, A., G. Saaltink, and L. Kuiper. *Energie uit biomassa in combinatieteelt (Energy from biomass in combination farming).* Wageningen: CPV/SBH, 1999.
5. Anonymous. *Living Energy: Design competition for energy farming in the landscape. Jury Report.* Utrecht/Den Haag/Wageningen: NOVEM/NIROV/IBN-DLO, 1999.
6. Eker, M., W. Elbersen, B. de Klerk, R. de Koning, N. van der Windt, and A. Wintjes. *Switch on! First prize winning entry for the 'Living Energy' design competition to introduce energy crop cultivation in the landscape.* Wageningen: SC-DLO, 1999.
7. Londo, M., L. Vleeshouwers, J. Dekker, and H. de Graaf. *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation.* Biomass and Bioenergy 2001, 20 (5): 337-350.
8. Börjesson, P. *Environmental effects of energy crop cultivation in Sweden - I: Identification and quantification.* Biomass & Bioenergy 1999, 16 137-154.
9. Börjesson, P. *Environmental effects of energy crop cultivation in Sweden - II: Economic valuation.* Biomass & Bioenergy 1999, 16 155-170.
10. Meeusen - van Onna, M.J.G. *Kostprijsberekening voor nieuwe landbouwgrondstoffen; methoden ten behoeve van haalbaarheidsstudies (cost price calculations for new agricultural materials: methods for feasibility studies).* Den Haag: LEI- DLO, 1997.
11. Gigler, J.K., M.J.G. Meeusen - van Onna, and E. Annevelink (eds.). *Kansen voor energie uit biomassa! Resultaten van een 4-jarig DLO-onderzoekprogramma (Opportunities for energy from biomass! results of a 4-year DLO research programme).* Wageningen: Dienst Landbouwkundig Onderzoek, 1999.
12. Coelman, B.T. (ed), B. Pijanowska, G.J. Kasper, J.K. Gigler, C. Sonneveld, W. Huisman, E. Annevelink, J. van Doorn, A. Bos, R. van der Pluijm, and M. de Boer. *Mogelijkheden voor kleinschalige energie-opwekking met geteelde biomassa (Possibilities for small-scale energy production with cultivated biomass).* Wageningen: CPV, IMAG-DLO, ECN, 1996.
13. Zeijts, H. van, E.A. Oosterveld, and E.A. Timmerman. *Kan de landbouw schone energie leveren? Onderzoek naar duurzaamheid van energiegewassen (Can agriculture produce clean energy? A study on sustainability of energy crops).* Utrecht: CLM, 1994.
14. Anonymous. *Good Practice Guidelines Short Rotation Coppice for Energy Production; The development of an economically and environmentally sustainable industry.* London: ETSU, British Biogen, Friends of the Earth, Environmental Resolve, 1996.
15. Aronsson, P. *Energy Forestry and Nature Preservation.* Uppsala: SLU, 1995.
16. Danfors, B., S. Ledin, and S. Rosenqvist. *Short-rotation willow coppice; Growers' manual.* Uppsala: Swedish institute of agricultural engineering, 1998.
17. Boyd, J., L. Christersson, and L. Dinkelbach. *Energy from willow.* Endinburgh: SAC/SLU/ECN/Altener/DTI, 2000.
18. Clay, D.V. *Weed control and soil management systems for short-rotation coppice: Present Knowledge and future requirements.* Bristol: Avon Vegetation Research, 1993.
19. McCracken, A.R. and W.M. Dawson. *Using mixtures of willow clones as a means of controlling rust disease.* Aspects of Applied Biology 1997, 49 97-103.

20. McCracken, A.R., W.M. Dawson, and G. Bowden. *Yield responses of willow (Salix) grown in mixtures in short rotation coppice (SRC).* Biomass and Bioenergy 2001, 21 311-319.
21. Anonymous. *Ons water, ons leven (our water, our life). Brochure on drinking water in the Netherlands.* Rijswijk/Den Haag: VEWIN / VROM, 1996.
22. Geleuken, B.P. van. *Gebiedsgericht grondwaterbeschermingsbeleid; de betekenis van congruentie (Region-oriented groundwater protection policy: the significance of congruence).* Nijmegen: KUN, 1998.
23. Metsers, C.M.L. and C.M. van Hemel. *Ecologisch beheer door drinkwaterbedrijven; stand van zaken 1996 en prognoses (ecological management by drinking water companies; state of affairs and prognoses).* Nieuwegein: KIWA, 1997.
24. Anonymous. *Provinciale milieuverordening Zuid-Holland (Provincial environmental regulation Zuid-Holland).* Den Haag: Province Zuid-Holland, 1998.
25. Grün, U.J.P. *De bemesting van energieteelt ten opzichte van de normen in het Nederlandse mestbeleid (fertilisation of energy farming in relation to the standards in Dutch mineral policy).* Utrecht: Universiteit Utrecht (NW&S), 1998.
26. Ministries of LNV and VROM. *Integrale Notitie mest- en ammoniakbeleid (Integral document on manure and ammonia policy).* The Heague: Ministries of Agriculture, Nature Management and Fisheries and of Public Housing, Spatial Planning and Environment, 1995.
27. Enting, G. *E-mail message, dated August 23, on the groundwater protection policy of the drinking water company in the province Drenthe.* Assen: Waterleidingmaatschappij Drenthe, 2001.
28. Doornbos, A.J. *E-mail message, dated September 1, on the groundwater protection policy of the drinking water company in the province Overijssel.* Zwolle: Waterleidingmaatschappij Overijssel, 2001.
29. Silvis, H.J. and C. van Bruchem (eds). *Landbouw-economisch bericht 2001 (agricultural economic report 2001).* The Hague: LEI, 2001.
30. Ledin, S. and K.L. Perttu. *Climatic, edaphic and management requirements for energy forestry.* In: Perttu, K.L. and P.J. Kowalik. *Modeling of energy forestry: growth, water relations and economics.* Wageningen: Pudoc, 1989.
31. Ledin, S. *Willow wood properties, productions and economy.* Biomass and bioenergy 1996, 11 (2/3): 75-83.
32. Ministries of LNV and VROM. *Integral Approach Manure Problems; Letter to the Parliament.* The Hague: Ministries of Agriculture, Nature Management and Fisheries and of Public Housing, Spatial Planning and Environment, 1999.
33. Anonymous. *Tweede monitoringsrapportage mineralen- en ammoniakbeleid (Second monitoring report mineral and ammonia policy).* Ede: IKC Landbouw, 2000.
34. LEI-DLO. *Analyse mineralenbalansen; deelrapportage resultaten 1998 (analysis mineral balances; partial report results 1998).* Arnhem: Project Praktijkcijfers, 1999.
35. Buijze, S.T. and J. van Miltenburg. *Resultaatbeloning in de grondwaterbescherming III; twee jaar praktijkexperimenten in de landbouw (result rewarding in groundwater protection III; two years of practical experiments in agriculture.* Utrecht: CLM, 1995.
36. Anonymous. *Milieumeetlat bestrijdingsmiddelen akkerbouw; werkboek (Environmental yardstick biocides; working book).* Utrecht/Wageningen: CLM/Kerngroep MJP-G, 2000.
37. Reus, J.A.W.A. *Milieumeetlat voor bestrijdingsmiddelen: ontwikkeling en plan voor toetsing (Environmental yardstick for biocides: development and plan for testing).* Utrecht: CLM, 1991.
38. Ridder, I. de. *Gewasbescherming in de energieteelt met wilgen (Crop protection in willow energy farming).* Utrecht: STS, Internal Report, 1998.
39. Buijze, S.T. and E.E. Biewinga. *Boeren op goed grondwater; normen voor landbouw vanuit grondwaterbescherming (Farming on good groundwater; standards for agriculture based on groundwater protection).* Utrecht: CLM, 1995.
40. Anonymous. *Achtergronden van de milieumeetlat voor bestrijdingsmiddelen (backgrounds of the environmental yardstick for biocides).* Ede: Kerngroep MJP-G, 1996.
41. Kasteren, J. van and G. Vinke. *Werken aan evenwicht; waterwinning en landbouw (working on equilibrium; groundwater extraction and agriculture.* Rijswijk: VEWIN, 1996.
42. Anonymous. *Schade-stimuleringsregeling grondwaterbeschermingsgebieden Gelderland (damage and stimulation regulation groundwater protection areas province of Gelderland).* Velp: Waterbedrijf Gelderland, 2000.
43. Anonymous. *Uitvoeringsregeling voor landbouw in de grondwaterbeschermingsgebieden van Drenthe en Groningen (implementation regulation for agriculture in the groundwater protection areas of the provinces Drenthe and Groningen).* Assen: WMD, NLTO, Waterbedrijf Groningen, 2001.

44. Spigt, R.M. and T.L.J. Janssen. *Kwantitatieve informatie akkerbouw en volllegrondsteelt 1997/1998 (Quantitative information arable farming and open soil horticulture 1997/1998).* Wageningen: PAGV, 1997.
45. Vlasblom, J. *Do Energy Crops boost the Economy? An assessment of the national and regional economic impacts of electricity from energy crops.* Utrecht: NW&S, 1997.
46. Ministry of LNV. *Facts and Figures 2000. Internet page http://www.minlnv.nl/infomart/feiten/, accessed on januari 8, 2001.* The Hague: Ministry of Agriculture, Fisheries and Nature Management, 2001.
47. Jalink, M.H., A.J.M. Jansen, A.F.M. Meuleman, and J. Wisse. *Ecologisch beheer door waterleidingbedrijven (Ecological management by drinking water companies).* Nieuwegein: KIWA, 1993.
48. Roose, M. *Energieteelt in Multifunctioneel Landgebruik; evaluatie van een aantal mogelijkheden om de teelt van biomassa te combineren met andere functies (Energy farming in multi-purpose land use; evaluation of a number of options to combine biomass cultivation with other functions).* Utrecht: Utrecht University, Dept. of Science, Technology and Society, 1999.
49. Herder, S. *Opbrengstperspectieven van low-input biomassateelten in relatie tot Europees stikstof emissiebeleid (yield perspectives of low-input biomass cultivations in relation to European nitrogen policy).* Groningen: IVEM, Groningen University, 1997.
50. Kuiper, L. *Personal communication on a willow plantation in Flevoland, the Netherlands.* Wageningen: Stichting Bos en Hout, 2000.
51. Zonderwijk, M. *Grienden; een technische en natuurtechnische beschouwing (traditional willow coppice; a technical and natural regard).* Utrecht: Utrecht University, 1982.
52. Tuinzing, W.D.J. *Gegevens betreffende de griendcultuur in Nederland (Data concerning osier bed culture in the Netherlands).* The Hague: Ministry of Agriculture, Fisheries and Food, 1956.
53. Schepers, J.A.M., A.A.M. van Haperen, and J.L. van der Jagt (ed.). *Grienden: hakken of laten groeien; inventarisatie van het hakgriendenarsenaal en mogelijkheden voor ontwikkeling (Traditional willow coppice: coppicing or letting grow; an inventory of the arsenal of traditional willow coppice and potentials for development).* Utrecht: IKC-NBLF, 1992.
54. Bal, D, H.M. Beye, S.R.J. Jansen, and P.J. van der Reest. *Handboek natuurdoeltypen in Nederland (Manual on Nature Targets Types in the Netherlands).* Wageningen: IKC Natuurbeheer, 1995.
55. Anonymous. *Subsidieregeling Natuurbeheer 2000 (subsidy regulation nature management 2000).* Den Haag: Ministry of Agriculture, Nature Management, and Fisheries, 2000.
56. Garskamp, R. *Personal Communication on traditional willow coppice.* Utrecht: Zuid-Hollands Landschap, 2000.
57. Sonneveld, C. *E-mail message on harvesting machinery.* Wageningen: IMAG-DLO, 2000.
58. Aalsburg, B. van. *Personal communication on willow harvesting machines.* Hellouw: Van Aalsburg B.V., 2000.
59. Heiningen, H. van. *Personal communication.* Waardenburg: State Forestry Service, regional management unit, 2000.
60. Ministry of LNV. *Natuurbeleidsplan, regeringsbeslissing (Nature Policy Plan, government decision).* Den Haag: Sdu uitgeverij, 1990.
61. Ministries of LNV, VROM, V&W, and OS. *Natuur voor mensen, mensen voor natuur; nota natuur, bos en landschap in de 21e eeuw (nature for people, people for nature; policy document on nature, woodlands and landscape in the 21st century).* The Hague: Ministries of Agriculture, Nature Management and Fisheries, of Public Housing, Spatial Planning and Environment, of Transport, Public Works and Water Management, and of Development Cooperation, 2000.
62. Anonymous. *Ecologische verbindingszones in Zuid-Holland; aanwijzingen voor inrichting en beheer (Ecological corridors in Zuid-Holland; indications for construction and management).* The Hague: Province of Zuid-Holland), 1998.
63. Anonymous. *Nota ecologische verbindinszones (Policy document on ecological corridors).* Groningen: Province of Groningen, 1999.
64. Anonymous. *Realiseringskader voor natuurlijke verbindingen en natuurtechnische voorzieningen (Framework for realisation for natural corridors and supporting constructions).* Leeuwarden: Province of Friesland, 1994.
65. Kooij, A. *Ecologische verbindingszones; gebiedsvisie natuur, bos en landschap (Ecological corridors; region vision nature, woodlands and landscape).* Assen: Province of Drenthe, 1997.

66. Reijnen, R. and B. Koolstra. *Evaluatie van de ecologische verbindingszones in de provincie Gelderland (Evaluation of the ecological corridors in the province of Gelderland).* Wageningen/Arnhem: IBN-DLO/Province of Gelderland, 1998.
67. Stam, S.M.E. and H. van Arkel. *Werkdocument ecologische verbindingszones provincie Utrecht (working document ecological corridors province of Utrecht).* Utrecht: Province of Utrecht, 1994.
68. Anonymous. *Groene wegen; een leidraad voor inrichting en beheer van ecologische verbindingszones in Noord-Holland (Green ways; a guide for construction and management of ecological corridors in Noord-Holland).* Haarlem: Province of Noord-Holland, 1999.
69. Londo, M., W. ter Keurs, and J. Dekker. *Willow Short Rotation Coppice for energy and breeding birds: An exploration of potentialsin relation to management.* Submitted to Biomass and Bioenergy.
70. Sage, R.B., P.A. Robertson, and J.G. Poulsen. *Enhancing the conservation value of short rotation biomass coppice - Phase 1: the identification of wildlife conservation potential.* Fordingbridge: The Game Conservancy Trust, 1994.
71. Coates, A. and A. Say. *Ecological Assessment of Short Rotation Coppice.* Harwell: ETSU, 1999.
72. Hine, H. *Werken aan wegen voor plant en dier; de uitvoering van het beleid voor de ecologische verbindingszones (Working on ways for plant and animal; the implementation of policy for ecological corridors).* Utrecht: Utrecht University/ Stichting Natuur en Milieu, 1998.
73. Bal, D. and R. Reijnen. *Natuurbeleid in uitvoering (Nature policy in execution). Achtergronddocument 8 Natuurverkenning 1997.* Wageningen: IKC-N / IBN-DLO, 1997.
74. Pelk, M., C.C. Vos, M.J.S.M. Reijnen, R. van Etteger, and D. Bal. *Kwaliteit door verbinden (Quality through connection).* Wageningen: Alterra / IKC-N, 2000.
75. Opdam, P., C. Grashof, and W. van Wingerden. *Groene dooradering; een ruimtelijk concept voor functiecombinaties in het agrarisch landschap (Green networking; a spatial concept for function combinations in the agricultural landscape).* Landschap 2000, 17 (1): 45-51.

Chapter 4

Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation[*]

Abstract

Measures to combat desiccation of Dutch nature reserves often lead to the establishment of buffer areas around them, in which soils become moister, and agricultural yields decrease. Cultivation of the flooding-tolerant energy crop willow may be an alternative in such areas. In this study, the performance of willow production is compared to that of grass for roughage. The effect of high groundwater tables on yields of both crops is estimated using the agro-hydrological model SWAP. Financial consequences are evaluated by calculating the biomass price that, for a farmer, makes willow equally competitive as grass.

At groundwater table class (Gt) II, common in buffer areas, willow physical yield is ca 15% lower than its optimum, but grass yield decreases by ca 25%, making willow more competitive. This results in a 20% lower break-even willow price on Gt II than in a dryer, optimal situation.

A sensitivity analysis shows that most parameters with a strong influence on the break-even willow price have reasonably high certainty. An uncertain value with strong influence is the willow yield without hydrological constraints, which could not be estimated from practical data. Methodological limitations of the study, both in the financial comparison between willow and grass, and in the yield estimations, are also discussed.

Keywords: Short rotation coppice, willow, desiccation abatement, agro-hydrological modelling, financial analysis, multi-purpose land use.

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[*]: Co-authors: Leo Vleeshouwers (Dept. of Theoretical Production Ecology, Wageningen University), Jos Dekker (Dept. of Science, Technology and Society, Copernicus Institute, Utrecht University) and Hans de Graaf (Section Environmental Biology, Institute of Evolutionary and Ecological Sciences, Leiden University). Biomass and Bioenergy 20 (2001), 337-350.

1. Introduction

The uncertainty in land availability for energy farming is a major obstacle for the introduction of energy farming [1]. This is mainly caused by the relatively low profitability of energy crops compared to e.g. food crops [2]. Combining biomass production with other functions such as nature conservation may increase profitability of both and lead to more efficient use of space and natural resources. In this study, we explore the potentials for energy farming combined with a specific nature conservation measure, i.e. buffering nature reserves against groundwater depletion, or desiccation.

In the Netherlands, many nature reserves suffer from low groundwater tables, as an impact of past rural development projects. In such projects, the land drainage capacity was increased in order to create better hydrological conditions for agriculture [3]. In surrounding nature reserves, this has caused lower groundwater levels and decreased upward groundwater fluxes. This process leads to a chain of side-effects, such as increasing mineralisation of soil organic matter (due to aeration) and increasing soil acidity (due to aeration and mineralisation). In many Dutch nature reserves, these processes have lead to changes in vegetation structure and composition, generally regarded a loss in nature quality. In the Netherlands, circa 600,000 ha of land (circa 15% of total land) were suffering from desiccation in 1998 [3]. Dutch environmental policy aims at a 40% reduction of the desiccated area by 2010 [3].

In order to recover a specific desiccated nature reserve, the hydrological system of which it is part should be modified. In general, the increased drainage capacity is reduced. Sometimes this can be done within the reserve itself, but it often also entails the side effect of wetter conditions in adjacent agricultural lands in a radius of several hundreds of meters, sometimes called buffer zones. Approximately 100,000 ha of agricultural land may be influenced by measures to reach the 40% reduction target [4, 5]. Lower yields in these zones are generally compensated financially, and in extreme cases farmers are bought out. Costs for these compensation payments are in the order of tens of millions of Euros [6].

The energy crop willow is well known for its tolerance of high groundwater levels [7, 8]. Therefore, it may perform relatively better than food crops in buffer areas with moist soils. For farmers surrounding desiccation abatement projects, cultivation of willow therefore may become more competitive to food crops than in a hydrologically optimal situation, solely aimed at optimising yields. In this study we explore the potentials for willow as an alternative crop in these buffer areas, and compare it to common grass cultivation for dairy farming, since this is the dominant crop currently cultivated in buffer zones [9]. The financial performance of willow vis-à-vis grass is assessed by calculating a break-even willow price; i.e. the price a farmer should obtain to make willow equally profitable as grass. This work is a case study in designing multiple land use in an agricultural context [10].

Essential input for such a calculation is the physical yield of willow and grass, in a buffer situation as well as in a yield-optimised one. Therefore, we adapted and used an agro-hydrological model to estimate such yields, as a relative percentage of a normal yield. Subsequently, we determined a break-even willow price making willow competitive to grass, and calculated such prices for buffer situations. We also performed a sensitivity analysis of the price calculations. Finally, we discuss the most salient points raised by the analysis and its implications.

2. Estimating relative yields of willow and grass in moist soils

2.1 Method

Yields of willow and grass in hydrologically optimised circumstances are available in the literature [11, 12]. However, yields in situations with water surplus are not easy to find. While for grass, yield reduction tables exist [13, 14], giving relative yields as a function of groundwater tables, no such information could be found on willow. Therefore, we developed a willow crop module in the agro-hydrological model SWAP to calculate relative yields for willow. For consistency, we used the same model with a ready-made grass module to calculate relative yields for grass.

SWAP[3], which stands for Soil-Water-Atmosphere-Plant [15], calculates growth reduction due to water surplus as a relative yield (RELY) compared to the yield in a hydrologically optimal situation. For the calculation of RELY, the model calculates actual relative root water extraction $S_a(z)$ as a function of soil water content for every small layer z in the root zone, for a large number of time steps. $S_a(z)$ and $S_p(z)$, the potential extraction, are related via a reduction factor α_w, which is dependent on the soil water pressure head h, a measure for soil water content. The model calculates h in each soil layer, on the basis of groundwater levels, atmospheric water input, actual uptake by the roots, and soil characteristics. The relation between α_w and h is schematised in Figure 4.1. The parameters h_1 to h_4 are crop-specific and input to the model. Figure 4.1 shows that a water content between h_2 and h_3 gives optimal root water extraction. When the soil becomes too wet (at h_2), water extraction is reduced until zero at h_1. On the other hand, when h decreases below h_3, water extraction is also reduced, because of drought.

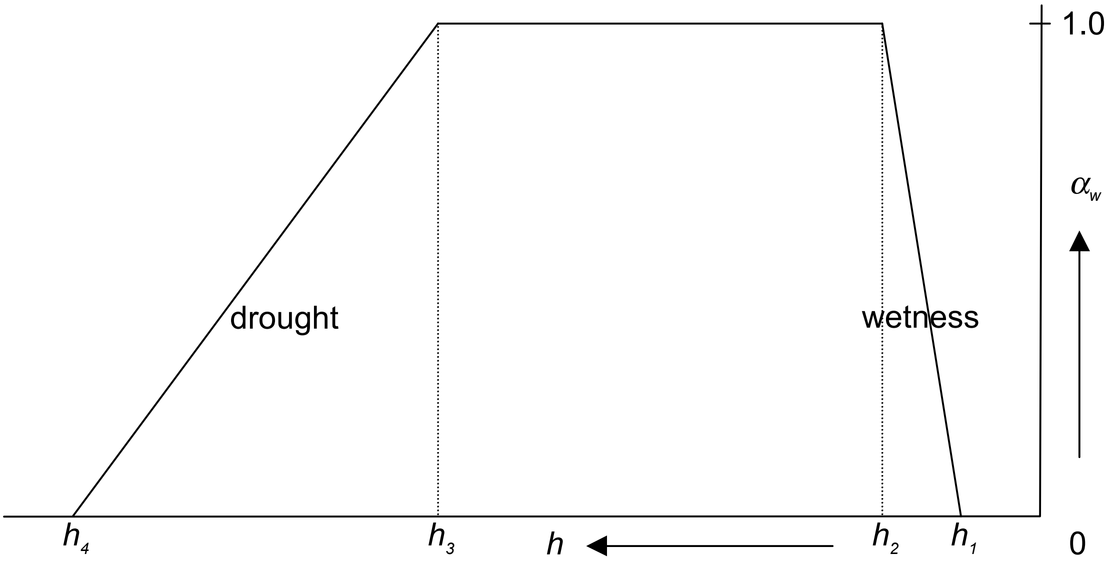

Figure 4.1: Reduction coefficient α_w as a function of soil water pressure head h. Source: Dam et al. [15], partially adapted.

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[3] : SWAP was developed by members of the Wageningen University and Research Centre.

By integrating $S_a(z)$ over the total root layer in each time step, the crop actual water extraction rate is calculated. By integrating this over the whole growing season, and comparing it to the potential extraction, a relative extraction factor is calculated. The relative yield RELY is then put equal to this factor. It should be noted that SWAP models growth reduction as a direct effect, caused by e.g. oxygen shortage in the root zone which leads to lower root activity and lower respiration rates. It neglects other indirect effects of water surplus, such as effects on soil temperature and lower nitrate availability [13].

Main ecophysiological inputs for the crop-water interaction module in SWAP are rooting depth, root density distribution and the critical pressure heads h_1 to h_4. It should be noted that the crop rooting depth is used as an external variable, independent of groundwater levels and soil type. Since in practice, rooting depth of any crop will depend on these factors, we adapted the rooting depth to the different groundwater levels modelled. Apart from such inputs, the model also needs several case-specific inputs on soil, hydrology, and weather conditions.

2.2 Parameterisation of the willow and grass crop modules in SWAP

SWAP requires a number of physiological crop parameters as inputs. For grass, the SWAP model package contains a ready-made module, which was used with minor adaptations (Table 4.1). For willow this module was parameterised by means of literature data. Parameters that affected the yield reduction are summarised in Table 4.1. The data used apply to *Salix viminalis*, the most commonly studied willow species for energy cropping, unless mentioned otherwise. Three parameters require some discussion.

Table 4.1: Crop parameters for willow and grass, serving as input for SWAP.

Parameter (SWAP code)	Willow						Grass
Start of crop growth (EMERGENCE)	June 1st after planting[1] May 15th after cutback[1] May 1st in other years[1]						March 15th [2]
End of crop growth (END_crop)	November 1st [1]						November 1st [3]
Rooting depth (RDTB) (cm)	Gt dependent [6]						40 or 30 [4]
h_1 (HLIM1) (cm)	20 [6]						-10 [5]
h_2 (HLIM2) (cm)	-20 [6]						-25 [5]
Root Density Distribution (RDCTB)	Rel. depth	0	0.22	0.33	0.56	1	Homogeneous[5]
	Rel. density[7]	2.3	1.9	1.6	1.3	0	

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[1]: Based on Iritz [16], Persson and Lindroth [17] and Eckersten and Slapokas [18]. Swedish data, Dutch season may be slightly longer.

[2]: Estimated by the temperature sum rule, supposing grass growth to start when the temperature sum has reached a value of 200 [19]. Given several years' weather data, March 15th is an average starting date.

[3]: Based on Dutch experience.

[4]: 40 cm given in SWAP model package. 30 cm is used only for the scenario with Gt I.

[5]: Value given in SWAP model package.

[6]: See text for details.

[7]: Based on Persson and Jansson [20].

Rooting Depth of willow (RDTB)

Given rooting depths for willow vary between 0.9 and 1.3 m in the literature [16, 20]. However, in soils with shallow groundwater tables rooting depth is probably less deep [7, 8]. We assumed that the crop roots do not grow underneath the lowest groundwater table that occurs throughout the year (see Figure 4.2). Furthermore, rooting depth is less during the first years after planting, since the root system is not yet fully developed at that time. Therefore we used different rooting depths for the first two years. Finally, willow with established roots responds to higher groundwater levels (in spring) by formation of new roots in the upper root zone [7, 8, 21, 22]. So we modelled the rooting zone slightly fluctuating throughout the year (see [9] for further details).

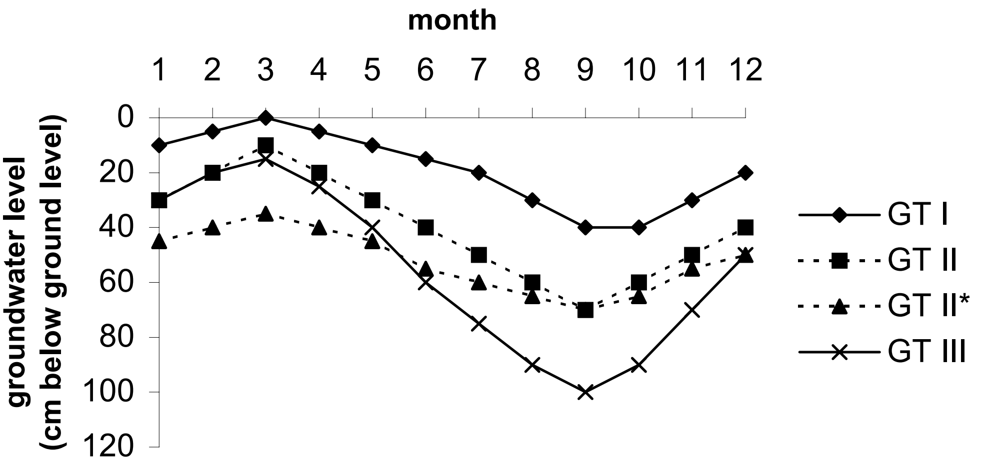

Figure 4.2: Groundwater levels during the year in the four chosen groundwater table class scenarios used in this study.

The critical pressure heads h_1 and h_2 of willow (HLIM1 and HLIM2)

These parameters were not directly available from the literature. Qualitatively, the flooding tolerance of willow is well known, and even supported by physiological observations, such as adventitious roots growth close to the water table [21], and the formation of aerenchyma, small internal channels through which air can diffuse into the anoxic parts of the roots [23]. Quantitative data were only available on pot experiments with willow growing in shallow groundwater levels [8, 21, 22, 24-26]. Although these studies consider different willow species, different soil types and different experimental conditions, we used them to get an estimation of h_1 and h_2. Figure 4.3 shows the linear regression, leading to +17 cm for h_1 and –21 cm for h_2.

Accounting for the fact that HLIM1 and HLIM2 are expressed relative to the root zone instead of relative to ground level, we rounded these figures to +20 cm for HLIM1 and –20 cm for HLIM2.

Case-specific inputs to SWAP

In order to make a rough indication of the hydrological situation in buffer areas, we scanned a number of Dutch region-oriented studies on desiccation abatement. Studies were selected that evaluated effects on nature, e.g. in terms of vegetation changes, as well as agriculture, e.g. in terms of yield losses [12, 27-34]. Data presented here were derived from these studies.

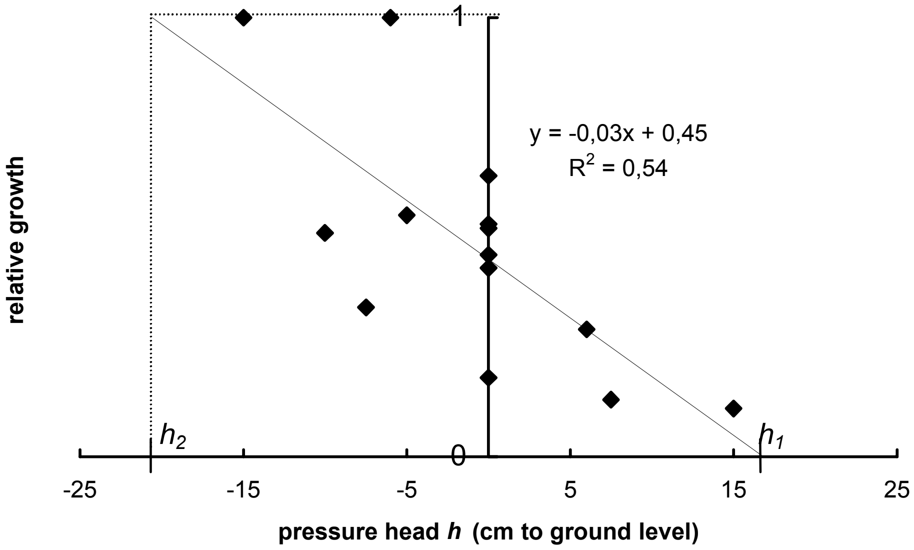

Figure 4.3: Estimation of h_1 and h_2 for willow from literature data.

Groundwater levels in lands surrounding desiccation abatement areas

In Dutch agro-hydrology, the conventional expression of groundwater levels is in terms of groundwater table class ('grondwatertrap', or Gt, in Dutch). A Gt is defined by a combination of average highest groundwater level and average lowest level throughout the year. Generally, the lower the Gt number, the moister the soil. The most frequently measured groundwater table classes in buffer zones were II and III. Corresponding yield reductions for grass varied from negligible to more than 20%. For this study we defined four groundwater table scenario's, roughly corresponding to Gt's I, II, II* and III. Figure 4.2 shows the corresponding groundwater fluctuations throughout the year.

Other case-specific inputs

We made calculations for a peaty topsoil on sand. This soil was chosen for its frequent occurrence in the abatement studies. The 'Staring Series' [35] was used to describe its hydraulic characteristics. We used day-to-day Wageningen meteorological station data, for the year 1986. This year had an average amount and pattern of rainfall (ca 700 mm) , compared to other years [30]. We modelled willow yields and yield reductions for a plantation with a 25-year total lifetime, with a 4-year rotation, which is relatively common for willow. We assumed that the crop is cut back after the first year after planting, to stimulate root growth and shoot formation. In the first year after planting, we assumed crop growth to be 25% of full-grown crop growth, and in each first year after coppicing to be 50% [11]. We considered grass to have a yearly growth cycle.

2.3 SWAP results and validation

In Figure 4.4, the relative yields (RELYs) for willow and grass at different Gt's are shown. For willow, these are 25-year averages taking differences in growth per year into account. For both crops, relative yields decrease with wetter conditions. Overall, willow has higher relative yields than grass, but at Gt's II* and III, the differences are relatively small. At Gt's II and I, there is a large difference between willow and grass, in favour of willow. Based on the physiological inputs for willow and grass, this result could be expected.

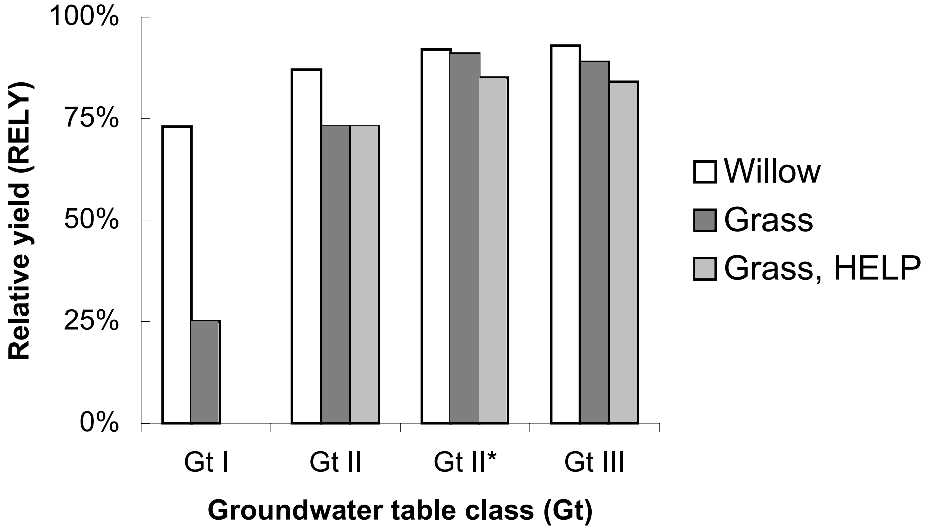

Figure 4.4: Relative Yields (RELYs) for willow and grass at different groundwater table classes, as calculated by SWAP, and the corresponding HELP data.

The results in Figure 4.4 can only be poorly validated, since field data on growth with water surplus of willow could not be found. For grass, the relative yields can be compared to those found in the 'HELP' tables, much-used yield reduction tables based on modelling and expert judgement. These commonly used data on yield depressions for grass and arable crops are based on modelling and field experience [13], and are also given in Figure 4.4. For Gt I, HELP does not give yield reduction figures. Generally, the relative yields given in the HELP table are slightly lower than those calculated by SWAP. This is what one would expect, since the HELP tables pretend to take all physiological effects of water surplus into account, including e.g. lower nitrate availability and effects on soil temperature. However, validation of these data should receive attention in future work.

3. Financial comparison of willow and grass production

The calculated relative yields can now be used for financial calculations. In this section we present a method for break-even price calculation. We do not perform a cost-benefit analysis or calculate an internal rate of return. This appeared to be impossible since currently there is no transparent market for energy wood in the Netherlands, making it impossible to estimate a willow sales price. As a consequence, we do not asses economic viability of the farming systems.

3.1 Method

The basic assumption in this study is that a farmer will start cultivating willow when his profit for cultivating willow is greater than that for his fodder crop (we neglect transition costs for a switch from grass to willow). We assume the farmer makes his decision purely on the financial criterion. In practice, non-financial arguments will complicate the farmer's crop choice, such as crop market security, acquaintance with the crop and its cultivation, and commitment to a farming style. We suppose that these factors are the same in buffer zones as in normal situations. As a consequence, the results of this study need not be representative for individual farmers' behaviour.

Grasslands are usually managed by dairy farmers for fodder production. We concentrated on a situation in which a part of their farm becomes buffer zone, and in which a possible compensation payment for the increased groundwater tables is maintained regardless of crop choice. Furthermore, we assumed that the farmer is not willing to adapt the whole farm structure, and keeps the same number of cows. So converting part of his grassland into willow plots means purchasing extra roughage elsewhere. This is financially attractive if the extra costs are less than the net profit for selling the energy crop (Table 4.2). Finally, we assumed that allocated costs for land and buildings are equal for grass and willow.

Table 4.2: The farmer's choice between grass and willow production in economic terms.

Situation: Farmer keeps milk production constant
Small part of his land becomes hydrologically sub-optimal buffer zone
Choice: keep buffer zone as grassland (1) or convert it into willow land (2)
Costs and benefits per ha per year

	Situation 1: Plot kept as grassland, No willow cultivation	Situation 2: Grass purchased externally, Plot converted into willow
Costs	Management of grassland (MC_g)	Purchase of grass (PC_g) Management of willow plot (MC_w)
Benefits		Sale of willow (SB_w)
Preferable when:	$SB_w - MC_w < PC_g - MC_g$	$SB_w - MC_w > PC_g - MC_g$

Based on the comparison in Table 4.2, we define the break-even willow price: the price of biomass that should be paid to make willow an equally competitive crop to grass. See Equation I, in which p_w^e is the break-even willow price (in €/odt), and y_w is the willow physical yield (in odt/ha.yr).

$$p_w^e = \frac{PC_g - MC_g + MC_w}{y_w} \qquad \text{I}$$

PC_g (in €/ha.yr) stands for the purchase costs of grass to substitute lost own production when willow is cultivated. The management costs MC_g and MC_w, defined in €/ha.yr, contain all costs necessary to maintain productive grassland or willow land, including fertiliser, contractor's work, and other factor and non-factor inputs. Since willow is a perennial species, and its costs vary over the years, these costs need to be calculated on an annual basis in order to enable a comparison to grass.

Equation I basically does not change when part of the farmer's land becomes buffer zone (assuming that a compensation is given independent of the crop type). The grassland productivity may decrease, but the farmer is compensated for this loss. Assuming that he keeps this compensation when converting, he still has a choice between grass and willow: the yields of both may be lower, and the ratio between both may change. Therefore p_w^e may be different.

3.2 Inputs for the break-even willow price calculation

In order to solve the cost-benefit comparison of Equation I and calculate a break-even willow price p_w^e, we made estimations of the different items.

Physical yields of willow (y_w)

Willow as an energy crop is not yet commercially cultivated in the Netherlands, so a 'normal' yield could not be derived from field data. According to the most recent assessment of crop yields for the Dutch situation [11], based on experimental field data and modelling, actual growth of a full-grown crop would be 13 odt/ha.yr. Our assumptions on crop growth after planting and coppicing then lead to actual yields of 3 odt/ha at first harvest after one year, and of 46 odt/ha in the following 4-year rotations. Conversion of these harvests into annuity at 7% gives an actual yield of 10 odt/ha.yr. In order to obtain actual yields at low Gt's, the yearly actual growth was multiplied by the corresponding RELY, summed to yields, and converted into annuity

Grass purchase costs (PC_g)

In a hydrologically optimal situation, grass can be grown to a value of € 1,400 /ha.yr (i.e. circa 12 odt/ha.yr at circa € 120 /odt). These data were obtained from the Dutch Agri-Economic Institute [36], as multi-year averages from a representative sample of Dutch dairy farms. To obtain grass purchase costs at lower Gt's, where yields will be lower, these costs were multiplied by the relative yields from Section 2. These numbers correspond fairly well to the compensation that is usually paid to farmers for damage due to water surplus. This amount varies between NLG 27 and NLG 30 per % damage per ha per year, corresponding to grass production values between € 1,200 and € 1,400 /ha.yr [27-29, 34].

Grassland management costs (MC_g)

The statistics on grassland management costs per hectare we used are given in Table 4.3 [36]. These data are based on a price for farmer's labour according to Dutch labour agreements (CAO), which is € 17 /h. This price often leads to a negative net result for the farm. Since farmers are still in business, it seems that farmers value their labour lower than at CAO rates. From statistical farm data [37] the farmer's value for his own labour can be estimated at € 5.1 /h. We corrected the data used for this difference.

Table 4.3: Total annual costs of willow and grassland management per ha used in this study. Based on: Coelman et al. [38] for willow and Langelaan [36] for grass.

Cost item	Willow costs (€/ha.yr)	Grassland costs (€/ha.yr)
Total attributable costs (fertiliser, other materials)	250	180
Contractor costs	210	170
Farmer's labour[1]	10	150
Farmer's machinery	450[1]	500
Other costs		100
Total costs	920	1,100

[1]: See text

Willow management costs (MC_w)

Willow management costs, derived from Coelman et al. [38], were also corrected for the lower valuation of the farmer's own labour, and converted into annuity at an interest rate of 7% (Table 4.3). Furthermore, we adapted the costs for farmer's machinery. The farmer's machines are used much less hours per ha per year in willow than in grass cultivation, so it seems plausible that the machine costs for willow cultivation are lower. On the other hand, we assumed that only a relatively small part of the farmer's land will become buffer zone, and potentially interesting for willow cultivation. Probably the farmer will still depreciate his machinery in the same amount of time, and his overall machine costs will stay the same [39]. He may, however, save some fuel and maintenance costs. We assume that a shift from grassland to willow will lead to a machine cost saving of 10% for the replaced hectares, leading to willow machine costs of € 451 /ha.yr. However, one could also assume that a farmer will re-optimise his machinery when he partly shifts to willow, and that his machine depreciation savings will not be negligible. Therefore, we also calculated a break-even price when machine costs are € 55 /ha.yr as mentioned in the literature [38], in the sensitivity analysis.

3.3 Results of the financial analysis

Table 4.4 shows the changes in the purchase costs for grass (PC_g) and willow yield (y_w) due to changes in groundwater table class. These changes result in different break-even willow prices p_w^e, which are also given. The values for the break-even willow price decrease when the situation gets wetter. It may seem paradoxical that willow competitiveness increases with decreasing physical yield. But this is caused by a stronger decrease in grass yields. At Gt II the break-even willow price is 20% lower than in an optimal, single purpose cultivation situation, which is a significant decrease.

Table 4.4: Values for grass purchase costs (PC_g), willow yield (y_w) and willow price at break-even (p_w^e), for different groundwater table classes on peaty soil.

	Gt I	Gt II	Gt II*	Gt III	Optimal[1]
p_w^e (€/odt)	24	100	120	120	125
PC_g (€/ha.yr)	360	1050	1300	1,300	1,400
y_w (odt/ha.yr)	7.3	8.7	9.2	9.3	10.0

[1]: Results for a hydrologically optimal situation, i.e. without any yield reduction for both crops.

For Gt I the break-even willow price becomes extremely low, with a price reduction of 80%. This means that cultivating grass on such land is extremely unproductive. It is questionable whether grassland is a realistic reference land use in such a case; may be willow should be compared to e.g. fallow land. Therefore we will not use the Gt I scenario any further. The physical yield of willow at Gt I, however, indicates that willow cultivation may still be physiologically possible at Gt I.

4. Sensitivity analysis

The data used have different reliability. Since validation of the results is practically impossible at the moment, we use sensitivity analysis as a method to explore the effects of variation in input parameters on the outcomes. Two types of parameters were analysed in the sensitivity analysis of break-even willow price in the Gt II scenario, viz. the most important financial items (Figure 4.5), and the dominant factors affecting the RELYs of willow and grass (Figure 4.6). For the SWAP parameters, a relative change was first translated into a change in RELYs, which was translated into a relative change in the break-even willow price.

Figure 4.5 and Figure 4.6 show that the inputs for grass cultivation with the strongest effect on p_w^e are the shadow price and the optimal yield, as could be expected. These inputs were derived from agricultural statistics and are relatively reliable. Of the inputs for willow, its optimal yield has the strongest impact (Figure 4.6). This figure is less reliable than the grass yield, since there is still little practical experience in willow cultivation for energy by Dutch farmers. When this experience is being built up, this input can be estimated better.

Changes in other financial items (Figure 4.5) have a relatively limited impact on p_w^e compared to the grass shadow price. Some changes in the input to SWAP, and thereby in the RELYs of willow and grass, require some discussion. Changes in the factors rooting depth (RDTB) and the length of the crop cycle with the starting date in spring as variable (LCC1) appear to have the strongest effect on yield reduction. For willow, the growth season data are reliable, but were derived from Swedish studies. The rooting depth data (RDTB) have been derived from a limited number of experiments, none of which was performed under relatively wet soil conditions. Furthermore, rooting depth can vary greatly per situation, in which soil type, compactness and penetrability for roots are important factors [40]. Therefore, more reliable and case-specific data for this parameter deserves priority.

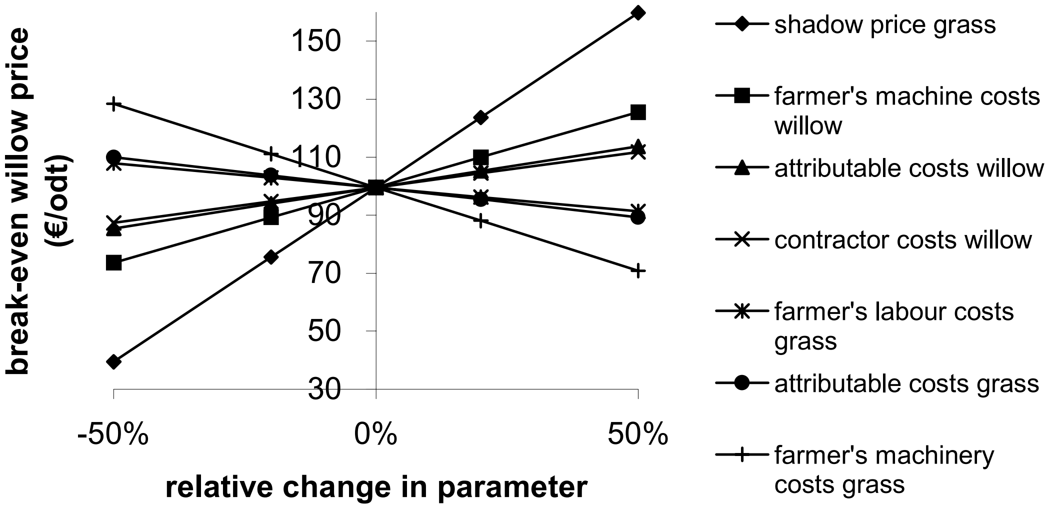

Figure 4.5: Effects of variation of financial inputs on the break-even willow price p_w^e.

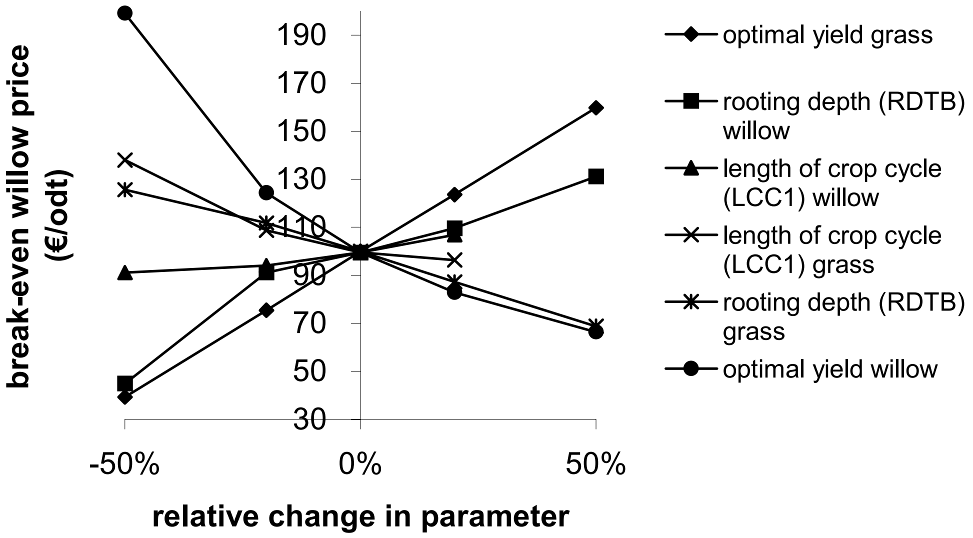

Figure 4.6: Effects of variation of yield inputs on the break-even price p_w^e.

Variations in the SWAP inputs h_1 and h_2 (HLIM1 and HLIM2 in the model) and the ending date of growth in autumn (LCC2) have less influence on the break-even willow price. As a consequence, the uncertainties in the relative growth line depicted in Figure 4.3 are not major contributors to errors in the yield reduction estimation.

An input parameter not depicted in Figure 4.6 is the relative root density distribution (RDD). Since this parameter cannot be varied simply as a percentage, we have calculated the effect of a homogeneous root distribution, and of one twice as superficial as the original one (i.e. 15% instead of 30% of all roots in the lower half of the root zone). The homogeneous distribution led to a higher break-even price (€ 104 /odt), the more heterogeneous one to a lower one (€ 95 /odt): relatively negligible effects.

Furthermore, we calculated the effect of changes in some assumptions (Table 4.5). A different machine costs saving calculation has a strong impact on break-even willow price. A price based on full saving is almost 50% lower than the price based on our assumptions. Both may be too extreme to approximate reality, but it is clear that the assumptions on machine costs need thorough consideration. The same applies to the choice to value farmer's labour not at a price according to labour agreements, but at a lower shadow price. With CAO prices, p_w^e decreases drastically, because grass cultivation is more labour intensive than willow. Finally, a 50% cheaper willow harvest leads to a smaller, but still significant decrease in break-even willow price, illustrating the effect of technical improvement and management cost savings, which, in harvesting costs, are still well to be expected.

Table 4.5: Effects of changes in some assumptions on the willow price p_w^e at Gt II.

Item	Change	Standard value	New value	Break-even willow price p_w^e at Gt II
Standard scenario	-	-	-	€ 100 /odt
Farmer's machinery	Willow machinery costs according to technical lifetimes	€ 451 /ha.yr	€ 55 /ha.yr	€ 54 /odt
Price farmer's labour	According to labour agreements (CAO)	€ 5 /h	€ 17 /h	€ 64 /odt
Harvesting costs willow	50% cost reduction	€ 101 /ha/harvest	€ 50 /ha/harvest	€ 89 /odt

5. Discussion

5.1 Comparison of calculated break-even willow prices to other studies

The break-even willow prices of this study can be compared to other studies. However, other studies in which willow cropping was compared to grass cultivation were not found. Therefore, we use three studies in which willow cropping was compared to arable crops, such as wheat and potatoes, or to fallow land, all in the Dutch context. We also compared the assumptions in these studies on labour and machinery costs, and their willow production cost calculations. In Table 4.6 the calculated break-even willow prices are compared to those estimated in this study.

The break-even prices for optimal situations in competition with other crops ([42], [43] and this study) lie in a relatively small price range. This is surprising, since grass as a crop has less value added than directly marketable crops such as potatoes or sugar beets. Therefore one would expect the price as calculated in this study to be lower. However, the other studies have other assumptions concerning labour costs, machinery and willow production costs, which may explain this effect. The comparison to grass fallow [41] is even more complicated: grass fallow should be non-value added, and therefore not a strongly competing crop. However, their assumptions are also different, and their willow yield estimation of 7.1 odt/ha.yr is low compared to the other authors, who assess yields between 10 and 12 odt/ha.yr.

Table 4.6: Overview of willow biomass prices in break-even situations with other crops.

Source	Comparison to	Assumptions		Willow production costs[3]	Break-even willow price p_w^e (€/odt)
		Labour[1]	Machine costs[2]		
Biewinga and Bijl [41]	Grass fallow	CAO	Unclear	Planting and harvesting ca 25% cheaper	106 [4]
Rijk [42]	Arable crops	CAO	Saving	Planting 25% and harvest 60% cheaper	133 [5]
Vlasblom [43]	Winter wheat	Shadow	No cost reduction	Overall ca 25% cheaper	137 [6]
This study	Grassland optimal	Shadow	No cost reduction	-	125
This study	Grassland at Gt II	Shadow	Id.	-	100
This study	Grassland at Gt II	CAO	Id.	-	64

[1]: 'CAO' means that farmer's labour is priced at the standard labour tariffs; 'Shadow' means that a lower shadow price for labour was used (for willow as well as for the other crop).

[2]: 'Saving' means that the farmer's machine costs decrease when he uses his machinery less in willow than in his competing crop; 'no cost reduction' is the approach adopted in this study.

[3]: Willow production costs estimations compared to those in this study.

[4]: Original data included a € 500 /ha.yr subsidy.

[5]: Original data included chipping costs.

[6]: Partly based on Coelman et al.[38]

The break-even willow prices calculated by others appear to be higher than the one at Gt II in this study. However, the differences in assumptions complicate the comparison. For example, when calculating farmer's labour at CAO prices, the break-even willow price at Gt II is circa 50% lower than as calculated by others in other optimal situations (see Table 4.6).

This comparison makes clear that willow energy cropping in a wet area may lead to a significantly lower break-even price compared to other cost estimations. This saving may be even greater when, at Gt II, willow would replace arable crops in buffer zones, since these are less well able to tolerate wet conditions than grass.

5.2 Discussion on the input data

The data on costs of willow and grass are relatively generic. Grassland management costs are based on generalised data; they are not applicable to a specific situation. The data on willow management are based on calculations and not on practice, and therefore may contain large uncertainties. However, the sensitivity analysis indicates that the break-even willow price does not change dramatically with changes in these cost items. The most influential parameter, the grass shadow price, is relatively reliable.

The data used for estimation of optimal and relative yields also contain uncertainties. The parameters with considerable uncertainty, i.e. h_1 and h_2, appear to have relatively little influence. Of the two most influential parameters, the optimal yields of willow and grass, the data for grass are relatively well known, while the willow yield is based on experiments and models. Relatively large uncertainties occur in medium important factors such as rooting depth and growth cycle length.

5.3 Methodological discussion

In this study the farmer's choice between two crops is reduced to a financial deliberation. As mentioned before, other aspects also influence this choice, such as acquaintance with a crop and commitment to a farming style. This means that not all farmers will start cultivating willow at p_W^e, and these results can not be used to predict farmer's behaviour. However, the results do give an impression of the difference between a hydrologically optimal and a buffer situation. But it should be noted that the figures can only be applied to a situation in which a farmer changes only a minor part of his farm into willow, and in which a financial compensation for yield losses is not affected by the crop choice.

Since the sensitivity analysis makes clear that the assumptions to estimate farmer's labour and machinery costs have significant implications for calculated break-even willow prices, they should be borne in mind when translating the methodology into other situations.

The survey on hydrological conditions in buffer areas illustrates that there can be large differences between such areas, and that a common rule cannot be given [9]. Therefore, a potential area with relatively low break-even willow prices cannot be given based on these data. However, the relevance of the results need not be limited to buffer areas only. A sample study indicates that more than 200,000 ha land in the Netherlands has been categorised as Gt II [44]. In these areas a competitive advantage for willow may also be expected.

The method to estimate relative yields in wet areas is still relatively preliminary. Quantitatively, only one aspect of water surplus was dealt with, and validation of the method was hardly possible. Furthermore, aspects of management adaptation are not considered. For example, farming on moist soils may lead to extra investment in adapted machinery, but reduced growth can also make it possible e.g. to decrease willow harvest intensity from once in four years to once in five years, thereby lowering costs. Comparable options are also possible for grassland. Such situation-specific management choices need to be worked out further.

Relative yields and cost and benefits were calculated on the basis of the weather conditions of one year, and for one soil type. In order to get an insight of the impact of these conditions, other years and soil types should also be calculated.

6. Conclusions

Model calculations on willow energy farming in buffer zones with relatively wet soil conditions show a lower break-even price in competition with grass than willow farming in dryer, hydrologically optimal situations. At Gt's I and II, willow has less yield reduction than grass, to which it was compared. Given the assumptions in this study and the input data used, differences in calculated relative yields lead to a 20% lower break-even willow price at Gt II. It should be noted, however, that the break-even price as defined in this study, can not directly be considered a potential cost price, since other factors play an important role in such price setting.

The break-even willow price in a hydrologically optimal situation, as calculated in this study, is comparable to the values found in other studies for the Netherlands. However, this comparison is complicated by differences in assumptions on labour, machine costs, and yield levels, and by the difference in value added between grass as roughage and food crops.

Analysis of the methodology and the data used indicates that the absolute values of the calculated break-even willow prices can be disputed. Nevertheless, we can still conclude that willow cropping is more competitive to grass production in wet areas, such as Dutch desiccation abatement areas, than it is in hydrologically optimal situations.

Acknowledgements

The authors would like to thank dr. Jos van Dam (Wageningen University, Department of Water Resources) for providing help with the SWAP model. Ir. Marieke Meeusen (Dutch Agricultural Economics Research Institute) is acknowledged for her advice on the economic comparison of crops. Drs. Wim ter Keurs (Leiden University, Environmental Biology) as well as prof. dr. Hans de Kruijf, dr. Pita Verwey and ir. Richard van den Broek (all Utrecht University, Department of Science, Technology and Society) provided useful comments on draft versions. And we would like to thank the two referees for their comments.

References

1. Hall, D.O. and J.I. House. *Biomass energy in Western Europe to 2050.* Land Use Policy 1995, 12 (1): 37-48.
2. Faaij, A., I. Steetskamp, A. van Wijk, and W. Turkenburg. *Exploration of the land potential for the production of biomass for energy in the Netherlands.* Biomass and Bioenergy 1998, 14 (5/6): 439-456.
3. RIVM, IBN-DLO, LEI-DLO, and SC-DLO. *Natuurbalans 1998 (Nature balance 1998).* Alphen aan den Rijn: Samson H.D. Tjeenk Wililink, 1998.
4. Beugelink, G.P. *Personal Communication dated September 30, 1998.* Bilthoven: RIVM, 1998.
5. Londo, M. *Unpublished calculations, based on data from RIVM et al., 1998.* Utrecht: Utrecht University, 1999.
6. Beugelink, G.P. and F.A.M. Claessen. *Operationalisatie van de 25%-doelstelling verdroging: maatregelen, kosten en effecten (Operationalisation of the 25% target on desiccation abatement: measures, costs and effects).* Bilthoven: RIVM/RIZA, 1995.
7. Good, J.E.G., J.D. Winder, E. Sellers, and T.G. Williams. *Species and clonal variation in growth responses to waterlogging and submersion in the genus Salix.* Proceedings of the Royal Society of Edinburgh 1992, 98B 21-48.
8. Jackson, M.B. and P.A. Attwood. *Roots of willow (Salix Viminalis L.) show marked tolerance to oxygen shortage in flooded soils and solution culture.* Plant and soil 1996, 187 37-45.
9. Londo, M., L. Vleeshouwers, J. Dekker, and H. de Graaf. *Energy farming in Dutch desiccation abatement areas: Effects on break-even biomass price.* Utrecht: Dept. of Science, Technology and Society, Utrecht University, 1999.
10. Londo, M., J. Dekker, P. Verweij, and H. de Graaf. *Multiple land use on land unit level in rural areas: towards operationalisation.* Submitted to Land Use Policy.

11. Gigler, J.K., M.J.G. Meeusen - van Onna, and E. Annevelink (eds.). *Kansen voor energie uit biomassa! Resultaten van een 4-jarig DLO-onderzoekprogramma (Opportunities for energy from biomass! results of a 4-year DLO research programme).* Wageningen: Dienst Landbouwkundig Onderzoek, 1999.
12. Minnema, B., R.J. Stuurman, and J.E. Vlot. *Hydrologisch onderzoek naar de regeneratie mogelijkheden van grondwaterafhankelijke natuurwaarden in de Mortelen en het Veldersbosch (Hydrological study on regeneration potentials of groundwater dependent nature values in the Mortelen and the Veldersbosch).* Delft: TNO-IGG, 1993.
13. Werkgroep HELP-tabel. *De invloed van de waterhuishouding op de landbouwkundige productie (Influence of water management on agricultural production).* Utrecht: Landinrichtingsdienst, 1987.
14. KWIN-V. *Kwantitatieve informatie veehouderij 1998-1999 (Quantitative Information on Cattle Farming 1998-1999).* Lelystad: Praktijkonderzoek Rundvee, Schapen en Paarden, 1998.
15. Dam, J.C. van, J. Huygen, J.G. Wesseling, R.A. Feddes, P. Kabat, P.E.V. van Walsum, P. Groenendijk, and C.A. van Diepen. *Theory of SWAP version 2.0; simulation of water flow, solute transport and plant growth in the Soil-Water-Atmosphere-Plant environment.* Wageningen: Wageningen Agricultural Univerisity and DLO Winand Staring Centre, 1997.
16. Iritz, Z. *Energy balance and evaporation of a short-rotation willow forest.* Uppsala: SLU (PhD Thesis), 1996.
17. Persson, G. and A. Lindroth. *Simulating evaporation from short rotation forest: variations within and between seasons.* Journal of Hydrology 1994, 156 21-45.
18. Eckersten, H. and T. Slapokas. *Modelling nitrogen turnover and production in an irrigated short-rotation forest.* Agricultural and Forest Meteorology 1990, 50 99-123.
19. Peerboom, J.M.P.M. *Waterhuishoudkundige schadefuncties op grasland (Hydrological damage functions on grassland).* Wageningen: SC-DLO, 1990.
20. Persson, G. and P.E. Jansson. *Simulated water balance of a willow stand on clay soil.* In: Perttu, K.L. and P.J. Kowalik (eds.). *Modelling of energy forestry: growth, water relations and economics.* Wageningen: Pudoc, 1989. 147-162.
21. Knighton, M.D. *Growth response of speckled alder and willow to depth of flooding.* St. Paul: Research paper NC-198, USDA Forest Service,, 1981.
22. Talbot, R.J., J.R. Etherington, and J.A. Bryant. *Comparative studies of plant growth and distribution in relation to waterlogging XII: Growth, photosynthetic capacity and metal ion uptake in Salix Caprea and S. cinerea spp. Oleifolia.* New Phytologist 1987, 105 563-574.
23. Kawase, M. and R.E. Whitmoyer. *Aerenchyma development in waterlogged plants.* Amer. J. Bot. 1980, 67 (1): 18-22.
24. Andersen, P.C., P.B. Lombard, and M.N. Westwood. *Leaf conductance, growth, and survival of willow and deciduous fruit tree species under flooded soil conditions.* J. Amer. Hort. Sci 1984, 109 (2): 132-138.
25. Iremonger, S.F. and D.L. Kelly. *The responses of four Irish wetland tree species to raised soil water levels.* New Phytologist 1988, 109 491-497.
26. McLeod, K.W., L. A. Donovan, N.J. Stumpff, and K.C. Sherrod. *Biomass, photosynthesis and water use efficiency of woody swamp species subjected to flooding and elevated water temperature.* Tree Physiology 1986, 2 341-346.
27. Walsum, P.E.V. van. *De waterhuishouding van het Bargerveen en het herinrichtingsgebied Schoonebeek; Scenario-analyse Waterbeheer (Water management of the Bargerveen and the reallocation area Schoonebeek: scenario analysis water management).* Wageningen: SC-DLO, 1998.
28. Leerdam, A. van, J.W.P.M. van Poppel, and D.L.J. Heikens. *Verdrogingsbestrijding Groote Molenbeek (Desiccation abatement Groote Molenbeek).* 's Hertogenbosch: IWACO, 1997.
29. Walsum, P.E.V. van and A.A. Veldhuizen. *Modelstudie waterhuishouding Fochteloërveen en omgeving (Model study water management Fochteloërveen and surroudings).* Wageningen: SC-DLO, 1996.
30. Massop, H.Th. L., J.M.P.M. Peerboom, and H.C. van Vessem. *Effectbepaling anti-verdrogingsmaatregelen Landgoed 'De Wildenborch'.* Wageningen: SC-DLO, 1994.
31. Anonymous. *Verdrogings- en eutrofieringsproject Maasmeanders (Desiccation and eutrophication project Maasmeanders).* Oosterhout: Oranjewoud, 1993.
32. Bruchem, A. van, P. van den Munckhof, L. Runia, and C. Schellingen. *Ecohydrologisch onderzoek Mariapeel-Deurnse Peel (Ecohydrological study Mariapeel-Deurnse Peel).* Oosterhout: Oranjewoud, 1993.
33. Goossensen, F.R. and D. van der Hoek. *Verbetering waterhuishoudkundige inrichting Bennekomse Meent (Improvement of hydrological management Bennekomse Meent).* Wageningen/Deventer: LU Wageningen/Heidemij, 1993.

34. Anonymous. *Landbouwopbrengsten in het Reestdal; veranderingen als gevolg van ingrepen in het waterbeheer (Agricultural yields in the Reestdal; changes due to measures in water management).* Groningen: IWACO, 1992.
35. Wösten, J.H.M., G.J. Veerman, and J. Stolte. *Waterretentie- en doorlatenheidskarakteristieken van boven- en ondergronden in Nederland: de Staringreeks (Water retention and permeability characteristics of top- and subsoils in the Netherlands: the Staring series).* Wageningen: SC-DLO, 1994.
36. Langelaan, I. *Data on grassland management costs and benefits. Unpublished calculations.* The Hague: LEI-DLO, 1999.
37. Anonymous. *Bedrijfsuitkomsten in de landbouw 1992/93-1997/98 (Company results in agriculture 1992/93-1997/98).* The Hague: LEI-DLO., 1999.
38. Coelman, B.T. (ed), B. Pijanowska, G.J. Kasper, J.K. Gigler, C. Sonneveld, W. Huisman, E. Annevelink, J. van Doorn, A. Bos, R. van der Pluijm, and M. de Boer. *Mogelijkheden voor kleinschalige energie-opwekking met geteelde biomassa (Possibilities for small-scale energy production with cultivated biomass).* Wageningen: CPV, IMAG-DLO, ECN, 1996.
39. Heaton, R.J., P.F. Randerson, and F.M. Slater. *The economics of growing short rotation coppice in the uplands of mid-Wales and an economic comparison with sheep production.* Biomass and Bioenergy 1999, 17 (1): 59-73.
40. Wiersum, L.K. and A. Reijmerink. *Beworteling (Rooting).* In: Locher, W.P. and H. de Bakker. *Bodemkunde van Nederland (Soil Science of the Netherlands).* Den Bosch: StiBoKa/Malmberg, 1987.
41. Biewinga, E.E. and G. van der Bijl. *Sustainability of energy crops in Europe; a methodology developed and applied.* Utrecht: CLM, 1996.
42. Rijk, P., S. van Loo, and R. Webb. *Haalbaarheidsstudie van een biomassa gestookte warmte/kracht-installatie in de gemeente Groningen (Feasibility study of a biomass-fueled CHP installation in the municipality of Groningen).* The Hague: LEI-DLO, 1996.
43. Vlasblom, J. *Do energy crops boost the economy? An assessment of the national and regional economic impacts of electricity from energy crops.* Utrecht: Utrecht University, Dept. of STS, 1997.
44. Loo, H. van het. *Steekproef voor de bodemeigenschappen en grondwatertrappen van de Bodemkaart van Nederland schaal 1:50.000; Kaarteenheden met Gt II (Random check on the soil characteristics and groundwater table classes of the Soil Map of the Netherlands scale 1:50,000; Map units with Gt II).* Wageningen: SC-DLO, 1997.

Chapter 5

Willow Short Rotation Coppice for energy and breeding birds: An exploration of potentials in relation to management[*]

Abstract

Short-rotation coppice of willow for energy may be an attractive habitat for many breeding bird species. In this study, we systematically explore the possible relations between design and management of willow SRC and the occurrence of individual species and ecological groups of breeding birds. An additional purpose is to develop hypotheses on ecological factors determining these relations. Methods are literature review and expert consultation.
The analysis indicates considerable opportunities to increase willow SRC potentials, with limited productivity reduction, especially for breeding birds of shrubs and hedges. Exemplary design and management packages, with corresponding breeding bird species, were developed. Notwithstanding the uncertainties and qualitative nature of the results, the analysis offers starting-points for managers willing to pay attention to breeding birds. It can also be worked out to hypotheses on management-breeding bird relations for further field research.

For government steering strategies to enhance adapted design and management of willow SRC, two approaches are evaluated in the framework of agency theory: rewarding behaviour versus rewarding actual results. A mixed type of policy may be most suited to reduce financial risks for the field manager, as well as to overcome the moral hazard problem and encourage the manager's creativity and learning.

Keywords: Breeding birds, willow, short rotation coppice, multiple land use.

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[*]: Co-authors: Jos Dekker (Dept. of Science, Technology and Society, Copernicus Institute, Utrecht University) and Wim ter Keurs (Section Environmental Biology, Institute of Evolutionary and Ecological Sciences, Leiden University). Submitted to Biomass and Bioenergy.

1. Introduction

The introduction of dedicated crops for bioenergy in densely populated countries such as the Netherlands is strongly hampered by land scarcity and the limited competitiveness of energy crops compared to food crops [1, 2]. Apart from crop management cost reduction and improvement of conversion technologies, combining energy farming with the production of other goods or services may be an option to improve chances for energy crops. Different strategies have been proposed:

- Multi-product cropping, e.g. selling part of a woody crop for construction, the other part for energy production [3];
- Cascading, e.g. first using wood for high-value applications, and later using the worn-out material for energy production [4, 5];
- Multiple land use, e.g. co-using energy cropland for other types of land use like nature conservation, recreation or groundwater protection [6-9].

In this study, we concentrate on energy cropping of willow in multiple land use systems. For this energy crop, with its relatively low-value wood, multiple land use may be the only suited option of the proposed three. In Londo et al. [10] (Chapter 2), we have discussed some methodological aspects of the multiple land use concept, including a method for feasibility assessment of specific combinations, and strategies for optimisation when land use requirements are conflicting. Many proposed co-uses of energy cropping, like recreation or wildlife protection, (partly) depend on the occurrence of flora and fauna in energy crops. Therefore, information on the potentials for flora and fauna in energy cultivation is needed, as well as insights in how e.g. densities and species composition can be steered by design and management of the plantation. While many studies have been reported describing wildlife in energy crops [11-18], studies that relate the occurrence of wildlife to design and management of the plots are scarce [19, 20]. In the optimisation of multiple land use systems (see chapter 2), such information is indispensable for the performance evaluation of willow production as well as nature-related co-functions.

In this study, we limit ourselves to a well-visible and well-studied group of fauna with broadly recognised relevance for nature conservation and recreation: breeding birds. We systematically explore the possible relations between design and management of willow in short rotation coppice (SRC) and the occurrence of breeding bird species by literature review and expert consultation, and seek for ecological factors causing these relations. An additional purpose is to develop hypotheses that can be tested in further field research. Some specific design and management options and their corresponding potentials for breeding birds are elaborated. Besides, we discuss possible policy strategies to stimulate such design and management in willow SRC in the framework of agency theory.

The structure of this chapter is as follows. We shortly discuss the general method of analysis in section 2; the results can be found in sections 3, 4 and 5. These are input for a synthesis: constructing management packages (described in the set of design and management variables) and corresponding breeding bird species to be expected. Some examples and a discussion on this can be found in section 6. Reflection and discussion on policy strategies on breeding bird enhancement can be found in section 7. We end with discussion and conclusions.

2. Methods

2.1 A 'classical' approach versus detailed optimisation

In studies on the relation between agriculture and nature, a classical approach is to assume an inverse relation between the two: intensification of field management (and corresponding higher productivity) leads to lower nature qualities [21-23]. Vice versa, improving nature quality then requires extensification of management and lower agricultural productivity (strategy 1 in Figure 5.1; note that, when loss in nature quality is irreversible, this reasoning cannot be applied). However, this agriculture-nature relation is a hypothetical one, and in practice many deviating combinations of productivity and nature quality can be observed. The relation between productivity and nature quality is caused by a number of system and management variables that can be optimised (strategy 2). In such a strategy, nature quality may be improved keeping productivity constant or even improving it: the two seemingly conflicting targets can be (partly) reconciled. An example of this strategy can be found in Kruk [24], in which the relation between dairy grassland productivity and meadow bird breeding success was analysed. It appeared that the statistical correlation between meadow bird density and general agricultural intensity (e.g. expressed in live stock units per ha), is probably explained by more specified management variables such as fertilisation intensity and mowing date. Depending on the weather in a specific season and the local arrival date of the first meadow birds, mowing dates can be set in such a way that bird clutches are hardly harmed and productivity is hardly diminished.

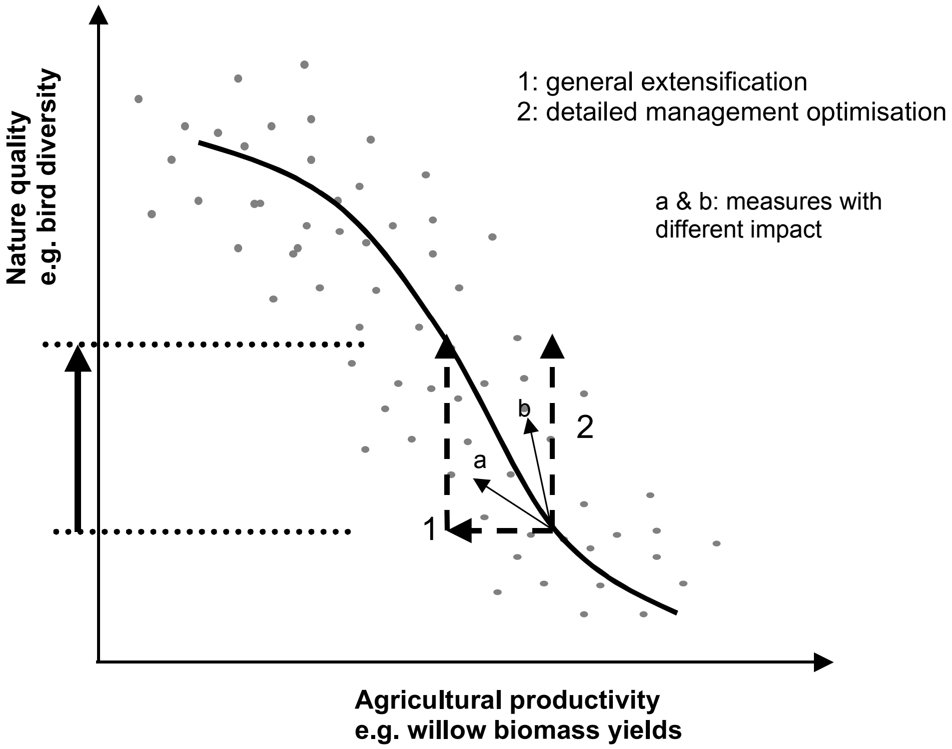

Figure 5.1: Fictitious illustration of two strategies for improving nature quality in agricultural systems. Source: Keurs [25], partially adapted.

Such a strategy of detailed management optimisation can be observed in more recent research on management strategies for agriculture and multifunctional woodlands [24, 26-28]. It is also part of our proposed procedure for multiple land use exploration, as a final phase in which a combination of two types of land use is optimised in its land use requirements [10].

In order to adopt a detailed optimisation strategy for improving nature qualities in willow SRC, detailed information is required on the effects of energy plantation design and management on productivity as well as on flora and fauna. While detailed insights in willow yields as a function of management are evolving [29, 30], ecological guidelines are still relatively generic [31]. Only Sage and Robertson [20] tried to statistically correlate songbird densities to specific site variables like planting density or crop height. They found songbird species diversity to be positively correlated to a 'structure variable', indicating vegetation density of crop and undergrowth. Sage [19] did a comparable study on wild plants. It is not surprising that such research is scarce: it requires extensive transversal and/or longitudinal field research to identify management-bird relations in detail. Such field research is currently impossible in the Netherlands, because willow SRC plantations for energy have only recently been established and are still scarce. Therefore we based this study mainly on literature research and expert consultation.

2.2 Choices and assumptions

We concentrate on willow as an energy crop, mainly because it is well studied, also in terms of wildlife occurrence [11, 12, 15-18]. As a species group we selected breeding birds, since this is a well-visible group significant for e.g. recreation and conservation, and well-surveyed in willow SRC [11, 12, 15-18]. We do not consider breeding birds as an indicator group for other groups of flora and fauna, or 'ecosystem health': for such an assumption, there is still insufficient knowledge on the correlation between different taxa, e.g. floral diversity and breeding bird density. We focus at the plantation level; plantation size set at ca 10 ha. This is a manageable unit for a plantation, and woodland bird densities are also commonly expressed per 10 ha. Furthermore, we assume that species using willow SRC for part of their activities, and surrounding habitats (grassland, cropland) for others, can find these surroundings without problems.

We also assume that colonisation will not be a limiting factor, and that, if the plantation is suitable for a specific bird species, the species will find and use it. Given that willow SRC can be considered a pioneer vegetation, originally occurring in dynamic environments, it can be assumed that related breeding birds will be well able to colonise new plantations. For migrant species, we do not deal with potential population reductions due to problems in migration or wintering habitats, which might lead to decreased use of (suitable) habitats in the bird's breeding area. We revert to these assumptions in the discussion.

We take breeding bird species diversity as our valued end point. Species appreciation in terms of conservation value (or other criteria) might be vital when it comes to subsidising the occurrence of species, but is not taken into account in this study.

2.3 Adopted method

Given these choices and assumptions, we analysed the relation between willow SRC design and management and the potential presence of breeding birds according to the model in Figure 5.2.

On the basis of a number of agro-technical studies on willow SRC, we specified plantation design and management in terms of a set of variables (see Section 3). We constructed a longlist of breeding birds to be expected, on the basis of field surveys in modern willow SRC as well as traditional willow coppice as it still exists in the Netherlands. These species were ordered according to an ecological group classification (see Section 4).

In order to analyse the links between management variables and (ecological groups of) breeding bird species, we interviewed a number of field experts as well as Dutch bird researchers. The interview results were presented and discussed in a workshop. Rather than a standard expert judgement, we also discussed the assumed mechanisms behind the judgements (see Section 5).

The integrated information obtained in interviews and workshop provided the basis for the construction of management packages (see Section 6).

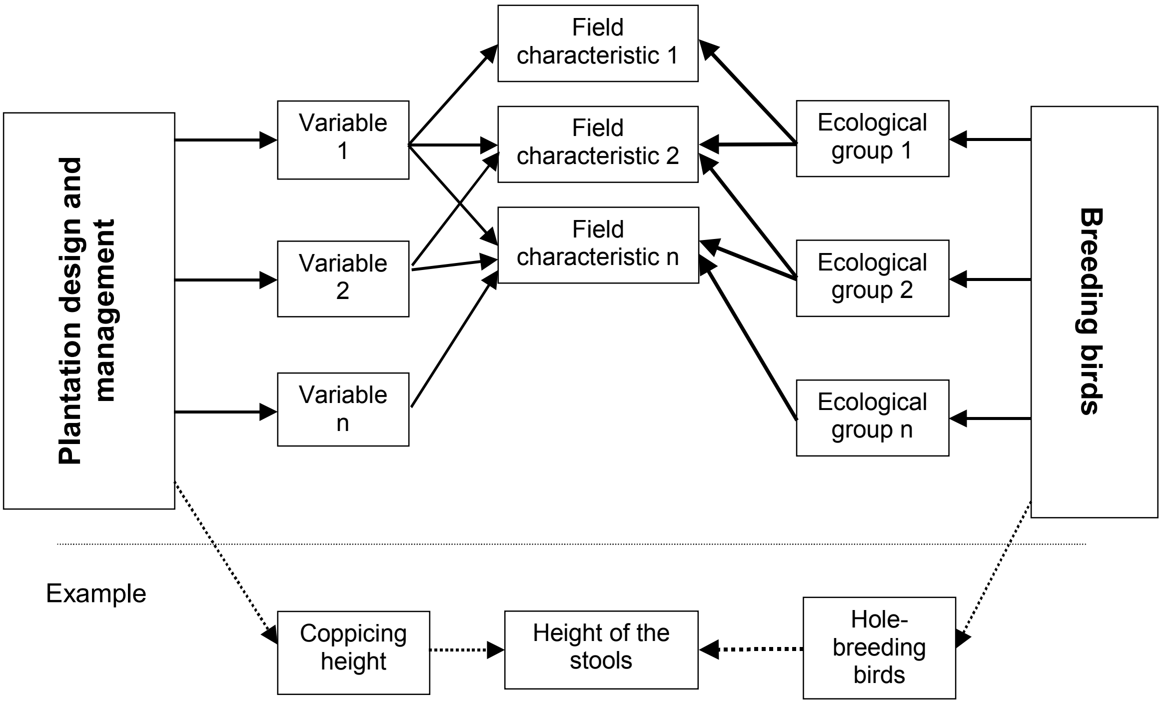

Figure 5.2: Model for the analysis of relations between plantation design and management and breeding birds' occurrence.

This method is closely related to the method as used in Chapter 2, in which products are associated with Land Use Types (LUTs), which are specified into Land Use Requirements (LURs) [10]. The design and management variables (Section 2) can be considered LURs. However, since birds merely respond to field characteristics, specification of land use is not sufficient, and LURs should be made concrete in their effect on field characteristics.

3. Design and management variables of willow SRC relevant for breeding birds

We made a list of design and management variables in a willow plantation, based on example systems and guidelines for willow farmers [2, 29, 31-34]. We checked the list to include variables affecting the field characteristics that had a significant effect on breeding

Table 5.1: Willow SRC design and management variables and their target values from a productivity point of view.

Variable	Range of tolerance for willow production	Productivity optimum Relation to variable	Refs.
Design variables:			
Species/variety choice	*Salix viminalis*, *S. alba*, species/variety mixtures	-	[30, 34]
Groundwater table	Gt I – V[1]	Gt III Too moist or too dry leads to yield reduction by waterlogging or drought.	[2, 30, 34, 35]
Plot edge-to-area ratio	Perfectly square – irregular	Rectangular. Usually decreased yields in edges, also effect on management costs	[31, 36]
Planting density and structure	10,000 – 30,000 stems/ha	Ca 10,000 stems /ha Too dense results in high mortality and susceptibility to pests and diseases, Too sparse results in establishment problems and low productivity in year after cut-back	[29, 30, 32, 34]
Management variables:			
Fertilisation	Absent – intensive	N: 60-120 kg/ha.yr; P: 20-50 kg/ha.yr	[2, 29, 30, 32, 34, 37]
Abatement of Competitive undergrowth	Absent – intensive	Intensive chemical or mechanical management in year of planting, thereafter less necessary	[29-31, 34]
Pests and disease Management	Absent – intensive	Some management necessary: e.g. preventive variety mixing and/or chemical abatement	[30, 31, 34, 38]
Rotation cycle length	3-6 years	3 or 4 years; shorter decreases productivity; longer complicates harvest	[30, 34]
Harvest spatial Distribution	Whole plantation at once – every year a part	Harvest in large parts Only affecting harvest costs	[31, 33]
Coppicing height	Near ground – 50 cm height	Near ground Long stems susceptible to harvest damage	[39]
Management schedule	Soil prep: Oct. – March Planting: March – April Weed control: April – Sept Fertilisation: ca April Harvest: Nov - April	-	[40]
'Independent' variables			
Wet elements in plan-Tation (pools, ditches)	-	-	
Tree rows around or Through plantation	-	-	
Nest boxes	-	-	

[1]: Dutch agro-hydrology uses groundwater table classes (Gt's). A lower number is a wetter soil. Gt I: winter groundwater level < 20 cm, summer < 50 cm. Gt V: winter < 40 cm, summer > 120 cm [41].

bird densities in the statistical analysis of Sage and Robertson [20]. We discern three types of variables: plantation design variables, plantation management variables, and relatively 'independent' variables, mainly affecting breeding birds and not directly affecting crop management and productivity. Table 5.1 contains the variables, their ranges and optima from a productivity perspective.

The ranges and productivity optima given in Table 5.1 are based on values found in the literature sources. The ranges are partly given by (scientific) uncertainties, partly by relative indifference of productivity within the ranges. For this study, we assume that willow cultivation with acceptable productivity is possible within the ranges, but that it is preferable to stick as close as possible to the given optimum value target in Table 5.1.

4. Breeding birds in willow SRC: species to be expected

In order to make a longlist of breeding birds potentially present in willow SRC, breeding bird inventories were obtained from literature. No surveys were found on willow coppice for energy in the Netherlands. We did find surveys in modern willow coppice from the UK [11, 16, 20], Sweden [17] and Germany [18], and Dutch surveys for traditional willow coppice [42-45]. We assume that the species sub-populations in the Netherlands do not have significant differences in ecological behaviour compared to the other countries. Only species were selected that occurred in both types of surveys. This also excluded species that may be common in the UK or Sweden, but do not occur in the Netherlands (such as Red-legged Partridge *Alextoris rufa* and Thrush Nightingale *Luscina luscina*). Some species (e.g. Yellowhammer, *Emberiza citrinella*) were re-selected, because their absence in Dutch surveys could be attributed to species absence in the specific regions where the surveys were done (as checked in Bekhuis et al. [46]), while they were found abundantly in the international surveys on willow SRC. Water birds were excluded since we primarily regarded willow SRC as a terrestrial ecosystem, as well as species found only very incidentally in the surveys which did not seem very likely to use willow SRC according to their habitat preferences [47].

This resulted in a list of 51 species (Table 5.2). We arranged these in ecological groups following a classification by SOVON Dutch Centre for Field Ornithology and the State Forestry Service [48]. This classification has been developed to facilitate field managers to have a clearer understanding in the relation between bird presence and their management. The total Dutch bird population was divided into 36 ecological groups, all species in each group having roughly identical habitat preferences. This classification is designed for the situation in the Netherlands. The 51 species selected from the surveys belong to nine different ecological groups: see Table 5.2.

5. Proposed relations between management variables and breeding bird species groups

In order to analyse relations between the identified management variables and the grouped longlist of breeding bird species, nine Dutch bird experts were interviewed. Four of these had a research background, five of them were field managers of nature conservation

Table 5.2: Longlist of breeding birds for willow SRC [11, 16-18, 20, 42-45]. Subdivided into ecological groups, according to Sierdsema [48], partially adapted.

600	**Groups of shrubs and hedges**
<u>601</u>	<u>Reed Bunting group</u>
	Roughness, low shrubs, wet or moist soils
m	Bluethroat, *Luscinia svecica*
m	Whinchat, *Saxicola rubetra*
m	Grasshopper Warbler, *Locustella naevia*
m	Sedge Warbler, *Acrocephalus schoenobaenus*
p	Reed Bunting, *Emberiza schoeniclus*
<u>603</u>	<u>Whitethroat group</u>
	Shrubs, very young woodland, woodland margins with shrubs
p	Dunnock, *Prunella modularis*
m	Nightingale, *Luscinia megarhynchos*
m	Marsh Warbler, *Acrocephalus palustris*
m	Icterine Warbler, *Hippolais icterina*
m	Lesser Whitethroat, *Sylvia curruca*
m	Whitethroat, *Sylvia communis*
m	Garden Warbler, *Sylvia borin*
m	Willow Warbler, *Phylloscopus trochilis*
p	Linnet, *Carduelis cannabina*
<u>604</u>	<u>Wren group</u>
	Young woodland, shrub layer in woodland
r	Pheasant, *Phasianus colchicus* *
m	Turtle Dove, *Streptopelia turtur* *
r	Wren, *Troglodytes troglodytes*
p	Robin, *Erithacus rubecula*
p	Blackbird, *Turdus merula* *
p	Song Thrush, *Turdus philomenos* *
m	Blackcap, *Sylvia atricapilla*
r	Long-Tailed Tit, *Aegithalos caudatus*
r	Willow Tit, *Parus montanus*
m	Bullfinch, *Pyrrhula pyrrhula*

700	**Groups of tree groups, open woodland and woodland margins**
<u>702</u>	<u>Yellowhammer group</u>
	Open woodland, tree groups and cut-down woodland with open sandy soil
r	Green Woodpecker, *Picus viridis* *
m	Tree Pipit, *Anthus trivialis* *
m	Redstart, *Phoenicurus phoenicurus* *
p	Yellowhammer, *Emberiza citrinella* *
<u>703</u>	<u>Goldfinch group</u>
	Woodland margins, tree groups with shrub
r	Magpie, *Pica pica* *
r	Carrion Crow, *Corvus corone* *
p	Greenfinch, *Carduelis chloris* *
r	Goldfinch, *Carduelis carduelis* *

800	**Groups of upgoing canopy-closed woodland**
<u>801</u>	<u>Chaffinch group</u>
	Upgoing deciduous woodland
p	Woodpigeon, *Columba palumbus* *
p	Long-Eared Owl, *Asio Otus* *
p	Mistle Thrush, *Turdus viscivorus* *
m	Wood Warbler, *Phylloscopus sibilatrix*
m	Chiffchaff, *Phylloscopus collybita*
r	Great Tit, *Parus major*
n	Jay, *Garrulus glandarius*
p	Chaffinch, *Fringilla coelebs*
<u>804</u>	<u>Great spotted woodpecker group</u>
	Older deciduous woodland, dead wood
r	Great Spotted Woodpecker, *Dendrocopos major*
m	Spotted Flycatcher, *Muscicapa striata*
r	Marsh Tit, *Parus palustris*
r	Blue Tit, *Parus caeruleus*
r	Short-Toed Treecreeper, *Certhia brachydactyla*
p	Starling, *Sturnus vulgaris* *
r	Tree Sparrow, *Passer montanus* *
<u>807</u>	<u>Hawk group</u>
	Birds of prey in woodland area
p	Sparrowhawk, *Accipiter nisus* *
p	Buzzard, *Buteo buteo* *
<u>808</u>	<u>Kestrel group</u>
	Birds of prey in areas with small-scale woodland
p	Kestrel, *Falco tinnunculus* *
p	Rook, *Corvus frugilegus* *

*: Marked birds use open (arable or grass) land for part of their activities. See also the discussion (Section 8).
m: migrant species; *p:* partially migrant species; *r:* resident species

Table 5.3: Relations between design and management variables, field characteristics and breeding birds, as proposed by the experts interviewed.

Variable	Range of tolerance for willow production	Effect on corresponding field characteristics[1]	Key characteristic and responding species or species groups[1,2]	Comments
Design variables:				
Species/variety choice	*S. viminalis, S. alba*, species/variety mixtures	-	-	
Groundwater table	Gt I – V[1]	From Gt V to Gt I: ↑ Soil wetness ↑ Undergrowth density & diversity ↑ Insect density & diversity	Birds foraging on wet densely-grown soil ↑ Reed Bunting group	Possibly, wet coppice is richer in undergrowth by weeding difficulty
Edge-to-area ratio	Perfectly square – irregular	From low E/A to high E/A: ↑ Amount of margins with denser undergrowth and warmer microclimate (espec. at dawn when oriented S/E).	All ground- or leaf-foraging birds ↑ Bluethroat, many from Whitethroat group, Chaffinch	
		↑ Contact area between coppice and surrounding other habitats	Woodland birds using mixed habitats ↑ E.g. Woodpigeon, Mistle Thrush, Linnet	
Planting density and structure	5,000 – 30,000 stems /ha	From low to high densities: In first year after coppicing: • No effect	• -	
		In years thereafter: ↑ Canopy closure ↓ Undergrowth and open spaces	Species favouring undergrowth ↓ many from Whitethroat and Wren groups	Only differential if undergrowth not actively removed
Management variables:				
Fertilisation	Absent – intensive	Intensifying fertilisation: ↓ Plant species diversity in undergrowth	Undergrowth –dependent species ↓ Reed Bunting, Whitethroat and Wren groups (possibly)	Only differential if undergrowth not actively removed
		↑ Undergrowth density	↑ Reed Bunting, Whitethroat and Wren groups	
Abatement of competitive undergrowth	Absent – intensive	Intensifying abatement: ↓ Undergrowth density & diversity	Undergrowth-dependent species ↓ Reed Bunting, Whitethroat, Wren groups Species foraging on bare soil ↑ e. g. Robin, Yellowhammer group	
Pest and disease management	Absent – intensive	Intensifying chemical abatement: ↓ Insect populations	Insect-foraging species ↓ (not specified)	Variety mixing prevents chemical use

(continued on next page)

Table 5.3, continued

Rotation cycle length	3-6 years	Extending rotation length: ↑ Variation in coppice height within plantation	↑ (possibly) species diversity	
		↓ Undergrowth density	Undergrowth- dependent species ↓ Reed Bunting, Whitethroat and Wren groups	
		↑ Canopy density and age	Species depending on older wood ↑ (possibly) Chaffinch and Great Spotted Woodpecker groups	
Harvest spatial distribution	Whole plantation at once – every year a part	From large-scale to small-scale harvest plots: ↑ Spatial variation in coppice height	↑ Species diversity	
Coppicing height	Near ground – ca 50 cm above ground	From near-ground to higher above ground: ↑ Stove height	Hole-breeders ↑ Great Spotted Woodpecker group	
Management schedule	Soil prep: Oct. – March Planting: March – April Weed control: April – Sept Fertilisation: ca April Harvest: Nov - April	Increasing activities in breeding season (ca April 1 – August 1): ↑ disturbance of breeding birds	Breeding birds ↓ All species	
'Independent' variables				
Establishment of wet elements in plantation (pools, ditches)	Possible, although elements take space and may complicate management	↑ Wet elements	Water-dependent species ↑ Reed Bunting group	
Establishment of tree rows around or through plantation	Possible, although elements cost space and may cast shadow over coppice	↑ Higher trees	Species nesting in higher trees (foraging in coppice) ↑ Yellowhammer, Goldfinch, Chaffinch and Great Spotted Woodpecker groups	
Introduction of nest boxes	Unlimited	↑ Nesting places for hole- breeding birds	Hole-breeders ↑ E.g. Blue Tit, Tree sparrow, Spotted flycatcher, also Kestrel group	

[1]: ↑: Dependent variable increases; •: Neutral to dependent variable; ↓: Dependent variable decreases.

[2]: Individual species: dependent variable is probability of species occurrence and density;
Species groups: dependent variable is number of species of the concerned group, and total number of individuals of that group.

organisations (see acknowledgements for details). After introduction of the research project, the experts first had the opportunity to comment on the management variable list and the breeding bird longlist. After that, each management variable was discussed, and the expert was requested to indicate the field characteristics affected by variation of this variable within the range of Table 5.1. The expert was then asked to assess per ecological group whether it would respond to a change in field characteristics, and which (ecological) mechanisms cause that response. This procedure differs slightly from the scheme as proposed in Figure 5.2, in the sense that the experts were not requested to indicate the most relevant field characteristics per ecological group.

The results of the interviews were structured and summarised, and presented for discussion in a workshop in which four of the nine experts were confronted with the results, especially with divergent opinions. The purpose was to force the participants to better motivate the relations they proposed and thereby further clarify their assumptions on the underlying ecological factors. In the discussions on the analysis, consensus arose during the workshop, although this was explicitly not the purpose of the discussion. In Table 5.3, the expert judgement relations are presented, including some comments on pitfalls and uncertainties that arose from the workshop. All given relations should be interpreted in terms of *probabilities* of species occurrence or changes in density. This in view of the many other factors that may influence bird occurrence and behaviour.

6. Synthesis: Construction of design and management packages

The results of the analysis can be material for the construction of land use types aimed at the enhancement of specific bird species or species groups in willow SRC. In such an exercise, the relations in Table 5.3 are used ‘backwards’: starting from bird species (groups), one can find the relevant field characteristics and corresponding design and management variables. All relevant variables should then be taken into account. For example, undergrowth in the coppice, a field characteristic relevant for many species groups, is influenced by inter alia planting density, undergrowth abatement, and rotation length. A land use type designed for undergrowth-dependent breeding bird species needs to be a coherent specification of all these variables. Planting density and rotation length aimed at an attractive understorey may be made useless by active weed abatement.

A minimum set of basic design and management rules may be positive for breeding birds and not negatively affecting plantation productivity. Such rules are e.g. the use of variety mixtures instead of monoclonal cultivations: this prevents problems with pests and diseases, and protects bird populations from negative effects of fungicides and insecticides. Such measures can be regarded a ‘minimum package’ of measures to enhance breeding birds in the plantation (see Table 5.4). Other sets can also be constructed. From the interviews and workshop, two field characteristics appeared to be highly relevant for birds: the presence of undergrowth and (adapted) management of margins and edges. In Table 5.4, two packages are elaborated with extra attention for these characteristics, including breeding bird species groups to be expected in such plantations. Other packages, however, are well conceivable.

Table 5.4: Examples of design and management packages, and an indication of expected breeding bird species and biomass productivity. See text for details.

Variable	(1) Minimum variant	(2) Variant with more undergrowth	(3) Variant with adapted margin management
Design variables:			
Species/variety choice	Mixture, to prevent pests/diseases	Mixture, to prevent pests/diseases	Mixture, to prevent pests/diseases
Groundwater table	Not specific	***Moist lands***	Not specific
Edge-to-area ratio	Not specific	Not specific	***High E/A***
Planting density And structure	High density (ca 20,000/ha)	***Medium to low density (<10,000)***	***High density (ca 20,000), but lower in margins (<10,000)***
Management variables:			
Fertilisation	Optimal (ca 100 kg N/ha)	Optimal (ca 100 kg N/ha)	Optimal (ca 100 kg N/ha)
Abatement of competitive Undergrowth	Not necessary after establishment	Not after establishment	Not after establishment
Prevention / abatement of Pests and diseases	By variety mixing	By variety mixing	By variety mixing
Rotation cycle length	4 years	4 years	4 years
Harvest spatial distribution	Each year 1/4	Each year 1/4	Each year 1/4
Coppicing height	Low (<25 cm)	***High (ca 50 cm)***	***Low, but high in margins***
Management timing	No activities in April-August	No activities in April-August	No activities in April-August
'Independent' variables			
Establishment of wet Elements in plantation (pools, ditches)	-	-	-
Establishment of tree rows Around/through plantation	-	-	***Yes, along North edge***
Introduction of nest boxes	-	-	-
Generated products/services:			
Bird species to be Expected:	Mainly generalists from Whitethroat and Wren groups, such as Willow Warbler, Blackbird, Robin, Song Thrush.	More species from Whitethroat and Wren groups, on moist land also Reed Bunting group	In margins Whitethroat and Wren groups, along tree rows Yellowhammer, Chaffinch, Goldfinch and Great Spotted Woodpecker groups, possibly Hawk & Kestrel groups.
Biomass productivity:	Optimal	Slight competition of undergrowth	Slightly lower productivity in margins

For all packages, the first one or two years after planting require some other management than later years. In the establishment period, the juvenile willow stems are relatively susceptible to competitive weeds. Problems with excessive weed growth in the first year may negatively affect willow productivity, of which some studies indicate the plantation will not recover in later years [49, 50]. This problem may especially play a role on highly fertile former arable or grasslands, which have a rich seed bank of competitive weeds [50], and less on former extensively managed lands. However, intensive chemical weed control in the establishment phase may also have long-term effects on species composition in willow SRC understorey: the introduction of less common, noncompetitive species will be delayed for several years. Therefore it may be useful to differentiate between two situations:

- On former intensively managed agricultural land, chemical weed control may be necessary. This will also negatively affect establishment of herbicide-susceptible undergrowth species in later years, but this effect will be relatively limited since especially former arable land will probably have a history of herbicide use.
- On former extensively managed lands, with a seed bank of less invasive species and less fertile soils, weed control may be limited to mechanical weed abatement. This also enhances herbicide-susceptible weed establishment in later years.

In both cases, disturbance for weed control in the plantation may be necessary within the breeding season (ca April-July). This has to be accepted in the first one or two years.

7. Policies for breeding bird enhancement in willow SRC

Breeding bird-friendly design and management of willow SRC will probably not be first priority for a land manager if there is no active stimulating policy to do so. A central or local authority may develop different types of incentives in order to stimulate such management. In this section, we evaluate incentive systems in the framework of agency theory.

Agency theory and principal-agent models focus on problems in different kinds of hierarchical co-operative systems [51, 52]. The relation between an authority stimulating bird-friendly willow SRC management (the ‘principal’) and a field manager administering a plantation (the ‘agent’) can be regarded as such a system. Central assumptions in agency theory are [53] that on one hand, principal as well as agent can *profit* from co-operation, but that on the other hand, there is a *conflict of interest*. The field manager can improve bird suitability (the authority target) and the authority can reward this activity with a compensation or subsidy (the field manager’s target), but suitability improvement takes the field manager extra effort or costs, e.g. in terms of extra management activities or productivity loss.

When, in such a situation, the agent has more information on the circumstances and activities leading to the results desired by the principal (*information asymmetry*), the problem of *moral hazard* arises [51-53]. The agent may not give full effort to fulfilling the principal’s targets, and given the information asymmetry the principal will not be able to notice this. In a set of agreements, the principal will try to prevent this moral hazard. An important feature in this contract is whether the agent will be rewarded for his behaviour or for the final results; in this case whether the field manager will be rewarded for specific bird-friendly measures in the coppice, or for the diversity of breeding bird species in the plantation. These different ways of rewarding we identified as steering on input and steering on output in Londo et al. [10]. Kruk et al. [54] previously used agency theory to compare a new method for stimulating meadow bird management with the conventional method in the Netherlands, the major difference being the way of rewarding.

Eisenhardt [51] identified a number of situation characteristics in which either behaviour or result rewarding is more effective. These characteristics are summarised in Table 5.5. In the remainder of this section, we discuss the relevance of these characteristics in the case of an authority willing to stimulate bird-friendly willow SRC management, in the context of the model we discussed in the previous sections.

Table 5.5: Situation characteristics favouring rewarding either behaviour or results. Derived from Eisenhardt [51], partially adapted.

	Favouring behaviour rewarding	Favouring result rewarding
1	If the results are uncertain (also depend on other factors than agent's behaviour)	If the results are certain (clearly depend on agent's behaviour only)
2	If the result is not measurable	If the result is measurable
3	If the principal can obtain information on the agent's behaviour	If the principal cannot obtain information on the agent's behaviour
4	If the agent's behaviour is programmable (can be specified in advance)	If the agent's behaviour is not programmable
5	If the agent is risk-averse	If the principal is risk-averse
6	If the principal's and agent's goals do not conflict	If the principal's and agent's goals conflict
7	If principal and agent have a long-term relationship	If principal and agent have a short-term relationship
8	If it is not important to enhance agent's creativity and expertise	If enhancement of agent's expertise and creativity is important

Results certainty

In nature management in general, the occurrence of flora and fauna is only partly dependent on management. Other factors, such as climate, history, coincidence, and effects from surroundings will also influence the system. Furthermore, the relations between specific design and management variables and breeding bird densities (as analysed in Section 5) are still highly probabilistic: there is lack of field experience in bird-friendly fine-tuning of willow SRC. Therefore we conclude that outcome uncertainty pleads in favour of rewarding behaviour.

Results measurability

Breeding bird presence in willow SRC, especially bird species diversity, is relatively easily measurable: there is sufficient experience with monitoring methods [11, 16-18, 20, 42-45]. In practice, measurements should be limited to field surveys every one or two years, preferably carried out by the field manager to make him familiar with his 'product' [54]. For breeding birds, this is probably not problematic; the measurability criterion pleads for rewarding results. For other, less easily monitored species groups, the situation will be different.

Principal's possibilities to obtain information on agent's behaviour

Logically, it pleads for rewarding behaviour when the principal can easily observe agent's behaviour. In the practice of a plantation, this would imply that the authority checks whether the manager complies with the agreed management. For some variables, e.g. in plantation design, such a check is relatively easy, but for others, e.g. not disturbing birds during the breeding season this may take considerable effort. On this criterion the situation is ambiguous.

Agent's behaviour programmability

Given the design and management packages in Section 6, field manager's behaviour may seem well programmable. However, detailed management optimisation requires continuous learning and adaptation to local circumstances and seasonal variations. In our opinion, it will be difficult to totally standardise manager's behaviour without eliminating valuable degrees of freedom. Especially considering the management variables, this criterion pleads for rewarding results.

Principal's and agent's attitude towards risk

In general, agents are considered to be more risk-aversive than principals, for the simple reason that an individual manager is more sensitive to uncertainties and variations in income than a subsiding authority in the degree in which policy targets are met and subsidy funds are expended. One can also argue that an agent taking the risk of setting up an energy plantation already takes a considerable risk, and that he will not be eager to add to his uncertainties. In our opinion, this criterion pleads for rewarding behaviour.

Goal conflicts

Logically, goal conflicts increase the risk of moral hazard. In this case, management measures that actually decrease plantation productivity will sharpen land use conflicts, while measures beneficial for birds and neutral to productivity are less subject to goal conflict. Therefore, it may be an option to split behaviour versus result rewarding along these lines.

Principal-agent relationship duration

The reasoning behind this criterion is that in a long-term relationship, the principal is more likely to invest in getting the necessary information on agent's behaviour, and that behaviour rewarding may be problematic in short-term relationships. Preferably, bird-friendly management should be stimulated on a long-term basis, because measures may only have effects on a long-term basis. Therefore, this criterion does not exclude behaviour rewarding.

Enhancing the agent's creativity and expertise

Rewarding results stimulates the manager to explore potentials for combining bird diversity and productivity, dependent on the specific plantation location, seasonal and other factors of influence, and develop his own management style. In behaviour rewarding, this stimulus is lacking. Since willow SRC for energy is a relatively new type of land use, such expertise development and creativity enhancement may be vital for new insights. This criterion pleads for result rewarding.

These considerations do not indicate a clear advantage of one of the two rewarding methods: rewarding 'produced breeding birds' has the disadvantage of uncertain outcomes, and corresponding risks for the field manager, rewarding bird-friendly behaviour can encounter the moral hazard problem and problems with behaviour check and control.

A well-suited mix may be found in behaviour-based rewarding of the minimum package of standard (mainly design) measures, such as the ‘minimum package’ in Table 5.4: easily controllable and not strongly conflicting with plantation productivity. Above this base system, extra efforts, of which the other packages in Table 5.4 are examples, may be rewarded by a result-based system. The latter may then become increasingly relevant when knowledge and experience of managers in fine-tuning their system increase. Obviously, the systematic approach in previous sections of this article can be a starting point.

8. Discussion

In this study we have tried to unravel the relations between willow SRC design and management and the occurrence of a specified set of breeding birds, and notably to clarify some of the ecological processes underlying these relations. Some general remarks on the results can be made. Field characteristics with high relevance for breeding birds are undergrowth, and the presence of (open) field margins. These results are consistent with other studies on willow SRC in the UK [20, 55-57]. However, the current study relates these field characteristics to concrete, detailed, and steerable design and management variables, and does so in a systematic way. The absence of detailed analytical field studies impelled us to use expert consultation, with corresponding uncertainties. However, the relations presented in Table 5.3 offer starting-points for managers willing to pay attention to breeding birds, and thereby increasing field experience. Furthermore, they can be worked out as hypotheses on management-breeding bird relations that can be subject to further research.

Many variables may affect the presence and densities of bird groups of shrubs and hedges (groups 600 in Table 5.2). Species groups of upgoing and canopy-closed woodland (groups 800) seem to have less preference for the short-rotation coppice, and can only be enhanced by an ‘independent’ variable, the planting of tree rows. In general, species from groups 800 were not believed to occur frequently in willow SRC by the interviewed. The reason why they have been found in several field survey studies may be because some of these studies surveyed willow as well as poplar coppice, and did not give fully separated information on the two types of coppice [11, 12]. The lower planting density and more closed canopy in poplar may attract more species of e.g. the Chaffinch group. Furthermore, many traditional willow coppice plots are located in regions with many upgoing woodland plots, introducing higher trees at close distance just like proposed in this study. And besides, some of the surveyed traditional coppice plots may not have been coppiced for a considerable number of years, improving attractiveness for 800 species.

Reflecting on the initial discussion on general extensification versus detailed optimisation of the system (Figure 5.1), we roughly identify measures that are likely to have a strong negative effect on productivity but a small positive on breeding bird presence (type a in Figure 5.1), and measures that have a stronger positive effect on breeding birds than negatively on productivity (type b in Figure 5.1). An example of type a is fertilisation. The effect of a nutrient input decrease on undergrowth, and thereby on breeding birds, is contradictory: undergrowth species diversity probably increases, but undergrowth density may decrease. On the other hand, negative effects on productivity, via exhaustion of nutrient stocks are well known and significant. Also, refraining from undergrowth abatement in the establishment years of the SRC is probably a type a measure. On the other hand, using land with a relatively high groundwater table seems to be a type b measure. Another example of this may be to adapt management in margins that have lower production anyway, with strong positive effects on breeding birds.

The analysis of potential stimulation strategies for enhancement of breeding birds in willow SRC according to agency theory leads to a complicated picture. While result rewarding circumvents moral hazard, and also stimulates the field manager's creativity in optimising his plantation for breeding birds, management rewarding entails less risk for the field manager given the still insecure and inexact relations between design and management variables and breeding birds. A mixed-type strategy may be the best compromise.

Some assumptions and limitations deserve attention. The field knowledge of the consulted experts may be confined to the region where they work, and therefore biased. Six of the nine experts had most of their experience in the delta area of the major Dutch rivers, the region in which most of the traditional coppice plots are located. This means that their opinions may not be fully applicable to other regions in the Netherlands. However, in construction of the species longlist we tried to correct for the effect that most Dutch field surveys were from the river delta area.

The bird surveys used for construction of the longlist partly came from (mostly) British, German and Swedish studies. This may cause some bias in the longlist. However, the interview and workshop respondents were all Dutch, so the final result will be mainly applicable to the Netherlands. In other regions in Northwest Europe, species behaviour may differ slightly, e.g. because of different sub-population characteristics.

We proposed that breeding birds using more than one habitat would find their supplementary habitat in the willow SRC's direct surroundings. This concerns breeding birds marked with an asterisk in Table 5.2. This assumption is less problematic, since some of these species may find their supplementary habitat within the coppice itself: species such as those corresponding to the Yellowhammer group may use freshly coppiced plots for foraging, and older coppice or surrounding trees for nesting.

We also assumed that bird species would, by definition, find the new willow SRC habitats if suited. This is only valid if breeding habitat is the limiting factor to population growth. For migrating birds, problems in the wintering area (such as extreme drought), or hunting in migration corridors might cause pressure on population size, and therefore limit colonisation. For resident species, a strong winter may have a comparable effect.

Colonisation can also be a problem for species with strong philopatry (birds sticking to their breeding area). However, a willow cultivation can be regarded a pioneer vegetation, originating from dynamic environments, and most associated species are likely to possess corresponding colonisation capability.

9. Conclusions

In this study, we systematically analysed (potential) relations between changes in design and management of a willow SRC plantation and responding breeding bird species. Notwithstanding the uncertainties and qualitative nature of the results, the analysis offers starting-points for managers willing to pay attention to breeding birds, and can also be elaborated to hypotheses on management-breeding bird relations that can be subject to further field research.

There seem to be considerable opportunities to increase willow SRC potentials for especially breeding bird species of shrubs and hedges, with limited productivity reduction. Exemplary design and management packages have been developed.

Governmental policies stimulating bird-friendly willow SRC plantations should apply a mixed type of rewarding. As a basis, easily controllable design measures can be rewarded directly, while an additional system of rewarding observed breeding birds can enhance field managers to use their creativity to further improve chances for them.

Acknowledgements

We would like to thank the following persons for participating in the workshop and/or the interviews (s.s.t.t.):

- Gerrie Abel (Birding Study Group Utrecht/IJsselstein)
- Jan van de Bosch (Field manager Gelderland Provincial Wildlife Trust)
- Nico de Bruin (Field manager State Forestry Service, region Hollandse Waarden)
- René Garskamp (Field manager Zuid-Holland Provincial Wildlife Trust)
- Hans van Heiningen (Field manager State Forestry Service, region Rivierenland)
- Dr. Roel Meijer (Central Bureau of Statistics)
- Drs. Henk Sierdsema (SOVON Dutch Centre for Field Ornithology)
- Drs. Rombout de Wijs (The Netherlands Natural Heritage Society)
- Prof. dr. Ies Zonneveld (ITC International Institute for Aerospace Survey and Earth Sciences)

Dr. Hans de Graaf (Environmental Biology, Leiden University), Prof. dr. Hans de Kruijf and Dr. Pita Verweij (both dept. of Science, Technology and Society, Utrecht University) provided useful comments on earlier versions.

References

1. Dinkelbach, L., J. van Doorn, and R. Jansma. Mogelijkheden voor kostenreductie bij energieteelt (potentials for cost rediction in energy farming). Petten: Novem, 1998.
2. Biewinga, E.E. and G. van der Bijl. Sustainability of energy crops in Europe; a methodology developed and applied. Utrecht: CLM, 1996.
3. Anonymous. Biocascade; geïntegreerde plantconversie met gecombineerde winning van producten en energie (Biocascade; integrated plant conversion with combined extraction of products and energy). S.l.: DCO, ATO-DLO, BTG, Cebeco, CPRO-DLO, LEI-DLO, LUW-Agronomie, LUW-Organische Chemie, TNO-MEP, Uniqema, 1999.
4. Sirkin, T. and M. ten Houten. The cascade chain. Resources, Conservation and Recycling 1994, 11 215-277.
5. Fraanje, P.J. Cascading of renewable resources hemp and reed. Industrial Crops and Products 1997, 6 201-212.
6. Eker, M., W. Elbersen, B. de Klerk, R. de Koning, N. van der Windt, and A. Wintjes. Switch on! First prize winning entry for the 'Living Energy' design competition to introduce energy crop cultivation in the landscape. Wageningen: SC-DLO, 1999.

7. Meeusen, M.J.G., H.H.W.J.M. Sengers, L.C. Kuiper, and P.A.G. Jansen. Energieteelt in bufferzones; een eerste inventarisatie van de mogelijkheden (energy farming in buffer zones; a first inventory of opportunities). Den Haag: LEI-DLO, 2000.
8. Heineman, A., G. Saaltink, and L. Kuiper. Energie uit biomassa in combinatieteelt (Energy from biomass in combination farming). Wageningen: CPV/SBH, 1999.
9. Börjesson, P. Environmental effects of energy crop cultivation in Sweden - I: Identification and quantification. Biomass & Bioenergy 1999, 16 137-154.
10. Londo, M., J. Dekker, P. Verweij, and H. de Graaf. Multiple land use on land unit level in rural areas: towards operationalisation. Submitted to Land Use Policy.
11. Coates, A. and A. Say. Ecological Assessment of Short Rotation Coppice. Harwell: ETSU, 1999.
12. Sage, R.B., P.A. Robertson, and J.G. Poulsen. Enhancing the conservation value of short rotation biomass coppice - Phase 1: the identification of wildlife conservation potential. Fordingbridge: The Game Conservancy Trust, 1994.
13. Jodl, S., A. Eppel-Hotz, and K. Marzini. Examination of the ecological value of miscanthus expanses - faunistic studies-. In: Kopetz, H., T. Weber, W. Palz, P. Chartier and G.L. Ferrero (eds.). Proceedings of the 10th European Conference and technology exhibition "Biomass for energy and industry". Rimpar: C.A.R.M.E.N, 1998. 778-779.
14. Christian, D.P., P.T. Collins, J.M. Hanowski, and G.J. Niemi. Bird and small mammal use of short-rotation hybrid poplar plantations. Journal of Wildlife Management 1997, 61 (1): 171-182.
15. Sage, R.B. and K. Tucker. Invertebrates in the canopy of willow and poplar short rotation coppices. Aspects of applied biology 1997, 49 105-112.
16. Warwick, S., J. Warwick, D. Bowes, and D. Bowes. Bird ringing study in Short Rotation Coppice. In: Richards, G.E. Wood energy and the environment. Harwell: Harwell Laboratories, 1992.
17. Göransson, G. Bird fauna of cultivated energy shrub forests at different heights. Biomass and Bioenergy 1994, 6 (1/2): 4.
18. Liesebach, M. and H. Mulsow. Zur Bedeutung des Biotops Kurzumtriebsplantage fur den Sommervogelbestand (The significance of the Short Rotation Coppice biotope for breeding birds). Beitr. Forstwitsch. u. Landsch.okol. 1995, 29 (1): 32-35.
19. Sage, R.B. Factors affecting wild plant communities occupying short rotation coppice crops on farmland in the UK and Eire. Brighton Crop Protection Conference- Weeds 1995, 7D-5 985-990.
20. Sage, R.B. and P.A. Robertson. Factors affecting songbird communities using new short rotation coppice habitats in spring. Bird Study 1996, 43 201-213.
21. Begon, M. , J.L. Harper, and C.R. Townsend. Ecology : individuals, populations and communities. Boston: Blackwell, 1996.
22. Green, B.H. Agricultural impacts on the rural environment. Journal of Applied Ecology 1989, 26 793-802.
23. Parmentier, F. Hoe de landbouwbedrijfsvoering de weidevogelstand beïnvloedt (How agricultural practice influences meadow bird populations). Landbouwkundig tijdschrift 1987, 99 (6/7): 23-27.
24. Kruk, M. Meadow bird conservation on modern commercial dairy farms in the western peat district of the Netherlands; Possibilities and limitations. Leiden: Leiden University, Environmental Biology (thesis), 1994.
25. Keurs, W.J. ter. Het streven naar een meer geïntegreerde landbouw en het onderzoek dat daarvoor nodig is (striving after a more integrated agriculture and the research necessary for that). In: Muyden, J.N. van. Hoger Landbouwonderwijs kijkt verder. Conference proceedings. Wageningen: SHAO, 1989. 31-42.
26. Meyer-Aurich, A., P. Zander, A. Werner, and R. Roth. Developing agricultural land use strategies appropriate to nature conservation goals and environmental protection. Landscape and Urban Planning 1998, 41 119-127.
27. Boersma, F. and G. Kuipers. Sturen op resultaat in multifunctioneel bos bij Staatsbosbeheer (Steering on results in multifunctional woodland at the State Forestry Service). Nederlands Bosbouwtijdschrift 1998, 70 (6): 262-268.
28. Hekhuis, H.J., J.G. de Molenaar, and D.A. Jonkers. Het sturen van natuurwaarden door bosbedrijven (Steering of nature values in forestry). Wageningen: IBN-DLO, 1994.
29. Gigler, J.K., M.J.G. Meeusen - van Onna, and E. Annevelink (eds.). Kansen voor energie uit biomassa! Resultaten van een 4-jarig DLO-onderzoekprogramma (Opportunities for energy from biomass! results of a 4-year DLO research programme). Wageningen: Dienst Landbouwkundig Onderzoek, 1999.
30. Danfors, B., S. Ledin, and S. Rosenqvist. Short-rotation willow coppice; Growers' manual. Uppsala: Swedish institute of agricultural engineering, 1998.

31. Anonymous. Good Practice Guidelines Short Rotation Coppice for Energy Production; The development of an economically and environmentally sustainable industry. London: ETSU, British Biogen, Friends of the Earth, Environmental Resolve, 1996.
32. Coelman, B.T. (ed), B. Pijanowska, G.J. Kasper, J.K. Gigler, C. Sonneveld, W. Huisman, E. Annevelink, J. van Doorn, A. Bos, R. van der Pluijm, and M. de Boer. Mogelijkheden voor kleinschalige energie-opwekking met geteelde biomassa (Possibilities for small-scale energy production with cultivated biomass). Wageningen: CPV, IMAG-DLO, ECN, 1996.
33. Aronsson, P. Energy Forestry and Nature Preservation. Uppsala: SLU, 1995.
34. Szuffa, L. (ed.). Short Rotation Forestry Handbook. Aberdeen: IEA Bioenergy, 1996.
35. Londo, M., L. Vleeshouwers, J. Dekker, and H. de Graaf. Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation. Biomass and Bioenergy 2001, 20 (5): 337-350.
36. Wilcox, A., N.H. Perry, N.D. Boatman, and K. Chaney. Factors affecting the yield of winter cereals in crop margins. Journal of agricultural science 2000, 135 (4): 335-346.
37. Zeijts, H. van, E.A. Oosterveld, and E.A. Timmerman. Kan de landbouw schone energie leveren? Onderzoek naar duurzaamheid van energiegewassen (Can agriculture produce clean energy? A study on sustainability of energy crops). Utrecht: CLM, 1994.
38. McCracken, A.R. and W.M. Dawson. Using mixtures of willow clones as a means of controlling rust disease. Aspects of Applied Biology 1997, 49 97-103.
39. Sonneveld, C. E-mail message on harvesting machinery. Wageningen: IMAG-DLO, 2000.
40. Gigler, J.K. E-mail message dated October 23, 1998 on willow management timing. Wageningen: IMAG-DLO, 1998.
41. Werkgroep HELP-tabel. De invloed van de waterhuishouding op de landbouwkundige productie (Influence of water management on agricultural production). Utrecht: Landinrichtingsdienst, 1987.
42. Jonkers, D. Vogelstand en griendbeheer (Bird populations and the management of traditional willow beds). Leersum: Rijksinstituut voor Natuurbeheer, 1982.
43. Schepers, J.A.M., A.A.M. van Haperen, and J.L. van der Jagt (ed.). Grienden: hakken of laten groeien; inventarisatie van het hakgriendenarsenaal en mogelijkheden voor ontwikkeling (Traditional willow coppice: coppicing or letting grow; an inventory of the arsenal of traditional willow coppice and potentials for development). Utrecht: IKC-NBLF, 1992.
44. Thissen, J.B.M. and M.J.S.M. Reijnen. Effect van verkeer op broedvogels in populierenbossen en grienden. Leersum: RIN, 1985.
45. Zonderwijk, M. Grienden; een technische en natuurtechnische beschouwing (traditional willow coppice; a technical and natural regard). Utrecht: Utrecht University, 1982.
46. Bekhuis, J., R. Bijlsma, A. van Dijk, F. Hustings, R. Lensink, and F. Saris (eds.). Atlas van de Nederlandse vogels (Atlas of Dutch birds). Arnhem: SOVON, 1987.
47. Cramp, S. (Chief Ed.), K.E.L. Simmons, I.J. Ferguson - Lees, R. Gillmor, P.A.D. Hollom, D.J. Brooks, N.J. Collar, E. Dunn, and C.M. Perrins. Handbook of the birds of Europe, the Middle East and North Africa : the birds of the Western Palearctic. Volumes I to IX. Oxford: Oxford University Press, 1977-1994.
48. Sierdsema, H. Broedvogels en beheer; Het gebruik van broedvogelgegevens in het beheer van bos- en natuurterreinen (Breeding birds and management; use of breeding bird data in management of woodlands and nature areas). Driebergen/Beek-Ubbergen: Staatsbosbeheer/SOVON, 1995.
49. Clay, D.V. and F.L. Dixon. Weed management in short-rotation energy coppice: selectivity of foliar-acting herbicides. Aspects of Applied Biology 1996, 44 109-116.
50. Clay, D.V. Weed control and soil management systems for short-rotation coppice: Present Knowledge and future requirements. Bristol: Avon Vegetation Research, 1993.
51. Eisenhardt, K.M. Agency theory: An Assessment and Review. Academy of Management Review 1989, 14 (1): 57-74.
52. Levinthal, D. A survey of agency models of organizations. Journal of Economic Behavior and Organization 1988, 9 153-185.
53. Hendrikse, G.W.J. Moderne organisatietheorieën (modern organisation theories). Schoonhoven: Academic Service, 1998.
54. Kruk, M., H.J. de Graaf, W. van Harmelen, W. Twisk, and W.J. ter Keurs. Natuurproduktiebetaling; een nieuw instrument voor agrarisch natuurbeheer (nature production payment; a new instrument for nature management on the farm). Openbare uitgaven 1995, (2): 94-99.
55. Sage, R.B. and P.A. Robertson. Wildlife and Game potential of short rotation coppice in the U.K. Biomass and Bioenergy 1994, vol 6, no 1/2 (1994) 8.

56. Baxter, D.A., R.B. Sage, and D.O. Hall. A methodology for assessing gamebird use of short rotation coppice. Biomass and Bioenergy 1996, 10 (5/6): 301-306.
57. Tucker, K., R.B. Sage, and G.P. Buckley. Introducing other plants into short rotation coppice willow. Aspects of Applied Biology 1997, 49 293-299.

Chapter 6

Energy farming in multiple land use: Methodological lessons and potentials in the Netherlands

As outlined in the general introduction, biomass is a source of renewable energy that is assumed to have a significant global potential. While, on a global scale, the potentials for bioenergy from residues are limited, the introduction of energy crops strongly depends on the availability of land for energy farming. Especially in countries with high land use intensity such as the Netherlands, the low value added of energy crops makes it difficult for them to successfully compete with other claims for land with more purchasing power. In this thesis, multiple land use (MLU) is proposed as a strategy to improve the revenues from energy cropland, and thereby improve the competitive position of energy crops.

The central research question of this thesis was whether, and to what extent, multiple land use is a useful strategy to improve opportunities for introduction of energy farming in comparison to single land use. We defined three criteria for these improved opportunities: biophysical feasibility of MLU combinations with energy farming, lower supply prices in MLU compared to single land use (and preferably lower than prices of other biomass resources), and an area scale significant to the national renewable energy targets.

For this exploration, we contributed to methodology development on design, optimisation and evaluation of MLU systems within a land holding (Chapter 2). Applying elements of this methodology, we explored the potentials of several MLU combination options of willow short rotation coppice and other land use types (Chapters 3 to 5). In this chapter, we start with an evaluation of the usefulness of the methods proposed, given the experiences in the applications (Section 1). The potentials of the different MLU options studied in the applications are summarised in Section 2. Finally, we come to answering the central research question, and outline the perspectives for energy crops in MLU on the longer term (Section 3).

1. Experiences in application of the methodology

A shift towards multiple land use will entail (economic) opportunities as well as risks for involved farmers and other land holders. Therefore, the merits of MLU should be explored in advance. The procedure for MLU system development and evaluation, as developed in Chapter 2, should help land holders to systematically explore potentials and limitations of MLU within their holdings. Furthermore, land use optimisation is more complex in MLU systems compared to single land use, and therefore we discussed a number of optimisation strategies. Both the procedure and the optimisation strategies were applied to specific combinations in Chapters 3 to 5, on which we reflect in this Section.

1.1 The procedure for multiple land use design and evaluation

The method for MLU design and evaluation contains, after an inventory of the land holding's targets, potentials and constraints, three explorative applied research phases (see Figure 2.1): A rapid appraisal of potential new single Land Use Types (LUTs); A rapid appraisal of potential new multiple LUTs; Detailed modelling of multiple LUTs. In all phases, LUTs are specified in their Land Use Requirements (LURs), physical or other inputs or land characteristics necessary for a certain land utilisation type. The LURs are compared to available land qualities, and in the second and third step the LURs of the LUTs to be combined are assessed on their feasibility jointly. While in the rapid appraisal, this is a qualitative or semi-quantitative comparison, the detailed modelling step focuses on more quantitative analysis of the critical LURs in the combination. After each step, it is evaluated to what extent the new LUTs can contribute to the land holding's targets, and whether the information generated is sufficient for implementation.

Within the context of this research project, there were no case studies available in which we could apply the proposed procedure completely. In the case studies, we applied the rapid appraisal of multiple LUTs in Chapter 3, and the detailed input-output modelling of a multiple LUT in Chapters 4 and 5. A number of tools were applied in the studies: the specification of land use in a product-LUT-LUR format, the break-even price as an indication of financial attractiveness of a LUT, and several methods for detailed modelling. Finally, the general limitations of the applications also require some discussion.

The product-LUT-LUR format

In the rapid appraisal of multiple LUTs in Chapter 3, multiple land use was elaborated in the product-LUT-LUR format. This format serves to systematically analyse the relation between the generated products and required land design and management. The format was relatively well applicable to the groundwater protection and extraction products, compared to the other combination options. The product drinking water with a specific quality is straightforwardly defined, and can be related directly to the essential LURs. The two LUTs that produced nature qualities, viz. traditional willow coppice and the ecological corridor, could be less easily elaborated in that format. Definitions of 'nature' as a product are often complex and dynamic, and the relation between the product and the LURs is less defined. In the last decade, efforts have been made to explicate types of nature more systematically in terms of corresponding flora and fauna, and to specify the required design and management variables. For nature reserves, an example can be found in the nature target types [1], for forests in target criteria [2]. For nature in agricultural systems, a nature yardstick was developed [3], nature as a product was defined in experiments with nature production payment [4]. The recent subsidy regulations on nature management in reserves [5] and in agricultural systems [6] also contain elements of a product-LUT-LUR sequence. Finally, the provincial policy documents on ecological corridors, used in Chapter 3 to identify the guide species, are attempts to such a specification.

However, such specifications of nature are still not easily applicable for MLU explorations in a product-LUT-LUR format. For example, the manual on nature target types [1] contains a specification of traditional wood coppice flora and fauna, which hardly matched with the results of field surveys in traditional willow coppice [7, 8]. Furthermore, descriptions of the relevant structures and processes in the nature target types are very brief and general; therefore this source was not sufficient for an adequate description of the traditional willow coppice land use type as required in the procedure. In general, it is still relatively difficult to specify reliable and detailed relations between management and the resulting nature quality. Therefore, product definitions of natural systems, and specification in terms of LUT and LURs, should be kept open and flexible in order to deal with uncertainties and lack of knowledge.

In the detailed modelling study on willow SRC in buffer zones for desiccation abatement (Chapter 4), the product ‘nature dependent on buffering in the hydrological system’ was not specified in a product-LUT-LUR format. Per desiccation abatement project, the final product, viz. the nature quality of the buffered reserve, will differ, and the relation between reserve nature quality and groundwater tables in the buffer zone will depend on the regional hydrological system. Therefore, we surveyed frequently occurring buffer zone groundwater table classes in studies on desiccation abatement, and used them as an ‘intermediate product’, with a value related to the end product.

Contrary to the nature-related combinations in Chapter 3, Chapter 5 contains a detailed specification of possible new nature targets for willow SRC, i.e. a wide range of breeding bird species for which this land use might be attractive. A qualitative, but detailed product-LUT-LUR specification appeared to be possible through systematic expert judgement. The expert judgement delivered a coherent overview of the relevant design and management variables affecting willow SRC productivity as well as suitability for specific breeding birds. Making such relations quantitative was not possible: it would have required too extensive (field) research in comparison to the context of this application study.

The applications indicate that, also for multiple LUTs, specification of land use in the product-LUT-LUR-format is possible. Flexible product specifications, and the definition of intermediate products may help application of the format.

However, finding relevant data, and especially data in the suited format, appeared to be laborious. This has consequences for the applicability of the proposed procedure. As mentioned in Chapter 2, it should preferably be used by groups of land holders, who can initiate a project of lager magnitude, probably supported by a regional or national authority. When experiences in joint projects lead to the construction of a database of multiple LUTs, the procedure may also become applicable to individual land holders. In the project on sustainable multiple land use in the Dutch region of Winterswijk, (in which energy farming was not subject to study) this has actually been the case [9]. However, upscaling the procedure to groups of land holders will also raise problems: with more actors involved, differences in perspectives and targets will occur, and the distinction between applied research and decision making will become increasingly important.

For that matter, a focus on groups of land holders is in concordance with the preferred scale level for energy crop introduction, and the preferred level to manage many proposed co-functions such as nature management or the protection of drinking water resources. Groups of land holders will be able to operate on a scale that is more suited for MLU than individual land holders.

Break-even prices and the land holder's perspective

In the Chapter 2 procedure, each applied research step generates information the land holder can use to evaluate whether the proposed new LUTs may contribute to his targets. In the application chapters, we reduced this information on the proposed new LUT to biophysical feasibility (as explored in the product-LUT-LUR format), and to financial benefits compared to other, currently existing LUTs. In Chapter 2, it is assumed that the bioenergy product can be valued in terms of financial benefits, i.e. that there is a known price for energy wood. However, in the current situation in the Netherlands, there is not yet a transparent energy wood market with an established equilibrium price. Therefore, we focused on the calculation of break-even prices in Chapters 3 and 4. When such a break-even price is paid to a land holder for his willow wood, the (multiple) willow SRC option is financially equally attractive as the competing (multiple) land use option. For a land holder considering a shift towards energy farming, this price can be useful: if the energy wood market develops, he can easily check whether the emerging market price is interesting according to his situation. And if he is offered a bilateral uutkomme Graddus! contract (without a transparent market), the break-even price can function as profitability criterion. Applied in this way, the break-even price concept can also be used by actors intending to buy energy wood, e.g. electricity companies, as an indication of a reference in negotiations with farmers on wood prices.

In this thesis, however, the break-even price also has another function. By comparing break-even prices in multiple land use versus single land use situations, we can assess whether MLU can actually lead to lower energy supply prices, and thus to improved financial competitiveness of energy cropping. This is a central element in the main research question.

The two different applications of the break-even price concept can be illustrated by the effect of a subsidy for energy farming. If, comparable to current subsides for e.g. cereals, the EU would introduce a hectare-based subsidy for energy crops, the break-even prices will drop. By such a payment, the farmer gains another source of income apart from the willow sales, energy cropping will become interesting at a lower market price, and he will have to reconsider his choices. For this study, however, such changes are less relevant. In multiple as well as single use situations, the break-even price will drop (supposed the subsidy applies to both), and if MLU is more efficient without the subsidy, it will remain more efficient with a subsidy. The ratio between the two break-even prices may change, but it will not turn. The same reasoning applies to other macro-economic effects, e.g. changes in market prices due to large-scale shifts from one type of land use to another.

When comparing break-even prices in multiple and single land use as in this study, it should be noted that in such calculations, potential benefits of improved financial efficiency through MLU are fully allocated to the energy wood buyer. After all, the break-even price indicates a situation in which, for the land holder, the two land use options are equally attractive in financial terms. If MLU leads to a lower break-even price than SLU, this price advantage goes to the buyer. In practice, benefits of improved financial competitiveness may be allocated otherwise. Both the land holder and the actor valuing the other function in the proposed MLU system may want to profit from it. An example of the latter can be found in the desiccation abatement study of Chapter 4. The valuation of the buffer function is currently a compensation payment for yield reduction due to increased soil wetness (the buffer function is not valued by the value of the nature quality in the reserve). If a new crop is introduced, which suffers less from soil wetness, the paying actor might reason that this crop needs less compensation payment since yields are less strongly affected. In such reasoning, the effect of MLU improved efficiency would (partly) be allocated to this actor. A comparable argument can be set up for the land holder: he may reason that the compensation payment should be continued since the buffer situation is maintained, and try to negotiate for a wood price higher than the break-even price.

Break-even price calculations require a considerable amount of information. First, costs of willow SRC management should be known. Second, the competing land use should be known, and its costs and benefits (management costs, product yields and product prices) should be known. And since capital and labour intensity of energy cropping is low compared to other arable land use, situation-specific choices should be made for the valuation of this difference, e.g. whether saved labour hours should be valued at a farm-internal or a market price.

In conclusion, the break-even price concept has appeared to be useful in two ways: as an indication of profitability of a certain land use type for a farmer, and as an indication of efficiency of multiple land use versus single land use. In practice, discussions about allocation of MLU benefits will complicate price setting, and the concept is only applicable in situations where detailed information about agricultural practice is available.

Options for detailed modelling

If the results of the rapid appraisal phase in the Chapter 2 procedure are promising, but not sufficient to support a land holder's decision to introduce the proposed multiple LUTs, a detailed modelling study is required. In such a study, the critical LURs are modelled in their relation to both products to be combined, in order to make trade-offs. Given the detailed studies on buffer zones and breeding birds in Chapters 4 and 5, several types of study can be discerned:

- Application of existing models. In Chapter 4, an existing model could be adapted for the assessment of willow relative growth in buffer areas. In e.g. the groundwater protection and extraction options, a critical LUR such as fertilisation can be analysed using the model for nutrient-limited willow growth as developed by Vleeshouwers [10]. On the relation between fertilisation and groundwater quality, also models exist, such as the ANIMO model developed by Alterra [11]. Combination of these models can facilitate fine-tuning of the fertilisation LUR. For the other critical LURs in these combinations, the application of biocides for weed and pest/disease control, specific knowledge on weed behaviour and pest/disease ecology is required for more detailed studies. For energy crops in particular, current knowledge in this field seems not yet sufficiently developed to make detailed, quantitative optimisation possible.

For existing model application, lack of crop physiological data is a key problem. In Chapter 4 for example, it took considerable effort to estimate willow crop characteristics such as rooting depth and root response to poor aeration, which are essential inputs to the model. This problem may occur in many situations, since willow is not (yet) a well-studied agricultural crop. Dedicated field experiments are needed to quantify essential model input data.

For nature-related LUTs, quantitative modelling will remain problematic. As stated earlier, the relations between product, LUT and LURs are still not sufficiently defined to make sound quantitative modelling possible.

- Detailed and systematic expert consultation, comparable to the study on relevant design and management variables for breeding birds and biomass productivity in Chapter 5. For most LURs in the traditional willow coppice option, such a consultation may help to analyse the effect of traditional coppice modernisation measures. However, the development of mechanical stool-sparing harvesting techniques seems to be the most critical LUR in this combination. This problem needs specific technological development, not further modelling. For the ecological corridor option, a consultation would be useful, provided it considers a specific planned corridor, for which the guide species at which the corridor aims are known.
- Construction of new models is another possibility, not applied in this thesis. Obviously, this requires more expertise and effort than adaptation of existing ones.

In short, elaboration of the detailed modelling phase in the procedure can be shaped by different types of study. However, the possibility to perform such a step depends on the availability of knowledge, data, and existing models, and on the available time and financial capacity. In the framework of the Chapter 2 procedure, it may be more efficient for a farmer to start with an MLU option after the rapid appraisal phase, and improve his insights in the combination in practice (possibly supported by consultants or researchers), than await a detailed modelling phase.

Application development

The applied research phases in the procedure should provide the land holder with information on the attractiveness of new MLU options, in order to support his decisions. In the studies in Chapters 3 to 5 this information is limited to biophysical feasibility of the proposed (multiple) LUTs, and to their expected financial performance. Other aspects that may influence the land holder's decision, such as labour and capital intensity of the LUT, were not explicitly dealt with. However, the information in this study makes two major elements for land holders' decision making explicit and distinguishable.

After each applied research step, a selection follows in which the analysed land use types are evaluated on their (potential) contribution to the holding's targets. We have not elaborated the structure of this decision-making. Multi-criteria analysis represents a suitable evaluation tool for this step, particularly when multiple LUTs are elaborated including aspects such as labour and capital intensity, and consistency with a farming style. Such aspects can only be described at the land holding level.

Some other steps in the procedure were also not detailed any further. For example, the first steps, viz. the inventory of the land holding's internal and external setting, would need more methodological elaboration. National and regional policies and regulations, and the land holding's biophysical, socio-economic and other starting-points should be surveyed systematically, leading to a clear set of holding targets, potentials and constraints. In their search for operationalisation of regional sustainable development, Graaf and Musters [12, 13] have brought up useful elements for such an elaboration, in their definition of a socio-environmental system and the framework for identification of its valuable characteristics. However, these elements would need to be translated to the land holding level.

1.2 Optimisation strategies

In the exploration of multiple LUTs, such systems may need to be optimised. In particular when the functions to be combined compete or conflict according to one or more LURs, this may be complicated: the optimum of the combination may be a situation in which the individual functions perform sub-optimally. In Section 5 of Chapter 2, we discerned 4 ideal types of optimisation strategies for a multiple LUT. Distinctive characteristics were the steering strategy (economic instruments versus command and control) and way of rewarding (output versus input). The case studies differ from these ideal types in two ways: in many cases, a combination of functions as such was not subject of study, but two combinations were compared. Furthermore, the break-even price was introduced.

Optimisation versus combination of combinations

The optimisation strategies of Chapter 2 were elaborated for a situation with two functions to be combined. In the study on willow SRC and breeding birds, we collected information for such an optimisation: the critical LURs for both functions were identified, and the product-LUT-LUR relations were assessed qualitatively. For an optimisation, however, either financial valuation or minimum standards would be needed, which were not available. Therefore this case study only provides information for an optimisation, not the optimisation itself.

In most case studies in Chapters 3 and 4, many proposed co-functions, such as groundwater protection and hydrological buffering, were currently fulfilled in other MLU combinations, mostly with common agriculture. In this context, the question was not how a specific combination of willow and a function B would be optimised, but how such a combination option would perform compared to the currently conventional combination with function B. Solely optimising the combination {willow + B} is not sufficient; it should be compared to the conventional combination {common agriculture + B}. In Figure 6.1, this more complex optimisation is illustrated, in a situation in which for all three functions, product-LUR relations are known quantitatively, and all products are valued financially. While the sum curves are not shown, it can be derived that in the right figure, the optimum of the combination {willow + B} will have a higher total financial result, and will lie more towards the function B maximum, than the optimum of {common agriculture + B}. This provided that in both combinations, the function B production curve is the same.

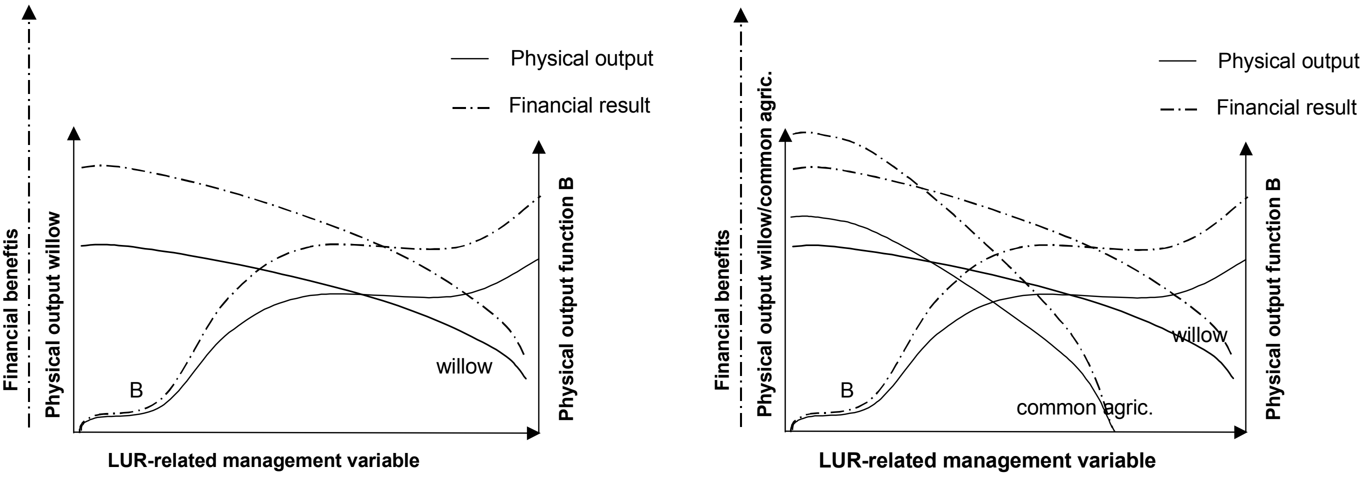

Figure 6.1: Difference between optimisation of a multiple LUT (left), and optimisation of a multiple LUT versus another multiple LUT (right).

The calculations on willow SRC in a hydrological buffer zone (Chapter 4) are a good example of this comparison of combinations. The combinations {buffering nature + willow} and {buffering nature + grassland} were compared, in which the nature buffering function was financially valued on an input parameter, viz. the groundwater table class. The buffering function was valued by a financial compensation for productivity losses in common agriculture. Assuming that willow wood would have a market price, this exercise is illustrated in Figure 6.2.

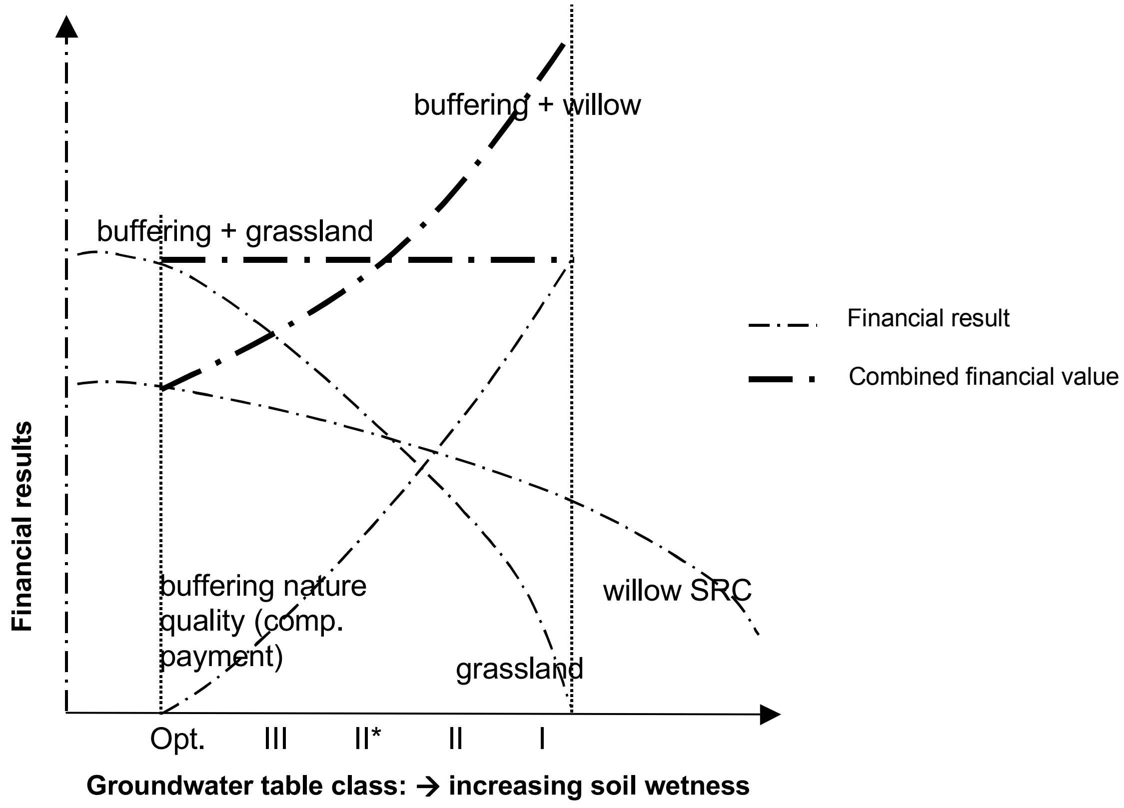

Figure 6.2: Illustration of a hypothetical optimisation in Chapter 4 (the desiccation abatement case), if there were a willow energy wood market price available.

By definition, the curve for the combined value of {buffering + grassland} is a horizontal line, since the valuation of the buffering function is a compensation payment. If the compensation, as a reward for the buffering function, remains unchanged while changing the MLU to {buffering + willow}, the new MLU will have an increasing combined value with increasing soil wetness because willow is less susceptible to this LUR. For a land holder, the optimum situation for the {buffering + willow} would be at Gt I, and this situation would be more profitable than {grassland + buffering} at any Gt.

Break-even prices and optimisation

In none of the case studies, we could straightforwardly apply any of the proposed optimisation strategies, since such optimisations require a market price for willow energy wood (in the case of economic instruments) or a minimum standard for willow SRC productivity (in the case of command and control). An energy wood market has not yet been fully established, and productivity standards have not (yet) been transparently defined. Instead, we introduced the willow break-even price. This approach circumvents the problem of absence of a willow market price. However, a break-even price is not necessarily related to an optimised situation: it only describes willow competitiveness compared to other land use.

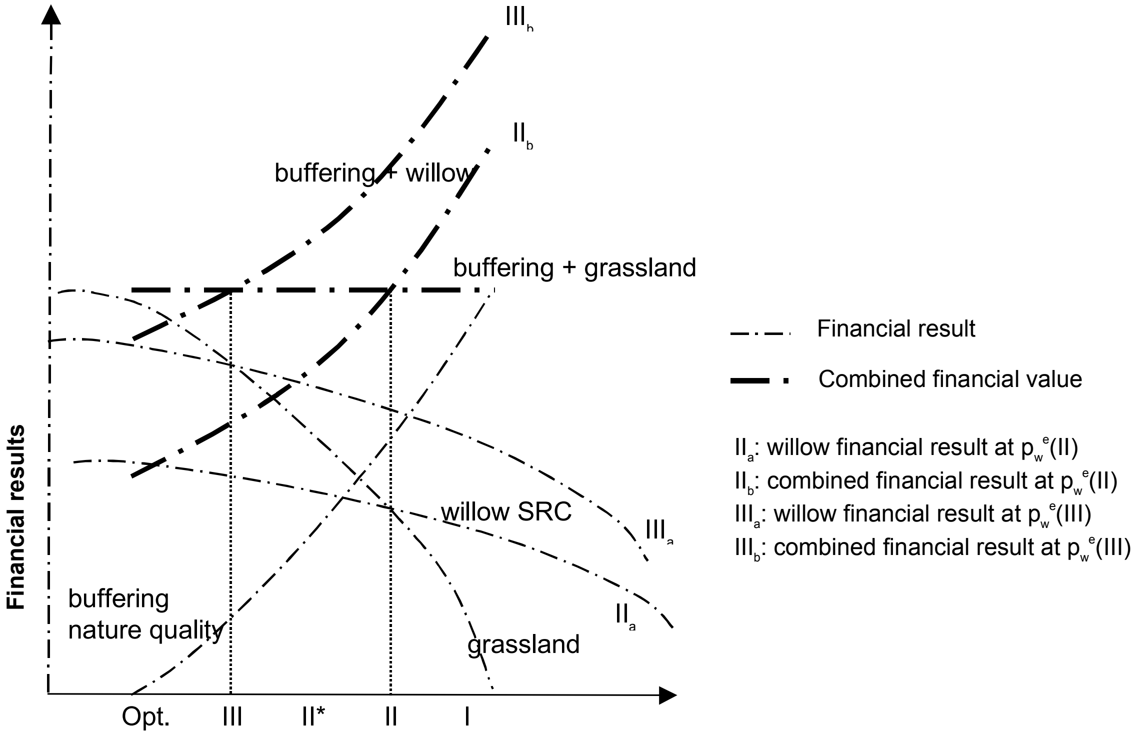

Figure 6.3: Willow break-even price calculations in the desiccation abatement case, for break-even prices at Gt II ($p_w^e(II)$) and Gt III ($p_w^e(III)$). See Chapter 4.

Again, the buffer study of Chapter 4 can illustrate this. Per Gt, the break-even price is that valuation of willow wood in which the benefits of the combination {buffer + willow} are equal to {buffer + grassland} at that specific Gt (see Figure 6.3). By comparing these break-even prices with break-even prices in a single-use comparison between grassland

and willow SRC, it becomes clear whether the MLU combination of willow SRC in a buffer zone leads to improved competitiveness. This break-even price indicates the minimum price a buyer would have to pay to make willow SRC equally attractive as grassland. In an optimisation a farmer would seek the Gt that gives him the highest overall profits, given a willow (market) price. These two approaches are not identical. For example, if a certain willow price p_w^e (III) would be agreed upon in a situation with Gt III (see Figure 6.3), a land holder could make more profits when the hydrological conditions are changed to Gt II and he obtains the Gt II compensation payment and willow profits.

The optimisation framework provides the basis for valuation of the combined land use types, also in the situation with a 'double comparison' of two multiple LUTs. The break-even price, however, indicates a minimum wood price. Although consistent with proposed optimisation strategies of Chapter 2, it does not provide any information on an optimal situation for a land holder. This problem will be solved when a transparent willow market has been established, including a market price.

2. Application potentials of the studied combination options

In Chapter 1, several factors hampering the introduction of energy farming in the Netherlands were identified: Current demand for land and corresponding need for efficient land use, and the relatively poor profitability of energy cropping compared to other types of land use. Given the concepts and methods proposed in Chapter 2, multiple land use (MLU) can be a strategy to enhance energy crop introduction. Multiple land use types may be more efficient than single types, and the fact that they generate more than one type of product or service may alleviate the problem of poor energy crop profitability. In this section, we overview all proposed combination options studied in this thesis, and discuss their biophysical feasibility, effect on willow financial competitiveness and potential area.

2.1 Selected combination options

In the Chapters 3 to 5, we evaluated a number of options for willow short rotation coppice (SRC) in multiple land use types. We shortly describe them here. In many cases, the combination option competes to another, currently practised MLU option. In Chapter 3 rapid appraisals of the following combinations options for willow SRC were performed:

In *groundwater protection areas*, energy cropping may be combined to the protection of groundwater quality for drinking water production. In these areas surrounding water extraction wells, specific regulations apply to land use, inter alia on fertiliser and biocide use. For common agriculture, the dominant land use in these areas, it remains problematic to comply with these regulations without productivity loss. Willow SRC, with its low external inputs, might have a competitive advantage in these areas.

In *groundwater extraction areas*, energy cropping may also be combined to drinking water production. These are smaller areas directly surrounding the wells. Here, restrictions on fertilisation and biocide use are stricter; low-input cereal cultivation and management for nature and landscape features are currently common. Again, willow SRC with its low inputs might be a competitive type of land use in these areas.

Traditional willow coppice lands in the Netherlands are valued for their specific nature and landscape features. Currently produced willow switches find declining sales in infrastructure and some small niche markets, but the material can also be used for energy. To enhance energy wood production, the coppice may be modernised, provided this modernisation does not have significant negative effects on the stands' nature and landscape features.

Ecological corridors are valued as a migratory area for fauna, to interconnect nature reserves. A willow plantation may also fulfil such a function.

Chapters 4 and 5 contain more detailed analysis of two specific combinations:

In *hydrological buffer zones around groundwater-dependent nature reserves*, the applied groundwater level is a land use requirement for nature quality in the buffered nature reserve. Since willow is well known for its tolerance towards flooding and moist soils, it might have advantages compared to the currently dominant land use, viz. common agricultural grasslands for dairy farming.

Modern willow SRC might also be managed to *enhance biodiversity within the plantation*. We explored the opportunities for detailed optimisation of plantation design and management for productivity as well as breeding bird species richness.

For comparison, we also include a combination option not elaborated in this thesis, but relatively well worked-out in a project by several research centres of Wageningen University:

On *polluted sediments and sludges*, willow SRC might improve sludge aeration, and thereby enhance decomposition of organic contamination [14]. As a decontamination technology, this option competes with physical or chemical techniques.

2.2 Feasibility criteria

The options were evaluated on three criteria: their biophysical feasibility, effects on willow financial competitiveness, and the potential areas available for each combination.

- *Biophysical feasibility* was assessed by analysing each proposed combination as a combination of two land use types (LUTs), each having a set of land use requirements (LURs, for details see Chapter 3). In such an approach, conflicting or competing LURs can be identified and possible solutions can be explored.
- *Effects on willow financial competitiveness* were assessed by the following. In principle, willow SRC always will have to compete to other types of land use. Given the dominant competing land use in a certain situation, a break-even price was calculated, i.e. the willow purchase price to be paid to a land manager in order to make willow SRC equally attractive as the competing land use. If this break-even price in a MLU combination comparison (e.g. willow in buffer zones versus common agriculture in buffer zones) is lower than the break-even price in a single-use comparison (e.g. willow SRC versus common agriculture), we consider the combination option to improve willow SRC financial competitiveness. Obviously, this competitiveness of willow SRC increases with decreasing break-even price of the combination option.

- *Potential area* assessment was based on the actual use or space claim of the function to be combined with willow SRC. The space claim was derived from policy targets or other literature estimations of the area needed.

2.3 Results

Table 6.1 summarises the findings for the seven different combination options. For each criterion, it is also indicated whether the result is relatively certain, based on reliable data and calculations or uncertain, based on less reliable data or indicative calculations. The column 'implementation problems' refers to text further on in this section.

Table 6.1: Seven combination options evaluated on three main feasibility criteria. See text for details.

Combination criterion	**Biophysical feasibility**[2]	Feasibility certainty[3]	Successful experiments in NL	**Effect on financial competitiveness**[4]	Financial effect certainty[3]	**Potential area (ha)**	Potential area certainty[3]	Implementation problems[5]	References
Groundwater protection areas	+	+	No	**0**	+	**71,000**	+	D	[15]
Groundwater extraction areas	+	+	Yes	+	-	**5,000**	+	CD	[15]
Traditional willow 1	+	+	No	**0**	+	**1,000**	+	AC	[15]
coppice lands[1] 2	-	-	No	+	-				
Ecological corridors	+	-	No	**?**		**2,000**	-	BCD	[15]
Hydrological buffer zones	+	+	No	+	+	**20,000**[6]	-	BD	[16, 17]
Breeding bird enhancement	+	+	No	**?**		**?**			[18]
On contaminated sludges[7]	+	+	Yes	++	+	**3,000**	+	AB	[14, 19, 20]

[1]: 1 is traditional coppice with manual harvest; 2 is modernised coppice with mechanical harvest.

[2]: Legend: -: option (currently) biophysically not feasible; +: option biophysically feasible.

[3]: Legend: - relatively uncertain; + relatively certain.

[4]: Legend: 0: no effect; +: 0-50% reduction of willow break-even price compared to single land use; ++: 50-100% reduction of willow break-even price compared to single land use.

[5]: Implementation problems: A: Societal resistance; B: Site uncertainty; C: Plot size. D: Area scatteredness (see Section 3.1).

[6]: A total area of ca 100,000 ha of hydrological buffer areas has been estimated [21, 22]. These areas will roughly fall in five groundwater table classes: Gt I to V. In a first-order approximation, the areas with Gt II will be 20,000 ha. For this Gt, the improved willow SRC competitiveness is the clearest. See [16] for further details.

[7]: Biophysical feasibility assessment in [14] not identical to the product-LUT-LUR format, but sufficient to confirm feasibility. Financial competitiveness: this land use can compete with other sludge decontamination options without any benefits from willow sales [19]; Potential area: based on ca 25 Mm^3 sludge suited for this option applied in a 1 m layer [20].

All combinations, except the modernised plantation on traditional willow coppice, seem to be biophysically feasible: their LURs can be reconciled. For the ecological corridor option, however, this feasibility is not very certain. For two options, practical experiences on the ground could even be found.

A certainly positive effect on willow SRC competitiveness (expressed in a lower break-even price compared to single land use) could only be found for two combinations: the hydrological buffer areas and the decontamination of sludges. For several other options, biophysical feasibility does not involve a lower willow break-even price, or there is a positive effect with high uncertainty. For example, willow SRC in groundwater protection areas, the option with the largest potential area by far, will hardly lead to better competitiveness. In these areas, improved financial competitiveness will not be an argument for energy crop introduction.

2.4 Implementation problems for the surveyed options

In Chapters the case studies, we focused on potentials for multiple land use willow SRC in terms of biophysical and financial aspects. However, practical implementation can also encounter problems of social, cultural and institutional nature, on which we shortly dwell here. In Table 6.1, a number of implementation problems are indicated that depend on the specific characteristics of a combination option.

a. Social resistance. A combination might be well feasible in biophysical and financial terms, but other features referring to social values may strongly hamper local or regional implementation. As an example from other studies, the combination with contaminated sludges experienced some public protest when a governmental permit was requested for a pilot site in the Dutch Wieringermeer polder [19]. Objections were that freight trucks delivering the contaminated sludges might cause noise nuisance, and there were also concerns about environmental safety and potential soil contamination. Social acceptance may be improved by open communication with the public about the combination’s positive and negative merits, and by taking local concerns seriously.
b. Site uncertainty. Some proposed co-functions, such as the hydrological buffer zones and the ecological corridors, are currently still under study. This uncertainty in potential area and planned sites can also be an implementation problem: it is not yet clear where the relevant area will be located. However, uncertainty on the proper location may also be turned into an advantage: the opportunity to introduce a function in combination with willow SRC may improve chances for the combination, and focus the search for suited locations.
c. Plot size. For willow SRC mechanisation and logistics, implementation will be easier if the combination is introduced on a reasonable scale, for which we assumed minimally ten ha. Some co-functions, such as ecological corridors, apply to small-scale plots, sometimes smaller than one ha, which hinders implementation of the combination.
d. Area scatteredness. Some functions are confined to a specific region in the Netherlands, in which the combination is concentrated. This facilitates logistics in terms of large-scale biomass transport to the power plant. Others apply in plots throughout the country, complicating implementation. The latter two problems may be

overcome by joining small or scattered areas to other combination options to provide sufficient critical mass for willow SRC introduction within a region.

Apart from option-specific problems, some more general problems related to multiple land use may be expected.

- In multiple land use, more actors, with potentially deviating perspectives, may be involved in design and management of the land. Apart from theoretical problems with tuning of activities, this requires mutual commitment and trust in practice: the actors depend on each other and they can also threaten each other's interests, e.g. by not sticking to arranged management. Single land use involves less land use related actors, and therefore entails less risk that such conflicts occur. Experiences in nature management on agricultural lands (also multiple land use) have shown that a structure of agreements and rewards is necessary to maintain mutual confidence [4, 23].
- Currently, most policies and regulations, also the ones for innovation in the rural area, are not explicitly tailored to new types of multiple land use [24]. The existing interest for multiple land use types including common agriculture, already exceeds the available regulations, as is illustrated by the rapid exhaustion of the subsidies for nature management on the farm [6, 25]. The existing instruments, however, are not directly applicable to options with willow SRC. Entirely new combinations such as willow SRC and sediment decontamination have this problem for both combined functions. As often, existing regulations and policies will rather raise barriers than apply incentives for fundamental innovations such as energy crop introduction and multiple land use.
- Post-WWII Dutch and EU agricultural policies have tended to emphasise agricultural specialisation and monoculture. While part of the farmers has always preferred multiple land use above single land use, for many farmers a shift towards multiple land use would require a fundamental attitude turnover. However, in many respects farmers can be characterised as a heterogeneous group, of which a group of 'front runners' will always be open to new developments. For them, multiple land use energy cropping represent be such a new challenge.

Finally: there will be implementation problems related to the introduction of energy cropping in general. Such problems, such as farmers' lack of practical knowledge on energy crop cultivation, personal preferences, logistics, etc., are not specific for multiple land use systems and therefore not subject to this study.

3. Perspectives for energy crop implementation in multiple land use

Given the results of the case studies, we can now answer the central research question of this thesis, and we discuss to what extent multiple land use will improve opportunities for energy crop introduction in the Netherlands. We dwell on the three selected criteria: biophysical feasibility, effect on biomass supply prices, and significance of the potential area. Furthermore, we outline the most influential long-term factors that may affect or alter the findings.

3.1 Multiple land use for enhancement of energy crop introduction

Biophysical feasibility of energy crops in multiple land use

From the assessments, many options for willow SRC in multiple land use seem to be biophysically feasible although a number of implementation problems require attention (Section 2.4). However, the studied combination options were pre-selected according to our general impression of feasibility. Therefore, the results in this thesis are probably optimistic compared to the picture for the broad range of currently suggested combination options in the literature [26-28].

New MLU combinations may offer new perspectives. For example, the idea that willow cultivation decontaminates sludges is relatively new. Currently, the new plans for extension of Dutch river floodplains and creation of temporary submersion areas may offer new possibilities not yet assessed in this thesis.

We concentrated on willow SRC as an energy crop. Other crops, such as poplar, or the grasses switchgrass and Miscanthus, have also been suggested for energy farming, with MLU as well [29-31]. These crops have other properties, and such MLU combinations need specific analysis. Since the agricultural inputs in these crops are roughly comparable to willow [32], combinations with input-dependent functions such as groundwater protection may yield comparable results. However, since their vegetation structures differ from willow SRC, combination feasibility with functions dependent on nature and landscape features may not be similar.

Supply prices of energy crops versus other bioenergy resources

As illustrated by Table 6.1, several combination options lead to lower break-even prices for biomass compared to single land use. In this sense, MLU improves the competitiveness of energy crops. However, supply prices for willow SRC in single use have been calculated at ca € 125 per oven-dry tonne and higher, depending on the competing land use [16, 33] (note that assumptions on labour, capital and farmer’s income strongly influence the break-even price). Current prices of e.g. forestry residues, (clean) waste wood and other biomass types of comparable quality, vary between ca € 0 and € 25 /odt before transport [34, 35]. Biomass prices within this range can be assumed to be competitive with fossil fuels such as coal, given the current incentive policy measures for renewable energy in the Netherlands. Bioenergy MLU price reductions as given in Table 6.1 will leave willow SRC at significantly higher price levels. For example, a price reduction of 20% for MLU, as found in Chapter 4, and a residue price of € 25 /odt would still leave a price gap of € 75/odt between the two biomass resources. Although smaller than in single land use energy cropping (€ 100 /odt), such a difference is still significant.

An option to reduce break-even prices would be to avoid competition for land with common agriculture, and seek for land dedicated to e.g. nature conservation and recreation. Obviously, its introduction should not deteriorate the area’s conservation or recreation function, which should be analysed by methods comparable to the product-LUT-LUR-format in this thesis. While several studies indicate that there might be potentials in recreational parks [26, 35], no systematic studies have been carried out so far. Energy farming in non-agricultural areas would have strongly different supply prices, since there is no competing crop. Energy cropping in recreational areas (without land rent) could lead to supply prices of ca € 40 /odt [35], significantly closer to the prices of residues than the break-even prices in this study. A comparable effect would occur if multiple land use energy farming were to be introduced on fallow land under the EU set-aside scheme [37]. However, it is questionable whether this set-aside scheme, originating from an internal market imperfection, will sustain.

Contribution to the national renewable energy supply

Most potential areas of the combination options are in terms of thousands of hectares. The totals of potential areas are ca 30,000 and 100,000 ha (for areas with and without financial benefits, respectively). These areas correspond to circa 0.1% and 0.5% of current domestic energy demand in the Netherlands. Studies concentrating on the demand for biomass energy estimate that between 20,000 and 100,000 ha of energy farming will be required to meet the 10% renewable energy target in the year 2020 [38-40] (see Figure 1.2). Therefore, the potential area of MLU willow SRC with improved financial competitiveness will probably not be sufficient to meet this target.

For the studied MLU combinations, potential areas will probably not increase. For the options in which an existing area was taken to assess potential area, these areas are not likely to increase in the future, and for the options for which policy targets were taken, it is already questionable whether these targets will be met. Only for the ecological corridor option, potential areas may become higher than assessed here due to new policy.

Obviously, other combination options might open up new areas for MLU with energy farming. For example, the plans for river floodplain expansion and creation of temporary buffers in time of peak discharge, constitute a major part of the ca 500,000 ha expansion claim for water in Table 1.1. An MLU combination with this function might create a significant area. However, as long as biophysical feasibility and financial competitiveness have not been studied, it is not possible to estimate the relevance of this area. A comparable reasoning can be applied to combinations with the recreation claim in Table 1.1.

General conclusions

Referring to the central research question, multiple land use will enhance opportunities for energy crop introduction in the Netherlands, but it will not be the panacea for large-scale introduction of competitive energy farming. Energy crops seem to be well suitable for multiple land use. However, MLU leads to financial benefits compared to single land use, but these are currently not that significant that supply prices can be reduced to the level of other currently available biomass resources such as residues. The potential areas in which a financial benefit occurs are probably not sufficient to supply the required area to meet the 2020 renewable energy target.

These perspectives are primarily relevant for the Netherlands. The multiple land use concept might also be useful in other countries, and as such, the Chapter 2 procedure can be applied there as well. However, many data used in Chapters 3 to 5 are specific for the Dutch context. For example, productivity figures in agriculture, policy targets for nature conservation on the farm, and ecological characteristics of breeding birds may be different in other countries. Therefore, these chapters are only applicable to other countries if differences in context are taken into account.

3.2 Long-term perspectives of energy crops

In the long term, several developments may alter the picture of limited competitive perspectives for energy crops in MLU. We shortly discuss four types: innovations in the cultivation of energy crops, developments concerning the EU Common Agricultural Policy (CAP), increasing valuation of (environmental) co-functions in MLU, and developments concerning energy and climate policy.

Innovations in energy crop cultivation

As mentioned before, new MLU combinations and new energy crops might as well be innovative and cost-reducing. Agronomic developments might also improve opportunities for energy crops, in management costs as well as productivity. These improvement options apply to energy farming in multiple as well as single land use

Cultivation of energy crops is a relatively new type of agriculture. While traditional forms of willow and poplar cultivation have existed for centuries, modern farming of energy crops has a history of circa ten years. Therefore, innovations in management and optimisation have more potentials in these crops than in common agricultural crops. For example, techniques for planting and harvesting (the most expensive activities in willow SRC) are still being ameliorated; cost reductions of tens of percents are likely in all energy crops [33, 41-43].

Costs per tonne biomass can also be reduced by (conventional) plant breeding, leading to more productive genotypes. New varieties may also lead to yield improvements of tens of percents [44, 45]. However, yield improvements in practice may be considerably lower, as illustrated by a comparison with past yield developments in cereals and silage maize [46].

These developments will lead to reduced supply prices of energy crops, in multiple as well as single land use. However, it is hard to estimate the extent of this reduction.

Developments in the EU Common Agricultural Policy

Agricultural land use in the EU is strongly influenced by the CAP. Changes, due to e.g. new WTO agreements or the access of a number of East European countries will therefore strongly affect potentials for energy crops, in multiple as well in single land use.

The EU market regulations, with their market protection and support payments to farmers, have always been disputed with GATT and WTO as being protectionist. If these regulations are to be abandoned, prices for common agricultural products will deteriorate. This may lead to improved opportunities for energy farming. On the other hand, a response to this threat in policy and practice is to develop new multiple land use and pluri-activity initiatives with common agriculture [50-53]. The effect of this response on energy farming is bipartite. On one hand, if common agriculture becomes better adapted to multiple land use, it may compete more strongly with energy farming. On the other hand, increasing general attention for multiple land use may also lead to increased opportunities for energy farming in multiple land use. The net effect of this development is hard to estimate.

The coming access of Central and East European countries like Poland and Hungary to the EU will be another incentive to reduce market regulation and price supports in common agriculture, which may have a positive effect on energy farming competitiveness.

On the other hand, if wood-exporting countries like the Baltic states are to join the EU, they will be able to dominate a future energy wood market. Given the low prices for land and labour in these countries, these countries may be able to outcompete inland energy farming in the Netherlands. Therefore, the net effect of EU extension is hard to estimate.

Increasing valuation of the co-functions in MLU

When co-functions are to be valued, the perspectives of multiple land use may improve. In the groundwater protection case for example, the low inputs and outputs of nutrients and biocides in willow SRC (compared to common agriculture) are currently not valued. However, if e.g. a drinking water company would provide a supportive payment for this protection of groundwater quality, the break-even price for willow SRC would drop. In order to reduce the break-even price to the currently indicated price level of biomass residues, a supportive payment up to € 100 /odt (or ca € 1,000 /ha) would be required, which is improbable. However, a smaller supportive payment can be one of the contributors to competitive price levels.

A similar effect might occur if supportive payments within the EU Common Agricultural Policy would be introduced dependent on the environmental and landscape efforts of farmers (cross-compliance). This feature has been suggested to compensate for a CAP reform in which price support and hectare payments to farmers are abandoned due to WTO commitments. If, for its environmental and landscape benefits or for other reasons, willow SRC for energy would also apply for such a reward, this would partly fill up the price gap with biomass residues. For example, if these rewards would be similar to the current direct payments to farmers of cereal, oilseeds and fibre crops (varying between ca € 300 and € 900 /ha.yr in the Netherlands [36]), this could reduce willow break-even prices (in MLU as well as SLU) with ca € 30 to 90 /odt.

Developments in energy and climate policy

Autonomous developments in fossil fuel prices are not likely to increase competitiveness of bioenergy, or renewable energy in general. Fossil resources seem to be sufficient for centuries of energy supply [47], and unless a major geopolitical conflict in the Gulf region will startle the world, a significant price increase will probably not occur.

However, EU concerns about climate change and meeting the Kyoto protocol might lead to the introduction of a pricing system for CO_2 emissions, either by CO_2 taxation or by a general emission ceiling accompanied by a trading system. Such pricing can have a strong impact on bioenergy profitability, since this is a (virtually) CO_2-neutral source of energy. For example, an emission price of € 20 /ton CO_2 (such an order of magnitude has recently been suggested in studies for the EU as well as the US [48, 49]) would indirectly mean a price reduction for biomass of almost € 40 /odt. However, such pricing is still uncertain and subject to debate; as most issues related to Kyoto.

These effects, however, will affect bioenergy regardless whether the type of biomass resource is energy crops or residues. Only when the demand for biomass grows to a level at which the marginal costs for residues start to increase due to the finiteness of this resource, this effect does not change the balance between energy crops and residues.

Most of these developments will influence chances and competitiveness of willow SRC in multiple as well as single land use. However, it remains clear that *if* willow SRC becomes more competitive, the multiple land use options with financial attractiveness described in this thesis will probably get into the picture earlier than single land use willow SRC.

References

1. Bal, D, H.M. Beye, S.R.J. Jansen, and P.J. van der Reest. *Handboek natuurdoeltypen in Nederland (Manual on Nature Targets Types in the Netherlands).* Wageningen: IKC Natuurbeheer, 1995.
2. Hekhuis, H.J., J.G. de Molenaar, and D.A. Jonkers. *Het sturen van natuurwaarden door bosbedrijven (Steering of nature values in forestry).* Wageningen: IBN-DLO, 1994.
3. Horlings, L.G. and J.C. Buys. *Zicht op natuurresultaat; De natuurmeetlat als beleidsinstrument (view on nature results. The nature yardstick as a policy instrument).* Utrecht: CLM, 1997.
4. Musters, C.J.M., M. Kruk, H.J. de Graaf, and W.J. ter Keurs. *Breeding birds as a farm product.* Conservation Biology 2001, 15 (2): 363-369.
5. Ministry of LNV. *Subsidieregeling Natuurbeheer 2000 (subsidy regulation nature management 2000).* Den Haag: Ministry of Agriculture, Nature Management, and Fisheries, 2000.
6. Ministry of LNV. *Subsidieregeling Agrarisch Natuurbeheer (subsidy regulation nature management on the farm).* Den Haag: Ministry of Agriculture, Nature Management and Fisheries, 2000.
7. Jonkers, D. *Vogelstand en griendbeheer (Bird populations and the management of traditional willow beds).* Leersum: Rijksinstituut voor Natuurbeheer, 1982.
8. Schepers, J.A.M., A.A.M. van Haperen, and J.L. van der Jagt (ed.). *Grienden: hakken of laten groeien; inventarisatie van het hakgriendenarsenaal en mogelijkheden voor ontwikkeling (Traditional willow coppice: coppicing or letting grow; an inventory of the arsenal of traditional willow coppice and potentials for development).* Utrecht: IKC-NBLF, 1992.
9. Graaf, H.J. de, M.J.D. Hack, and O.C.H. de Kuijer. *Stimuleren van Meervoudig Duurzaam Landgebruik in de praktijk: toegankelijk maken en uitdragen van kennis, inzichten en methoden (Stimulating multiple sustainable land use in practice: making knowledge, insights and methods accessible and carrying them out).* Leiden / Wageningen / Amsterdam: Environmental Biology / SC-DLO / KDO Consultancy, 1999.
10. Vleeshouwers, L. *Assessment of biomass energy systems: Yield potentials under various land use options.* Wageningen: Wagenngen University, 2001.
11. Groenendijk, G. and J.P. Kroes. *Modelling the nitrogen and phosphorus leaching to groundwater and surface water with ANIMO 3.5.* Wageningen: Winand Staring Centre, 1999.
12. Graaf, H.J. de, C.J.M. Musters, and W.J. ter Keurs. *Regional opportunities for sustainable development; theory, methods and applications.* Dordrecht: Kluwer academic publishers, 1999.
13. Graaf, H.J. de and C.J.M. Musters. *Resultaten project Duurzaam Landgebruik, fase B/C (Results project sustainable land use, phase B/C).* Delft: DTO, 1997.
14. Boels, D., J.J.H van den Akker, J.E. Dijkhuis, R. Duijn, J. Harmsen, R. Kampf, W. Ma, A. van den Toorn, G.D. Vermeulen, and J.J. van der Waarde. *Kwaliteitsverbetering van baggerspecie op basis van extensieve biorestauratie in combinatie met energieteelt (sediment sludge quality improvement based on extensive bioresturation in combination with energy farming).* Gouda: CUR/NOBIS, 1999.
15. Londo, M., M.E. Roose, J. Dekker, and H. de Graaf. *Willow short rotation coppice in multiple land use systems: evaluation of four combination options in the Dutch context.* Submitted to Biomass and Bioenergy.
16. Londo, M., L. Vleeshouwers, J. Dekker, and H. de Graaf. *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation.* Biomass and Bioenergy 2001, 20 (5): 337-350.
17. Meeusen, M.J.G., H.H.W.J.M. Sengers, L.C. Kuiper, and P.A.G. Jansen. *Energieteelt in bufferzones; een eerste inventarisatie van de mogelijkheden (energy farming in buffer zones; a first inventory of opportunities).* Den Haag: LEI-DLO, 2000.
18. Londo, M., W. ter Keurs, and J. Dekker. *Willow Short Rotation Coppice for energy and breeding birds: An exploration of potentialsin relation to management.* Submitted to Biomass and Bioenergy.
19. Breteler, H. *Personal communication on willow farming on contaminated sediment sludges.* Wageningen: IMAG-DLO, 2001.

20. Breteler, H. *E-mail message dated March 8, 2001, on sludge decontmination by landfarming.* Wageningen: IMAG-DLO, 2001.
21. Beugelink, G.P. *Personal Communication dated September 30, 1998.* Bilthoven: RIVM, 1998.
22. Londo, M. *Unpublished calculations, based on data from RIVM et al., 1998.* Utrecht: Utrecht University, 1999.
23. Kruk, M., H.J. de Graaf, W. van Harmelen, W. Twisk, and W.J. ter Keurs. *Natuurproduktiebetaling; een nieuw instrument voor agrarisch natuurbeheer (nature production payment; a new instrument for nature management on the farm).* Openbare uitgaven 1995, (2): 94-99.
24. Luttik, J. and J.T.C.M. Sprangers. *Combineren met natuur; Economische, sociale en ecologische duurzaamheid van functiecombinaties (Combining with nature: Economic, social and social sustainability of function combinations).* Wageningen: SC-DLO, 1999.
25. Ministry of LNV. *Persbericht: Veertig miljoen gulden extra voor agrarisch natuurbeheer (Press release: Fourty million guilders extra for nature management on the farm).* The Hague: Ministry of Agriculture, Nature Management and Fisheries, 2000.
26. Heineman, A., G. Saaltink, and L. Kuiper. *Energie uit biomassa in combinatieteelt (Energy from biomass in combination farming).* Wageningen: CPV/SBH, 1999.
27. Börjesson, P. *Environmental effects of energy crop cultivation in Sweden - I: Identification and quantification.* Biomass & Bioenergy 1999, 16 137-154.
28. Eker, M., W. Elbersen, B. de Klerk, R. de Koning, N. van der Windt, and A. Wintjes. *Switch on! First prize winning entry for the 'Living Energy' design competition to introduce energy crop cultivation in the landscape.* Wageningen: SC-DLO, 1999.
29. Ma, Z., C.W. Wood, and D.I. Bransby. *Soil management impacts on soil carbon sequestration by switchgrass.* Biomass and Bioenergy 2000, 18 469-477.
30. Jodl, S., A. Eppel-Hotz, and K. Marzini. *Examination of the ecological value of miscanthus expanses - faunistic studies-.* In: Kopetz, H., T. Weber, W. Palz, P. Chartier and G.L. Ferrero (eds.). *Proceedings of the 10th European Conference and technology exhibition "Biomass for energy and industry".* Rimpar: C.A.R.M.E.N, 1998. 778-779.
31. Fernando, A.L., I. Falcão, and J.F. Santos Oliveira. *Bioremediation of contaminated soils with heavy metals with Miscanthus sinensis giganteus - Effects on growth, productivity and biomass quality.* In: Kyritsis, S., *et al. Proceedings of the 1st World Conference on Biomass for Energy and Industry.* Seville: 2000. 353-356.
32. Biewinga, E.E. and G. van der Bijl. *Sustainability of energy crops in Europe; a methodology developed and applied.* Utrecht: CLM, 1996.
33. Dinkelbach, L., J. van Doorn, R. Jansma, A. de Raad, J. Jager, M.J.G. Meeusen - van Onna, W. Huisman, A. Heineman, E. Annevelink, and G.J. Kasper. *Geteelde biomassa voor energieopwekking in Nederland; identificatie van de meest veelbelovende mogelijkheden tot kostenreductie in vier ketens (Cultivated biomass for energy production in the Netherlands, identification of the most promising opportunities for cost reduction in four chains).* Petten: ECN, 1999.
34. Zeevalking, J.A. and J. Koppejan. *EWAB marsroutes, Taak 1; Beschikbaarheid van biomassa en afval (EWAB Marching routes, task 1; Availability of biomass and waste).* Utrecht: NOVEM, 2000.
35. Schulte, B., H.M. Londo, and E.J. Bruls. *Duurzame energie in Recreatiegebieden (renewable energy in recreation areas).* Utrecht: Ecofys, Utrecht University, Stichting Recreatie, 2001.
36. PAV. *Kwantitatieve Informatie akkerbouw en vollegrondsteelt 2000/2001 (quantitative information on arable and open soil agriculture).* Lelystad: Practical research for arable agriculture and cultivation in open soils, 2001.
37. Vlasblom, J. *Do Energy Crops boost the Economy? An assessment of the national and regional economic impacts of electricity from energy crops.* Utrecht: NW&S, 1997.
38. Ruijgrok, W. and M.C. Kalf. *Bouwstenen bio-energie 2020 (Building blocks bio-energy 2020).* Anhem: KEMA, 1998.
39. Heuvel, E.J.M.T. van den and J.K. Gigler. *Is er grond voor biomassaproductie in Nederland? (Is there ground for biomass in the Netherlands?).* Utrecht: NOVEM, 1998.
40. Ree, R. van, T. Gerlagh, B. Groenendaal, L. Dinkelbach, J. van Doorn, and K. Hemmes. *Kritische succesfactoren biomassa (critical succes factors biomass).* Petten: ECN, 2000.
41. Lewandowski, I., J.C. Clifton-Brown, J.M.O. Scurlock, and W. Huisman. *Miscanthus: European experience with a novel energy crop.* Biomass and Bioenergy 2000, 19 209-227.
42. Huisman, W., P. Venturi, and J. Molenaar. *Costs of supply chains of Miscanthus giganteus.* Industrial Crops and Products 1997, 6 353-366.

43. Schneider, B. and S. Deimling. *Brennstoffkosten und Brennstoffpreise (Fuel costs and fuel prices).* In: Deimling, D., *et al. Leitfaden Bioenergie; Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen (Guidebook Bioenergy: Planning, operation and profitability of Bioenergy systems).* Gülzow: Fachagentur Nachwachsende Rohstoffe, 2000.
44. Anonymous. *Svalöf Weibull Willow Varieties.* Svalov: Svalöf Weibull, 2001.
45. Clifton-Brown, J., I. Lewandowski, B. Andersson, G. Basch, D.G. Christian, J. Bonderup Kjeldsen, U. Joergensen, J.V. Mortensen, A.B. Riche, K-U Schwarz, K. Tayebi, and F. Teixeira. *Performance of 15 Miscanthus genotypes at five sites in Europe.* Agronomy Journal 2001, 93 1013-1019.
46. Vleeshouwers, L. *Yield increases of biomass energy crops: a look to the future.* In: Ierland, E. van, A. Oude Lansink, and E. Schmieman. *Sustainable Energy: New challenges for agriculture and implications for land use. Conference Proceedings.* Wageningen: Wageningen University, 2000.
47. Goldemberg, J. (chief ed.). *World Energy Assessment: Energy and the challenge of sustainability.* New York: UNDP / UNDESA / WEC, 2000.
48. Capros, P., N. Kouvaritakis, and L. Mantzos. *Economic evaluation of sectoral emission reduction objectives for climate change; Top-down analysis of greenhouse gas emission reduction possiblilities in the EU.* Utrecht/Athens: Ecofys/AEA/NTUA, 2001.
49. Brown, M.A., M.D. Levine, W. Short, and J.G. Koomey. *Scenarios for a clean energy future.* Energy Policy 2001, 29 1179-1196.
50. Broekhuizen, R. van, L. Klep, H. Oostindie, and J.D. van der Ploeg. *Atlas van het vernieuwend platteland (Atlas of the renewing countryside).* Doetinchem: Misset, 1997.
51. Stortelder, A.H.F., R.A.M. Schrijver, H. Alberts, A. van den Berg, R.G.M. Kwak, K.R. de Poel, J.H.J. Schaminée, I.M. van den Top, and P.A.M. Visschedijk. *Boeren voor natuur; de slechtste grond is de beste (Farming for nature; the worst soil is the best).* Wageningen: Alterra, 2001.
52. Hillebrand, J.H.A. and B. Koole. *Atlas ontwikkeling landbouw (Atlas development agriculture).* The hague: LEI-DLO, 1999.
53. Ploeg, J.D. van der. *On rurality, rural development and rural sociology.* In: Haan, H. de and N. Long. *Images and realities of rural life.* Assen: Van Gorcum, 1997.

Summary and conclusions

1. Introduction

Concerns about climate change related to fossil fuel carbon dioxide emissions require the development of alternative energy resources. In most scenario studies on future energy supply, bio-energy is one of the dominant renewable alternatives foreseen. ‘Modern’ biomass energy can be CO_2 neutral and sustainable, in contrast to traditional biomass use, which often leads to deforestation and other environmental problems. Several types of material can be applied as biofuels. Organic waste and residues from e.g. agriculture and forestry are relatively easily available, but their supply potential is limited. Therefore, the cultivation of dedicated ‘energy crops’ will also be necessary. In the Netherlands, current resources for bioenergy are only residues. However, it is estimated in the future, between 20,000 and 300,000 ha in this country would be used for energy crops. This growing need for bio-energy crops is a significant extra demand for rural land, which may be problematic to accommodate, especially since other sectors such as water management, nature conservation and housing will also require extra land. Compared to these claims, energy farming can hardly compete for land, since it has a low value added compared to other functions.

A strategy that may help overcome these problems is multiple land use: combining the production of energy crops to other targets on the same tract of land. If a plot not only generates biomass, but also serves other functions such as nature management, more value added may be generated, and overall land use efficiency may increase. Especially for energy farming, with its relatively low intensity in terms of e.g. inputs and activities, this may be an option that enhances its introduction.

Central question in this thesis is whether, and to what extent, multiple land use can improve opportunities for energy crops in the Netherlands, in comparison with energy cropping as single land use. We specified this question into three criteria. First, there should be multiple land use energy farming options that are biophysically feasible, i.e. the generation of other products or services should be combined with energy farming. Second, such combinations should lead to lower biomass supply prices compared to energy farming as single land use. And finally, such combinations should open up an area for energy cropping significant to the national renewable energy targets.

Multiple land use as a concept is relatively ill-operationalised, which makes it hard for land holders to explore opportunities for multiple land use. Therefore, the first research topic was to further identify and specify the concept, and develop an operationalisation procedure (Chapter 2). Specific options for combination of energy crop cultivation with another function were elaborated on two levels. In a relatively simple and qualitative way, we analyse four options with willow as energy crop (Chapter 3). We execute more detailed studies on two combination options (Chapters 4 and 5). Finally, we examine the consequences of the findings in the case studies, to evaluate our operationalisation methodology and to answer the central research question (Chapter 6).

Some general delineations need attention. We do not study energy crop conversion into e.g. electricity: our system boundary is at the point when the harvested material is ready for logistics. In the thesis, we concentrate on willow as an energy crop. This is one of the most promising energy crops in the Dutch context. Given the relatively low inputs of willow cultivation, it has good opportunities for combination with other functions. A broad range of co-products/services for energy crops has been proposed in the literature; here we focus on services related to environmental quality and biodiversity. Finally, the thesis focuses on multiple land use in the Netherlands. In this country, with its high population density and high land use intensity, the urge for multiple land use is relatively strong.

2. Multiple Land Use: operationalisation on land unit level in rural areas

Multiple Land Use (MLU), the central concept in this thesis, is currently mostly used as a relatively vague, strategic concept. While this may motivate many actors with different perspectives to take initiatives related to it, this may also lead to inflation of the concept and confusion in application. Therefore we delineated it, and developed tools for the introduction of multiple land use at the level of a land unit (plot) in the context of a land holding (farm or other socio-economic management unit).

We define Multiple Land Use as land use aimed at the generation of more than one type of product and/or service. The MLU concept can be applied at several spatial and temporal scales, e.g. a region, a land holding (farm), or a plot. The concept goes beyond land use with general standards on environmental protection. Such standards are rarely related to concrete products or services. In Multiple Land Use all relations between products/services and necessary activities are made explicit, so that the effects of changes in land use on the generated product or service can be made visible.

We developed a procedure for the exploration of opportunities for MLU. This procedure aims at land holders, or groups of land holders, interested in land use improvement, to provide them with information on the perspective MLU can offer in reaching their targets. The terminology applied in the procedure is consistent with FAO land use planning methodologies: a Land Use Type (LUT) indicates a general description of land use with its generated product or service, and is specified by Land Use Requirements (LURs): a set of physical or other inputs or land characteristics.

The procedure starts with an inventory of the land holding's setting in biophysical (available land and its qualities) as well as socio-economic terms (available knowledge, technology, labour and capital), and the holding's context of regional or national policies and regulations. In this frame, targets, potentials and constraints can be identified. The MLU exploration then follows in three steps:

1. A rapid appraisal of possible single Land Use Types. Potential goods/services to be produced are identified as LUTs, and their corresponding LURs are compared to the available Land Qualities (LQs). This leads to selection of promising LUT combinations.
2. A rapid appraisal of multiple LUTs: via combination of LURs of different LUTs and comparison to the available LQs, a qualitative scan is made to estimate feasibility of LUTs that generate more than one product.
3. When more detailed or quantitative assessment on critical LURs in the combination is desired, detailed modelling of a multiple LUT facilitates a better feasibility estimation and an optimisation of the system as a whole.

The information generated in these steps facilitates the land holder’s decision making whether to introduce new multiple LUTs on plots within his holding. After each step, the land holder may decide that he has got sufficient information to quit the procedure, and either stick to Single Land Use Types or move forward to introduction of multiple LUTs. Furthermore, the procedure explicitly separates decision making steps from applied research, keeping the key responsibility for management choices where it belongs.

The procedure may seem data-intensive. However, applied research for steps 2 and 3 may also be carried out separately, resulting in ready-made ‘building blocks’, worked-out multiple LUTs to be used in any MLU exploration project. Furthermore, an individual land holder may use it in a simplified form.

As mentioned previously, single Land Use Types may be competing on some LURs and otherwise be well combinable. In such cases, a combination of them needs to be optimised on the sum benefit of all products/services. However, produced nature and landscape qualities can hardly be valued by a market price. In such case, a government can create a framework for optimisation. The way of optimisation will depend on two aspects of the governmental steering strategy: financial instruments versus command and control, and rewarding results versus rewarding management. This results in 4 ideal types of optimisation, classified on two axes, viz. governmental steering with physical or economic instruments, and rewarding on results or behaviour. By this classification, we identify and graphically illustrate four ideal types of optimisation, for each of which examples can be found in practice.

The proposed procedure and optimisation strategies can help to develop and specify multiple land use types, and compare their potentials to single land use. Furthermore, the methodology is also applicable on products that usually are not expressed in financial terms, such as public goods and services.

3. A rapid appraisal of four MLU options with energy farming

The procedure as described in Chapter 2 contains a rapid appraisal research step of multiple Land Use Types, in which a qualitative or semi-quantitative assessment is made of the feasibility of such a LUT. For four combination options with willow short rotation coppice (SRC) as one of the LUTs, we did this rapid appraisal and explored biophysical feasibility, financial performance, and potential area (Chapter 3). Co-functions were groundwater protection for drinking water production (in groundwater protection areas and in groundwater extraction areas), conservation of nature in traditional willow coppice, and land use as an ecological corridor. In the biophysical assessment, Land Use Types were compared on the level of their land use requirements (LUR). Financial performance was evaluated in terms of a willow wood price (per tonne dry matter) that has to be paid to a farmer to make the Land Use Type with willow production financially equally attractive as a competing Land Use Type with common agriculture (break-even price). Two situations are compared: the multiple LUT with willow production (e.g. willow and groundwater protection) competing with a multiple LUT with common agriculture (e.g. arable farming and groundwater protection), and willow as a single LUT competing to common agriculture (e.g. arable farming) alone. When the willow break-even price in the first comparison is lower than in the latter, there is a financial benefit for willow in the multiple LUT compared to single use. Finally, a potential area for the combination was assessed.

Groundwater protection areas (GPAs) are relatively wide zones (> 10 ha) surrounding groundwater extraction wells, in which special regulations and standards apply. Comparison of these LURs with those of willow SRC indicates that the combination is biophysically feasible. Potentially conflicting LURs are fertilisation and biocide application, but inputs of these substances in willow SRC are lower than the acceptable levels in GPAs. This in contrast to common agriculture, which still has difficulties in meeting these standards. However, this biophysical compatibility does not lead to significant financial competitiveness improvement. Financial incentives applying in GPAs lead to a willow break-even price only a few percents lower than the break-even price in a single LUT comparison, and common agriculture still has considerable options to lower its nutrient emissions without productivity loss. The potential area of this option is significant: there is circa 80,000 ha of GPAs in the Netherlands. However, while these are biophysically available for willow SRC, these areas are not financially more attractive than others.

Groundwater extraction areas (GEAs) are smaller zones directly around the groundwater extraction wells. In these zones stricter regulations apply. Fertilisation is strongly restricted, and biocide use is forbidden. While the latter need not be a major obstacle for willow SRC given modern non-chemical crop protection strategies, non-fertilisation will reduce willow yields considerably. Common agriculture, however, is almost completely non-existent in these areas, with the exception of some cereal arable crops. Most areas are managed ecologically, e.g. as heathland, woodland or shrub. Financial performance was assessed in two ways. As an ecological management option, non-input willow cultivation is relatively cheap compared to other options considering only costs. Comparing willow SRC yields and costs to low-input cereal cultivation, calculations indicate that willow break-even prices may be lower in the GEA situation than in a situation without fertilisation limitations. These results, however, strongly depend on assumptions on crop yields under non- or low fertilisation regimes. Therefore, the potential area for this option of circa 5,000 ha is biophysically usable, and may be financially more attractive than common agricultural land.

Traditional willow coppice stands in the Netherlands are currently more acknowledged for their valuable flora and fauna and landscape features than for their wood productivity. The harvested material currently is being sold for construction in dikes and other infrastructure, or left on the field. Possibly, energy wood could be a new market for this material, but it is also interesting to explore whether elements of modern willow SRC (increasing productivity and decreasing management costs) are applicable in these stands without decreasing their nature and landscape features. In the first option, with unchanged management, using the produced wood for energy by definition will be possible without changing the stands' other features. As for the second option, a comparison of traditional coppice LURs to those of modern willow SRC indicates that some modernisation may be possible, but mechanical harvesting in which stool lifespan is extended over 25 years (essential for the stand's nature features) is currently not possible. Thus, modern willow SRC on traditional coppice stands is currently, technically spoken, not feasible. In the first option, calculation of an energy wood break-even price versus sales prices for application in infrastructure suggests that this option is roughly as competitive as single-use willow versus common agricultural crops. So a competitive advantage is not to be expected. In the second option, assuming technical innovation make the option possible, this could lead to significantly lower break-even prices, and therefore improved competitiveness. The potential area of this option, either in current management or modernised, given an estimation of the currently remaining area of traditional coppice stands, is circa 1,000 ha.

Since the beginning of the nineties, *ecological corridors* have been part of formal Dutch nature policy. The ecological corridor policy is explicitly open towards combination with other Land Use Types. However, a straightforward biophysical assessment on a LUT/LUR basis could not be made, since the planned ecological corridors as LUTs are still only roughly defined. Guide species have been selected per region and corridor type, for which the corridor should function. Therefore, we adapted the LUT/LUR approach. First, we selected the planned corridors that will (partly) consist of woody vegetation (and excluded marshes, meadows, etc.), subsequently we selected the corresponding guide species and checked whether these species had been observed in field surveys in willow SRC. Of all guide species for woody vegetations, ca 25% occurred in most willow SRC survey, and another 25% occurred in some. This implies that, depending on the specific situation, willow SRC could play a role as ecological corridor. A financial assessment could not be made: cost data on competing LUTs serving as corridor were not available, and in general funding opportunities for ecological corridors are still small and diffuse. The total amount of (woody) ecological corridors for which these considerations apply will be around 2,000 ha. While these are biophysically suitable, this study cannot indicate financial competitiveness.

4. Willow SRC and desiccation abatement

The procedure proposed in Chapter 2 also contains a more detailed modelling step of multiple LUTs, to be carried out if desired. We performed such a quantitative modelling study on the potentials to combine willow SRC as a LUT with buffering of groundwater-dependent nature reserves (Chapter 4). Measures to combat desiccation of these reserves often lead to the establishment of buffer areas around them, in which soils become moister, and yields of common agriculture decrease. Farmers obtain a compensation payment for this decrease. Cultivation of the flooding-tolerant energy crop willow may be an alternative in such areas.

In this study, the performance of willow production is compared to grass for roughage, with the shallow groundwater tables occurring in buffer areas as the shared Land Use Requirement. The groundwater tables necessary for effective buffering were derived from several studies on specific reserves to be buffered. The effect of high groundwater tables on yields of both crops was estimated using an agro-hydrological model (SWAP). This model can calculate relative yield losses compared to yields in a hydrological optimal situation, as a function of groundwater tables throughout the year, soil characteristics, and several crop specific parameters such as growing season, and the root critical pressure heads, i.e. the water pressure at which roots start to suffer from oxygen shortage.

The model results indicate that more shallow groundwater tables lead to yield reductions for willow and grass, the latter being reduced stronger. For example, at groundwater table class (Gt) II, common in buffer areas, willow physical yield is ca. 15% lower than its optimum, but grass yield decreases by ca. 25%, making willow more competitive.

Financial consequences are evaluated in the same way as in Chapter 3: comparison of the willow break-even price in buffer situations to this price in single-use, hydrologically optimal circumstances. At Gt II, the willow break-even price is circa 20% lower in the buffer situation than in the hydrologically optimal situation, because of the smaller yield reduction of willow.

A sensitivity analysis shows that the input parameters with high certainty, such as grass physical yields in optimal situations, have a relatively strong influence on the break-even willow price. The input data that were estimated with relatively high uncertainty, viz. the root critical pressure heads of willow, appeared to have relatively limited influence. An uncertain value with strong influence is the willow yield without hydrological constraints, which could not be estimated from practical data. Input data improvement efforts therefore can best be spent on this parameter.

This modelling study has several methodological simplifications. The use of a break-even price reduces the farmer’s crop choice to a financial deliberation. Other aspects will also influence this choice, such as acquaintance with a crop, sales security, or commitment to a farming style. Furthermore, the SWAP model to assess relative yields only takes root oxygen shortage into account. High groundwater tables can also cause other effects, such as growth delay in spring and soil compaction. Regardless of these limitations, the study indicates that willow SRC in a multiple LUT with desiccation abatement has a competitive advantage compared to SRC in single use. As an example of a detailed modelling study, it also shows that optimisation at such a level of detail takes considerable effort in terms of factors and variables to take into account.

5. Willow SRC and breeding birds

In Chapter 4, the combination of willow SRC for energy and nature conservation is only dwelt upon in an indirect way, by the SRC functioning as a buffer for nature reserves. We go into the possibilities to enhance nature quality of the coppice itself in Chapter 5. Especially for breeding birds, willow SRC for energy may be an attractive habitat. However, the relations between coppice management and productivity on one hand and breeding bird occurrence on the other are still poorly understood.

In this study, we systematically analyse these relations, with a focus on the relations between willow SRC design/management and the occurrence of individual species and ecological groups of breeding birds. An important additional purpose was to set up hypotheses on ecological processes underlying these relations. By this detailed analysis, it is possible to go beyond the often-used, 'one-dimensional' assumption that increased breeding bird diversity automatically corresponds to decreased productivity; target was to find specific measures beneficial for birds, not (significantly) harmful for productivity. The study can be regarded a step 3 (qualitative) detailed modelling study as proposed in the procedure (Chapter 2).

On the basis of a number of agro-technical studies on willow SRC, we specified plantation design and management in terms of a set of variables (LURs). We constructed a longlist of breeding birds to be expected, based on field surveys in modern willow SRC as well as traditional willow coppice. The species were ordered according to an ecological group classification. The processes between management variables and (ecological groups of) breeding bird species were analysed in interviews with Dutch willow coppice field experts and bird researchers. The interview results were presented and discussed in a workshop, in which we paid most attention to the assumed processes underpinning the judgements. This approach results in a systematic survey of design and management variables, their ranges of tolerance from a productivity point of view, relevant field characteristics responding to changes in each variable, and responding (groups of) breeding birds.

The results of the analysis were integrated into management packages: A 'minimum package', with only bird-friendly measures not affecting productivity, a package concentrating on undergrowth in a well-developed plantation, and a package concentrating on edge and margin management. All are internally consistent measure sets with special attention for certain breeding bird ecological groups. The first two years of the plantation, of vital importance for its overall success, are discussed separately: in this period, successful plantation establishment deserves priority.

Notwithstanding the uncertainties and qualitative nature of the results, the analysis and synthesis give starting-points for managers willing to pay attention to breeding birds, and also provides hypotheses on management-breeding bird relations that can be subject to further field research. On the basis of the analysis, there seem to be considerable opportunities to increase willow SRC potentials for especially breeding birds of shrubs and hedges, with limited productivity reduction.

Finally, possible government steering strategies to enhance the occurrence of breeding birds in willow SRC are discussed, distinguished in rewarding adapted behaviour (management) versus rewarding actual results (occurring birds). These are the two approaches from agency theory as also discussed in Chapter 2. From the literature, a set of criteria was drawn up to evaluate which strategy is most opportune in the case of breeding bird enhancement in willow SRC. The evaluation does not indicate a clear advantage of one of the two rewarding methods: while rewarding 'produced breeding birds' has the disadvantage of relatively uncertain outcomes, a risk for the field manager, rewarding bird-friendly behaviour can encounter problems with behaviour check and control. A well-suited mix may be found in behaviour-based rewarding of the minimum package of standard (mainly design) measures, easily controllable and not strongly conflicting with plantation productivity while result rewarding can be applied to stimulate extra efforts.

This also encourages the managers to increase their knowledge in fine-tuning their management. Obviously, the analysis of this study can be a start for this.

6. Synthesis

From the cases in Chapters 3 to 5, we can learn to what extent the methodology proposed in Chapter 2 is applicable. Furthermore, the central research question of this thesis can be answered by the results of the cases.

Considering the *methodology*, only the applied research phases were actually adopted, in stead of the full procedure. The product-LUT-LUR format appeared to be a clear and well-applicable format, although the elaboration of Land Use Types related to nature management still takes considerable effort. Given the current efforts to make nature as a product more concrete, and better relate it to required activities, this situation may improve. Furthermore, making product definitions flexible, or defining essential product inputs as 'intermediate products' can help applying the product-LUT-LUR format. The break-even price, as introduced in Chapters 3 and 4, proved to be a useful measure to indicate whether the proposed multiple LUT is financially attractive, and thereby contributes to the land holder's financial targets. The break-even price can also be used to compare multiple to single LUTs, thereby assessing differences in competitiveness between the two. The detailed modelling phases appeared to be complicated studies. Therefore, they should only be applied when the information resulting from the rapid appraisal phase is insufficient for a choice pro or contra MLU.

In the applications, optimisations were not performed as proposed in Chapter 2 for two reasons. First, the optimisation in Chapter 2 assumed one combined LUT. In the cases, mostly a combination of energy farming with another function was compared to common agriculture combined with that other function. Second, a clear market price for energy wood was not yet available. To circumvent this problem, the break-even price was developed. However, the break-even price is not related to optimisation of a land holder's benefits, but indicates the minimum price a wood buyer would have to pay to make a land holder switch to willow. As such, it is merely a wood buyer cost minimisation instrument.

Considering the *central research question*, the applications give insights in the three criteria formulated: biophysical feasibility of MLU combinations, effect on energy crop financial competitiveness, and significance of the potential area for MLU

Most studied options of combining willow SRC with another Land Use Type into a multiple LUT appeared to be biophysically feasible. However, since the options were pre-selected according to our first impression of feasibility, this picture may be optimistic in proportion to feasibility of the broad range of combinations proposed in the literature. Obviously, new MLU options, or options with specific other energy crops may offer new perspectives.

The effect on financial competitiveness of introducing willow SRC in Multiple Land Use varies per combination. In some cases, like the option in groundwater protection areas, competitiveness remains unchanged, which means that willow energy farming will still have the disadvantage of low value added. In others, for example the combination in buffer areas, a significant competitiveness increase can be obtained. However, these break-even price reduction are not in the order of magnitude that the price of energy crops draws near to the current prices of biomass residues, the only resource currently applied for bioenergy. In situations in which energy farming does not have to compete with common agriculture, this situation may be different. When e.g. energy farming can be combined to functions such as recreation or nature conservation, on lands specially designated for these functions, break-even prices may drop significantly.

The total of land potentially suitable for the investigated options adds up to ca. 100,000 ha. The area with improved financial competitiveness is ca 30,000 ha in total. Given the projections on required area for meeting the national renewable energy objective, MLU areas with improved financial competitiveness will probably not be sufficient to meet this area claim. Obviously, this picture would change when other MLU options not studied in this thesis also appear to lead to lower break-even prices.

Apart from biophysical, financial and potential area considerations, other factors may also affect introduction of energy crops in multiple land use. For some of the options studied, social resistance, uncertainties in location of the combination, plot size and geographical scatteredness may be implementation problems. In general, MLU options require more complicated commitment of more actors than in single land use, and an attitude shift of farmers and policy makers, who have been focusing on single land use in the last decades.

Referring to the central research question, multiple land use will enhance opportunities for energy crop introduction in the Netherlands, but it will not be the panacea for large-scale introduction of competitive energy farming. Potential areas remain limited, as well a financial benefits compared to single land use, and several implementation problems may hamper introduction in practice.

This limited perspective on the short term may be altered by several long-term developments. Technical innovations in energy cropping can still lead to decreasing cultivation costs and productivity increases, leading to supply price reductions of tens of percents. Developments in the EU Common Agricultural Policy will strongly influence (agricultural) land use in the Union. Changes in the current market regulations and supportive payments to farmers, as proposed in response to pressure from the WTO and the future entrance of Central and East European countries, will generally improve chances for energy crops. One consequence will probably be increased attention for the combination of agriculture with other functions (and improved valuation of these functions), for which energy crops are well suitable. Finally, if climate change concerns lead to increasing demands for bioenergy, or to a pricing system of CO_2 emissions, energy cropping may profit, especially when the finite amounts of available residues are not sufficient to meet these demands.

Samenvatting en conclusies

1. Inleiding

Er zijn serieuze aanwijzingen dat de uitstoot van kooldioxide in de atmosfeer leidt tot veranderingen in het mondiale klimaatsysteem, oftewel het versterkte broeikaseffect. Aangezien het grootste deel van de emissies van kooldioxide wordt veroorzaakt door het gebruik van fossiele brandstoffen, is het nodig om alternatieve energiebronnen te ontwikkelen. De meeste scenariostudies over het toekomstige mondiale energieverbruik voorspellen dat energie uit biomassa (ook wel bio-energie) een van de belangrijkste vormen van duurzame energie zal gaan worden. Bij de moderne vorm van bio-energie komt per saldo geen kooldioxide vrij, en het leidt niet tot de problemen zoals we die kennen bij het traditionele gebruik van biomassa, zoals ontbossing. Bio-energie is niet veel anders dan energiewinning uit allerlei soorten plantaardig materiaal. Dat kan bijvoorbeeld afval zijn uit landbouw en bosbeheer: materiaal dat makkelijk beschikbaar is, maar niet in onbeperkte hoeveelheden. Daarom wordt ook gedacht aan de introductie van speciale 'energiegewassen': planten die worden geteeld enkel en alleen om er energie uit te winnen.

In Nederland staan momenteel al enkele bio-energiecentrales die stroom opwekken uit snoei- en afvalhout. De overheid heeft het doel gesteld dat duurzame energiebronnen in het jaar 2020 10% van onze energiebehoefte moeten dekken. Er zijn daarom schattingen dat er op termijn tussen de 20.000 en 300.000 hectare aan energiegewassen zal komen (ter vergelijking: het totale Nederlandse areaal aan landbouwgrond is circa 2 miljoen ha). Het vinden van grond voor energieteelt zal echter problematisch worden: de ruimte in Nederland wordt intensief gebruikt, en diverse sectoren claimen ook extra ruimte in de komende decennia, voor bijvoorbeeld woningbouw, infrastructuur, recreatie, natuur en het opvangen van piekafvoeren in de grote rivieren. Energieteelt heeft in de concurrentiestrijd om grondgebruik het nadeel dat energiegewassen financieel weinig opbrengen: biomassa is tenslotte maar een grondstof voor energie, en energie is goedkoop.

Een mogelijke oplossing voor dit probleem ligt in meervoudig landgebruik: het combineren van de teelt van energiegewassen met andere functies op hetzelfde stuk land. Als een terrein niet alleen energiegewassen produceert, maar ook dient als bijvoorbeeld natuur- of recreatiegebied, wordt er wellicht meer toegevoegde waarde gecreëerd, en is het grondgebruik mogelijk ook efficiënter. Zeker omdat energiegewassen zich goed lenen voor extensief beheer (weinig verstorende activiteiten, weinig gebruik van kunstmest en bestrijdingsmiddelen), zou dit een optie kunnen zijn die de kansen van energieteelt verbetert.

De centrale vraag in dit proefschrift is dan ook of, en in welke mate, meervoudig ruimtegebruik de mogelijkheden voor energieteelt in Nederland kan verbeteren. Hiervoor hebben we drie criteria aangelegd. In de eerste plaats moeten opties voor meervoudig ruimtegebruik met energieteelt biofysisch mogelijk zijn. Dat wil zeggen, het moet mogelijk zijn om het land zo te beheren, dat én de energiegewassen kunnen groeien, én de andere functie vervuld wordt. Ten tweede moeten dergelijke combinaties leiden tot een beter financieel resultaat, vergeleken met de teelt van energiegewassen in enkelvoudig landgebruik. Tenslotte moet het areaal dat beschikbaar komt voor combinaties substantieel kunnen bijdragen aan de verwezenlijking van de Nederlandse 10%-doelstelling voor duurzame energie.

Het concept meervoudig landgebruik is momenteel nog nauwelijks geoperationaliseerd, waardoor het moeilijk is om ermee aan de slag te gaan. Daarom was het eerste deel van het onderzoek gericht op het definiëren en specificeren van meervoudig landgebruik, en het ontwerpen van een methode waarmee landgebruikers kunnen verkennen of meervoudig landgebruik in hun situatie mogelijkheden biedt (hoofdstuk 2). Specifieke cases voor energieteelt gecombineerd met een andere functie zijn in dit proefschrift op twee niveaus uitgewerkt, analoog aan twee stappen in de methode van hoofdstuk 2. Op een relatief eenvoudige en kwalitatieve manier hebben we vier combinaties bekeken (hoofdstuk 3). Twee andere combinaties hebben we meer in detail onderzocht (hoofdstukken 4 en 5). In hoofdstuk 6 gebruiken we de gezamenlijke resultaten van de cases op twee manieren: ten eerste om de ontwikkelde methode te evalueren, en ten tweede om de centrale onderzoeksvraag te beantwoorden.

Een paar algemene afbakeningen. De omzetting van energiegewassen naar bijvoorbeeld elektriciteit komt niet aan de orde in dit proefschrift. De systeemgrens ligt bij het moment dat de geoogste biomassa aan de weg ligt, klaar voor transport naar bijvoorbeeld een centrale. Wilg is het energiegewas waar we naar kijken. Dit is een van de meest veelbelovende energiegewassen in de Nederlandse context. Bovendien vereist wilg weinig intensief beheer, waardoor het een goede kans maakt gecombineerd te kunnen worden met andere functies. In de literatuur wordt een breed scala aan co-functies aangedragen. In dit proefschrift concentreren we ons op producten en diensten die gerelateerd zijn aan milieukwaliteit en natuur. Tenslotte richten we ons op Nederland. Gezien de hoge bevolkingsdichtheid en het intensieve gebruik van de ruimte is er in dit land een sterke prikkel tot meervoudig landgebruik.

2. Meervoudig landgebruik: operationalisatie op perceelsniveau voor het landelijk gebied.

Meervoudig landgebruik (multiple land use, MLU[4]), het centrale concept in dit proefschrift, wordt momenteel in diverse beleidsvelden gebruikt als een vrij vaag, strategisch concept. Dit motiveert een veelheid aan actoren met uiteenlopende perspectieven om het op te pakken, maar het kan ook leiden tot verwarring bij de

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[4]: In deze samenvatting gebruiken we de Engelstalige acroniemen, om ze gelijk te houden aan die in de rest van het proefschrift.

toepassing. Daarom hebben we het afgebakend. Bovendien hebben we een methode ontwikkeld voor de introductie van meervoudig landgebruik op het perceelsniveau in de context van een beheerseenheid (bijvoorbeeld een boerderij).

We definiëren meervoudig landgebruik als landgebruik gericht op het voortbrengen van meer dan een soort product en/of dienst. Het concept kan worden toegepast op diverse tijd- en ruimteschalen, bijvoorbeeld een regio, een beheerseenheid of een perceel. Het begrip gaat verder dan landgebruik met een algemene norm voor natuur- en milieubescherming. Dergelijke normen zijn vaak nauwelijks te relateren aan concrete producten of diensten. Bij MLU gaat het er juist om alle relaties tussen product of dienst en de vereiste beheersactiviteiten boven tafel te krijgen, zodat het effect van veranderingen in het landgebruik op product of dienst zichtbaar kan worden gemaakt.

De in dit proefschrift ontwikkelde procedure voor verkenning van de mogelijkheden van MLU richt zich op landbeheerders (bijvoorbeeld boeren) of groepen landbeheerders (bijvoorbeeld in een gezamenlijk vernieuwingsproject) die geïnteresseerd zijn in het verbeteren van hun landgebruik, en leidt tot informatie over de mate waarin MLU kan bijdragen aan het bereiken van hun eigen doelstellingen. De terminologie in de procedure is ontleend aan methodes voor ‘land use planning’ van de FAO: een bepaald product komt voort uit een landgebruikstype (land use type, LUT), een algemene beschrijving van een bepaalde vorm van landgebruik, die gespecificeerd wordt met een set vereisten voor dat landgebruik (land use requirements, LURs), in termen van fysieke of andere inputs, of kenmerken van het land.

De procedure begint met een inventarisatie van de uitgangssituatie van de beheerseenheid, in termen van biofysische eigenschappen (kenmerken van het land), sociaal-economische eigenschappen (beschikbare kennis, technologie, arbeid, kapitaal), en ook de relevante context qua beleid en regelgeving op regionaal en landelijk niveau. Op basis hiervan worden doelstellingen, mogelijkheden en knelpunten voor de beheerseenheid geïdentificeerd. De hierop volgende verkenning van MLU bestaat uit drie stappen:

1. Een snelle verkenning van mogelijke enkelvoudige landgebruikstypen. Potentiële producten of diensten worden beschreven als LUTs, en de bijbehorende LURs worden vergeleken met de kenmerken van het beschikbare land. Op basis hiervan wordt een eerste selectie gemaakt van LUTs die mogelijk combineerbaar zijn.
2. Een snelle verkenning van mogelijke meervoudige landgebruikstypen: combinaties van LUTs worden vertaald in gecombineerde sets LURs en deze worden vergeleken met de kenmerken van het land. Zo wordt een kwalitatieve scan gemaakt van de voorgestelde combinaties.
3. Wanneer na de snelle verkenning onduidelijkheid blijft bestaan over de combineerbaarheid, bijvoorbeeld doordat twee enkelvoudige LUTs elkaar beconcurreren op een of meer LURs, kan een gedetailleerde studie meer inzicht verschaffen in hoe een optimale combinatie eruit zou kunnen zien.

Alle informatie die uit deze stappen voortkomt ondersteunt de landbeheerder bij de beslissing wel of niet te beginnen met meervoudige systemen binnen zijn bedrijf. Na elke stap kan de landbeheerder beslissen dat hij voldoende informatie heeft om de procedure te stoppen, en te blijven bij enkelvoudig landgebruik dan wel met meervoudig gebruik aan de slag te gaan. De vooraf geformuleerde doelstellingen, mogelijkheden en knelpunten dienen hierbij als referentiekader. Verder bevat de procedure een scheiding tussen beslisstappen en informatievoorziening (die vaak door adviseurs zal worden gedaan), om de besluitvorming bij de beheerder zelf te laten.

De procedure lijkt kennis- en dataintensief. Het onderzoekswerk in stappen 2 en 3 kan echter ook buiten de procedure worden uitgevoerd, waarmee ‘bouwstenen’ worden gemaakt, uitgewerkte meervoudige systemen die overal gebruikt kunnen worden waar landbeheerders geïnteresseerd zijn in een bepaalde combinatie. Bovendien kunnen landbeheerders de procedure in een versimpelde vorm als een denkschema gebruiken.

Sommige meervoudige systemen zullen op een of enkele LURs tegengestelde eisen hebben. Dergelijke systemen moeten geoptimaliseerd worden op het totaal van de geproduceerde producten en/of diensten. Voor geleverde producten als natuur of landschapkwaliteit bestaat echter geen (markt)prijs. Een overheid kan wel beleid voeren waar in de optimalisatie rekening mee moet worden gehouden. Twee kenmerken van het beleid zijn dan van belang in de optimalisatie: gaat het om een economisch instrument of om normstelling, en wordt afgerekend op het product of op beheersactiviteiten die leiden tot dat product. Op deze manier zijn er vier ideaaltypen te onderscheiden, die ook bruikbaar zijn voor bijvoorbeeld collectieve goederen of diensten. Voor deze typen zijn de optimalisaties uitgewerkt, en geïllustreerd met praktijkvoorbeelden.

3. Een snelle verkenning van vier typen meervoudig landgebruik met energieteelt

De procedure van hoofdstuk 2 bevat een snelle verkenningsstap voor meervoudige landgebruikstypen: een kwalitatieve of semi-kwantitatieve inschatting van de haalbaarheid van een combinatie. Voor vier combinaties met wilgenteelt als één van de functies hebben we deze snelle verkenning uitgevoerd (hoofdstuk 3). Hierbij werden biofysische haalbaarheid, financieel resultaat, en potentieel areaal onderzocht. Co-functies waren de bescherming van grondwater bij de productie van drinkwater (in grondwaterbeschermingsgebieden en in waterwingebieden), natuurbehoud in traditionele wilgengrienden, en de functie van ecologische verbindingszone. Voor de biofysische evaluatie werden de landgebruikstypen (LUTs) met elkaar vergeleken op het niveau van hun LURs. Het financieel resultaat werd afgemeten aan de prijs voor wilgenhout die betaald zou moeten worden aan een boer om de combinatie financieel even goed te laten renderen als een concurrerend landgebruik (de break-even prijs). De break-even prijs werd voor twee situaties berekend: bij concurrentie tussen twee meervoudige LUTs (bijvoorbeeld wilgenteelt in een grondwaterbeschermingsgebied versus gangbare landbouw in datzelfde gebied), en bij concurrentie tussen twee enkelvoudige LUTs (wilgenteelt versus gangbare landbouw op normale landbouwgrond). Wanneer de break-even prijs in het eerste geval lager is dan in het tweede, leidt de combinatie tot financieel voordeel. Het potentiële areaal werd ingeschat op basis van het huidige areaal van de co-functie, en de beleidsdoelstellingen voor die functie.

Grondwaterbeschermingsgebieden (groundwater protection areas, GPAs) zijn zones (groter dan 10 hectare) rond een grondwaterwinput. In deze gebieden gelden specifieke regels voor het landgebruik. Deze LURs blijken goed combineerbaar met die van wilgenteelt. Beide functies hebben wel tegengestelde eisen wat betreft bemesting en bestrijdingsmiddelengebruik, maar deze blijken elkaar niet uit te sluiten. Dit in tegenstelling tot de gangbare landbouw, die nog hoeveelheden meststoffen en bestrijdingsmiddelen op het land brengt die bedreigend kunnen zijn voor de drinkwaterwinning. Het feit dat wilgenteelt en grondwaterbescherming beter combineerbaar zijn leidt echter niet tot een betere concurrentiepositie voor wilgenteelt. De financiële stimuleringsregelingen die gelden in GPAs leiden tot een break-even prijs die slechts enkele procenten lager is dan die buiten GPAs, en er zijn binnen de gangbare landbouw nog mogelijkheden om de emissies te verlagen zonder productieverliezen. Het potentiële areaal van deze optie is overigens groot: er is in totaal circa 80.000 ha GPAs in Nederland. Financieel zijn deze gebieden echter voor wilgenteelt momenteel niet aantrekkelijker dan normale landbouwgronden.

Waterwingebieden (groundwater extraction areas, GEAs) zijn kleinere zones direct rond de waterwinputten. De regels zijn hier strenger: bemesting wordt sterk beperkt, bestrijdingsmiddelen zijn verboden. Het niet gebruiken van bestrijdingsmiddelen hoeft geen probleem te zijn voor wilgenteelt, aangezien er ook niet-chemische gewasbeschermingsmethoden beschikbaar zijn. Nul-bemesting maakt de teelt niet onmogelijk, maar zal de productiviteit wel doen afnemen. De teelt van gangbare landbouwgewassen is echter helemaal niet mogelijk in deze gebieden, behoudens enkele graansoorten. De meeste GEAs worden ecologisch beheerd, bijvoorbeeld als heideveld, bos of ruigte. Het financieel resultaat van deze combinatie is op twee manieren ingeschat. Als vorm van ecologisch beheer blijkt wilgenteelt qua beheerskosten relatief goedkoop in vergelijking met andere vormen van ecologisch beheer. Wanneer we wilgenteelt vergelijken met graanteelt zonder bemesting, wijzen de berekeningen erop dat de break-even prijs voor wilg lager is in GEAs dan daarbuiten, wat wijst op een beter financieel resultaat. Deze resultaten hangen echter sterk af van aannames over de opbrengsten van beide gewassen bij nul- of zeer lage bemesting. Daarom kan alleen gesteld worden dat wilgenteelt in de ca 5.000 ha waterwingebied biofysisch haalbaar is, en dat het er mogelijk ook een financieel voordeel heeft in vergelijking met gewone landbouwgrond.

Traditionele wilgengrienden in Nederland worden tegenwoordig meer gewaardeerd om hun flora en fauna en om hun karakteristieke plaats in het rivierengebied dan vanwege hun houtproductie. Het geoogste materiaal wordt momenteel nog gebruikt voor de dijkversterking, of het wordt op het perceel achtergelaten. Wellicht kan energie een nieuwe markt zijn voor dit hout. Bovendien is het interessant om na te gaan of nieuwe elementen van moderne wilgenteelt zouden kunnen worden ingebracht in de traditionele grienden, waardoor de productiviteit stijgt en de beheerskosten dalen, zonder dat de natuur- en landschapskwaliteiten hieronder lijden. Bij ongewijzigd beheer is de optie per definitie biofysisch haalbaar: er verandert niets in vergelijking met de situatie van nu. Bij de verkenning van modernere beheersmethoden blijkt dat enige modernisering mogelijk is, maar dat mechanische oogst momenteel niet mogelijk is zonder de levensduur van de wilgenstobbe te verkorten tot circa 25 jaar. De aanwezigheid van grote, oude wilgenstoven is echter juist kenmerkend voor een traditioneel griend. Daardoor is de combinatie momenteel technisch niet mogelijk. Bij ongewijzigd beheer is de berekende break-even prijs vergelijkbaar met die op normale landbouwgrond. Het concurrerende landgebruik is in dit geval gebruik van het hout in infrastructuur. Wanneer bij modernisering een mechanische oogstmethode ontwikkeld is die de stobbe spaart zijn break-even prijzen mogelijk die tientallen procenten lager zijn: een financieel voordeel in vergelijking met normale landbouwgrond. Het potentieel areaal van deze optie is overigens maar klein: in Nederland bevindt zich nog zo'n 1.000 ha griend.

Sinds het begin van de jaren ’90 is de ontwikkeling van *ecologische verbindingszones* onderdeel van het Nederlandse natuurbeleid. Het beleid voor deze zones staat expliciet open voor functiecombinaties. Aangezien deze verbindingszones veelal globaal zijn gedefinieerd, kon voor deze combinatie geen biofysische evaluatie worden gedaan op basis van LUTs en LURs. Omdat er echter wel gidssoorten voor verbindingszones zijn vastgesteld, hebben we daar gebruik van gemaakt. Ten eerste werden die verbindingszones geselecteerd die (deels) bestaan uit bosachtige vegetatie. De gidssoorten die hierin moeten voorkomen werden vergeleken met veldinventarisaties van fauna in (moderne) wilgenteelt. Van deze gidssoorten kwam 25% vrijwel altijd voor in dergelijke inventarisaties, en nog eens 25% kwam in sommige inventarisaties voor. Dit betekent dat, afhankelijk van de specifieke situatie, wilgenteelt een rol als ecologische verbindingszone kan vervullen. Een financiële evaluatie kon niet worden uitgevoerd: er waren geen gegevens beschikbaar over kosten van andere typen verbindingszones, en specifieke fondsen voor verbindingszones zijn er nog maar nauwelijks. Het potentieel areaal aan bosachtige verbindingszones, waarin wilgenteelt een rol kan spelen, bedraagt op basis van de huidige beleidsdoelstellingen circa 2.000 ha. Hierin is wilgenteelt biofysisch mogelijk, maar over de financiële aspecten valt nog niets te zeggen.

4. Wilgenteelt en verdrogingsbestrijding

De procedure in hoofdstuk 2 bevat ook een stap waarin een meervoudige LUT gedetailleerd gemodelleerd wordt. We hebben een dergelijke kwantitatieve modellering uitgewerkt voor de mogelijkheden om wilgenteelt te combineren met de buffering van grondwaterafhankelijke natuurreservaten (hoofdstuk 4). Maatregelen tegen verdroging betekenen vaak dat er bufferzones rond deze terreinen worden aangewezen, waarin de waterpeilen omhoog gaan en daardoor de opbrengsten voor gangbare landbouwgewassen dalen. Deze productiviteitsdaling wordt veelal financieel gecompenseerd. Aangezien wilg goed bestand is tegen hoge waterstanden, is het wellicht een alternatief gewas in deze zones.

In deze studie is de productiviteit van wilgenteelt vergeleken met die van grasland voor ruwvoerproductie, met als beperkende factor de ondiepe grondwaterstanden in bufferzones. De grondwaterstanden werden herleid uit studies over buffers rond een aantal natuurgebieden in Nederland. Het effect van deze grondwaterstanden op beide gewassen werd geschat met een agro-hydrologisch model (SWAP). Met dit model kunnen relatieve opbrengsten worden berekend ten opzichte van opbrengsten onder voor het gewas optimale hydrologische omstandigheden. Invoergegevens voor het model zijn onder andere het grondwaterregime door het jaar heen, diverse bodemkarakteristieken en fysiologische gegeven van het gewas zoals bewortelingsdiepte, het groeiseizoen, en de grondwaterstijghoogte waarbij de wortels last krijgen van zuurstofgebrek.

De resultaten van het model geven aan dat beide gewassen minder fysieke opbrengst geven bij ondiepe grondwaterstanden, waarbij de opbrengst van grasland het sterkst daalt. Bij grondwatertrap II bijvoorbeeld, een veelvoorkomend regime in bufferzones, is de fysieke opbrengst van wilg 15% lager dan optimaal, maar de opbrengst van gras daalt met circa 25%, wat een relatief voordeel oplevert voor wilg.

De effecten op het financieel resultaat zijn geschat op de zelfde manier als in hoofdstuk 3: vergelijking van de break-even prijs voor wilg versus gras in bufferzones met de break-even prijs in een hydrologisch optimale situatie met enkelvoudig landgebruik. Bij grondwatertrap II blijkt de break-even prijs circa 20% lager uit te komen dan bij enkelvoudig gebruik, als gevolg van de kleinere opbrengstreductie in wilg.

Uit een gevoeligheidsanalyse blijkt dat juist de betrouwbare invoergegevens een relatief groot effect hebben op de break-even prijs. Voorbeeld hiervan is de fysieke opbrengst van grasland onder optimale omstandigheden. De invoergegevens die met minder zekerheid geschat konden worden, zoals de stijghoogte van water waarbij wortels van wilg minder actief worden, blijken veel minder effect te hebben. Een onzekere parameter met veel invloed is de opbrengst van wilg onder optimale omstandigheden, waarvoor nog niet veel veldgegevens beschikbaar zijn. Pogingen om de kwaliteit van de invoergegevens te verbeteren kunnen dus het best worden besteed aan deze parameter.

Deze modelstudie bevat een aantal methodische versimpelingen. Het gebruik van een break-even prijs bijvoorbeeld reduceert de keuze van een boer tot een puur financiële overweging. Andere aspecten spelen zeker ook een rol, zoals bekendheid met een gewas, afzetzekerheid, en de bedrijfsstijl van een boer. Bovendien kijkt het model SWAP alleen naar opbrengstdaling door zuurstoftekort in de wortelzone. Hoge grondwaterstanden kunnen ook leiden tot andere nadelige effecten, zoals groeivertraging in het voorjaar (doordat de grond langer koud blijft) en inklinking van de grond. Ondanks deze beperkingen geeft deze studie wel een indicatie dat wilgenteelt in het meervoudig landgebruik van een bufferzone beter kan concurreren om land dan wilgenteelt in enkelvoudig landgebruik. Als voorbeeld van een modelleringsstudie geeft het ook aan dat optimalisatie op een dergelijk gedetailleerd niveau behoorlijk wat informatie vraagt, in termen van de variabelen en effecten waarmee rekening moet worden gehouden.

5. Wilgenteelt en broedvogels

In hoofdstuk 4 is op een indirecte manier gekeken naar de relatie tussen wilgenteelt en natuurbeheer, door de mogelijkheden in bufferzones te verkennen. De mogelijkheden om aan natuurbeheer binnen de teelt zelf te doen, worden verkend in hoofdstuk 5. Zeker voor broedvogels lijkt wilgenteelt een aantrekkelijk habitat, gezien de hoge diversiteit en dichtheden die in traditionele grienden voorkomen. Over het afstemmen van het beheer van de teelt op enerzijds productiviteit en anderzijds het voorkomen van broedvogels is echter nog weinig bekend.

In deze studie hebben we deze verbanden systematisch onderzocht, waarbij we vooral hebben gekeken naar het verband tussen inrichting en beheer van de teelt en het voorkomen van soorten en soortengroepen vogels. Nevendoelstelling daarbij was het formuleren van hypotheses over de ecologische processen die deze relaties bepalen. In een dergelijke analyse is het mogelijk het traditionele, eendimensionale beeld te verlaten waarbij een toename aan diversiteit van broedvogels automatisch gepaard gaat met een afname van de productiviteit: doel van de studie was om die maatregelen te vinden die wel gunstig zijn voor de diversiteit aan broedvogels, en die niet of nauwelijks de opbrengsten verlagen. Het is een gedetailleerde modelleringsstudie zoals die genoemd wordt in de MLU procedure van hoofdstuk 2.

Op basis van een aantal agronomische studies over wilgenteelt, specificeerden we eerst inrichting en beheer van de teelt in een set variabelen, in feite landgebruiksvereisten

(LURs). Daarnaast stelden we een lijst samen van soorten broedvogels die in wilgenteelt kunnen voorkomen, op basis van veldinventarisaties in moderne wilgenteelten in het buitenland en inlandse traditionele grienden. Deze soorten werden vervolgens gegroepeerd aan de hand van een classificatie in ecologische groepen: groepen met (deels) overeenkomstige kenmerken, bijvoorbeeld qua habitatvoorkeur of voedselpakket. De vraag hoe deze groepen reageren op de verschillende variabelen in inrichting en beheer werd geanalyseerd door een aantal griendbeheerders en vogeldeskundigen te interviewen. De resultaten daarvan werden samengevat en bediscussieerd in een workshop met deze mensen, waarin we vooral aandacht besteedden aan de onderliggende ecologische processen. Hierdoor kregen we een systematisch overzicht van inrichtings- en beheersvariabelen, hun bandbreedtes waar het gaat om productiviteit, terreinkenmerken die afhankelijk zijn van die variabelen, en (ecologische groepen van) broedvogels die daar op reageren.

Ondanks de onzekerheden en het kwalitatieve karakter van de resultaten, bevat deze studie handvatten voor beheerders van wilgenteelten die aandacht willen besteden aan broedvogels, en bovendien bevat ze hypotheses over relaties tussen broedvogels en beheer die nader onderzocht kunnen worden. Op basis van deze analyse lijkt het erop dat wilgenteelten vooral aantrekkelijk kunnen worden gemaakt voor groepen broedvogels van struikgewas en heggen, zoals de rietgors-, grasmus- en winterkoninggroep, zonder dat daar een sterke opbrengstdaling tegenover staat.

De resultaten van deze analyse werden geïntegreerd in beheerspakketten: een minimumpakket, met alleen vogelvriendelijk maatregelen die geen invloed hebben op de productiviteit, een pakket met extra aandacht voor de ondergroei in een goed ontwikkelde teelt, en een pakket met extra aandacht voor randenbeheer. Deze pakketten zijn intern consistent, en richten zich op specifieke ecologische groepen broedvogels. De eerste twee jaren van een wilgenplantage vallen buiten de beheerspakketten: omdat in de eerste jaren de wilgenstekken erg kwetsbaar zijn, dient het beheer dan vooral gericht te zijn op hun ontwikkeling.

Tenslotte wordt in dit hoofdstuk een korte discussie gewijd aan sturingsstrategieën van een overheid die de aanwezigheid van broedvogels wil stimuleren. Hierbij maken we onderscheid tussen strategieën die aanpassingen in het beheer belonen en strategieën die de aanwezigheid van vogels zelf belonen. Dit zijn twee benaderingen die in ‘principal-agent’ modellen worden onderscheiden (zie ook hoofdstuk 2). Op basis van literatuur werd een set criteria opgesteld om na te gaan welke strategie het meest geschikt is voor het stimuleren van broedvogels in wilgenteelt. Uit de evaluatie blijkt dat geen van de twee strategieën duidelijk voordeel heeft boven de ander: het belonen van resultaten geeft veel onzekerheid voor de beheerder, die nog niet precies weet hoe hij die resultaten kan bereiken, maar het belonen van aangepast beheer heeft het nadeel dat het gecontroleerd moet worden. Een mengvorm is wellicht het meest geschikt: afrekenen op gedrag kan worden toegepast op een minimumpakket aan maatregelen die vooral bij inrichting van de teelt van belang zijn en dus goed controleerbaar, terwijl extra inspanningen kunnen worden beloond door te kijken naar het resultaat. Zo’n systeem stimuleert beheerders ook om zelf te zoeken naar het optimale beheer voor hun specifieke situatie, waarbij de resultaten van onze analyse van pas kunnen komen.

6. Synthese

Uit de case studies in de hoofdstukken 3 tot en met 5 kunnen we opmaken in hoeverre de methodologie uit hoofdstuk 2 toepasbaar is. Bovendien kunnen we de samengevatte resultaten uit de cases gebruiken om de centrale onderzoeksvraag te beantwoorden.

Wat betreft de *methodologie*: in de cases is niet de gehele procedure doorlopen, maar zijn alleen de fasen met toegepast onderzoek gebruikt. In deze fasen blijkt het schema van product/dienst via landgebruikstype naar landgebruiksvereisten (product-LUT-LURs) helder en goed toepasbaar. Het kost echter nog steeds moeite om LUTs die te maken hebben met natuurbeheer op een dergelijke manier uit te werken. Aangezien in het natuurbeleid steeds meer pogingen worden gedaan om natuur ‘concreet’ te maken en het te relateren aan beheersactiviteiten, zal dit probleem in de toekomst waarschijnlijk kleiner worden. Bovendien kan een dergelijk product flexibel worden gedefinieerd, en soms kunnen essentiële inputs voor het product als ‘tussenproduct’ worden gedefinieerd, zoals de grondwaterstand in de bufferstudie. De break-even prijs, zoals we die gebruikt hebben in de hoofdstukken 3 en 4, bleek een nuttige maat te zijn om aan te geven of een voorgestelde meervoudige LUT ook financieel aantrekkelijk is voor een landbeheerder, en dus kan bijdragen aan zijn financiële doelstellingen. Daarnaast kan de break-even prijs gebruikt worden om meervoudige en enkelvoudige systemen te vergelijken, en na te gaan welke beter kan concurreren met andere functies om land. De fase van gedetailleerd modelleren bleek te leiden tot gecompliceerde studies. Daardoor is het aan te raden die fase alleen in te gaan wanneer de informatie uit een snelle verkenning niet voldoende is voor een keuze voor of tegen meervoudig landgebruik.

In de case studies zijn geen optimalisaties gedaan op de manier zoals voorgesteld in hoofdstuk 2. Hiervoor waren twee redenen. Ten eerste gingen we in hoofdstuk 2 uit van het optimaliseren van één meervoudige LUT. In de case studies was bijna altijd sprake van een vergelijking tussen twee meervoudige LUTs, waarvan één met energieteelt. Ten tweede bleek er nog geen duidelijke marktprijs te vinden voor energiehout, als product van wilgenteelt, waardoor optimaliseren niet mogelijk was. Om dit probleem te omzeilen is het begrip break-even prijs ontwikkeld. Een break-even prijs houdt echter geen verband met optimalisatie van de baten voor een landbeheerder: het geeft de minimumprijs aan die een koper van energiehout moet betalen om te zorgen dat een landbeheerder kan overstappen op wilgenteelt. Als zodanig is het dus eerder een instrument om de kosten van de koper van hout te minimaliseren dan om de baten van een boer te optimaliseren.

Wat betreft de beantwoording van de *centrale onderzoeksvraag*: de toepassingen werpen licht op de drie criteria die waren geformuleerd: biofysische haalbaarheid van MLU combinaties, het effect op de financiële concurrentiepositie van wilgenteelt, en de grootte van het potentieel areaal.

De meeste van de bestudeerde opties voor het combineren van wilgenteelt met een andere vorm van landgebruik blijken biofysisch haalbaar. Omdat deze opties waren voorgeselecteerd op basis van onze eerste indruk van de haalbaarheid, is dit beeld wellicht optimistisch in vergelijking met het hele scala aan combinatie-opties dat in de literatuur wordt voorgesteld. Nieuw te ontwikkelen opties, of opties met andere energiegewassen, hebben mogelijk ook andere perspectieven.

Het effect op de financiële concurrentiepositie van wilgenteelt in meervoudig ruimtegebruik verschilt per combinatie. In sommige cases, zoals de optie in grondwaterbeschermingsgebieden, verandert er niets aan die concurrentiepositie. In andere cases, bijvoorbeeld de combinatie in bufferzones, kan een substantiële verbetering worden verwacht. Ook de verlaagde break-even prijzen zijn echter nog zo hoog dat ze niet in de buurt komen van de huidige prijzen van biomassa-reststromen, de enige grondstof die momenteel wordt gebruikt voor bio-energie. In situaties waarin energieteelt niet hoeft te concurreren met gangbare landbouw zou deze situatie nog wel eens anders kunnen zijn. Wanneer bijvoorbeeld energieteelt zou kunnen worden ingepast in recreatieterreinen, of kan worden geïntegreerd in natuurgebieden (vooropgesteld dat de recreatieve en natuurfuncties hiervan geen schade ondervinden) kunnen de break-even prijzen veel lager uitvallen.

Het totale areaal in Nederland dat biofysisch geschikt is voor de onderzochte opties is ongeveer 100.000 ha. Het areaal waarbij sprake is van een verbeterde concurrentiepositie is ongeveer 30.000 ha. Gegeven de projecties over het areaal energieteelt dat nodig zal zijn om de nationale duurzame-energiedoelstelling te halen, zal het areaal dat ook financieel voordeel geeft niet voldoende zijn. Uiteraard verandert dit beeld wanneer ook andere, niet onderzochte opties tot verlaagde break-even prijzen leiden.

Los van biofysische, financiële en areaalinschattingen zullen andere factoren van invloed zijn op de introductie van energiewassen in meervoudig landgebruik. Voor sommige bestudeerde opties kunnen problemen bij implementatie ontstaan door maatschappelijke weerstanden, onzekerheden in de exacte locatie van de combinatie, de grootte en de geografische gefragmenteerdheid van de percelen. In het algemeen zijn bij meervoudig landgebruik meer actoren betrokken, wat invoering bemoeilijkt. Bovendien is er een attitudeverandering nodig bij boeren en beleidsmakers, die zich in de laatste decennia vooral hebben gericht op enkelvoudig landgebruik.

Wat betreft de centrale onderzoeksvraag: meervoudig landgebruik vergroot de kansen voor energiegewassen in Nederland, maar het zal onder de huidige omstandigheden geen panacee zijn voor grootschalige introductie van rendabele vormen van energieteelt. Het potentieel areaal blijft beperkt, evenals de financiële voordelen ten opzichte van enkelvoudig landgebruik, en diverse problemen rond implementatie kunnen de vertaling naar de praktijk bemoeilijken.

De beperkte perspectieven voor energieteelt kunnen op termijn veranderen onder invloed van een aantal lange-termijnontwikkelingen. Technische innovaties in energieteelt kunnen de beheerskosten doen dalen en de opbrengsten doen stijgen, waardoor de productiekosten nog tientallen procenten kunnen dalen. Ontwikkelingen in het Gemeenschappelijk Landbouwbeleid van de EU zullen het (agrarisch) landgebruik in de Unie sterk beïnvloeden. Wanneer de huidige marktordeningen en steunbetalingen aan boeren veranderen, zoals aan de orde is onder druk van de WTO en door de toekomstige toetreding van een aantal Centraal- en Oost-Europese landen, zullen de kansen voor energiegewassen waarschijnlijk verbeteren. Een van de consequenties is mogelijk een toenemende aandacht voor combinatie van landbouw met andere functies (en een toenemende waardering voor die functies), waarvoor energiegewassen goed geschikt zijn. Tenslotte kunnen energiegewassen mogelijk profiteren van een toenemende vraag naar bio-energie, of van een systeem waarbij emissies van kooldioxide een prijs krijgen. Dit zal vooral effect hebben wanneer de vraag zo groot wordt dat de eindige hoeveelheden reststromen niet genoeg zijn om te voldoen aan deze vraag. Veel van deze effecten zullen van invloed op energieteelt in zowel enkelvoudig als meervoudig landgebruik. Wanneer energieteelt echter meer concurrerend wordt, moge het duidelijk zijn dat de opties in meervoudig landgebruik eerder in beeld zullen komen dan die in enkelvoudig landgebruik.

Curriculum Vitae

Marc Londo werd geboren in Emmen op 8 december 1970. In 1989 behaalde hij op de Gemeentelijke Scholengemeenschap aldaar het VWO-diploma met een gymnasium-β pakket. Zijn studie Scheikunde aan de Universiteit Utrecht rondde hij in 1994 cum laude af, na een afstudeeronderzoek naar het gedrag van organische verontreinigingen in sedimenten. Hierna was hij bijna een jaar lang werkzaam bij de Chemiewinkel van de Universiteit Utrecht, voor het schrijven van ‘Basisboek Bodem’, een basishandleiding over bodem, bodemverontreiniging en bodemsanering. Naar aanleiding hiervan werkte hij mee aan een hoofdstuk in de Leidraad Bodembescherming over de verschillende stappen bij bodemonderzoek en –sanering.

In 1996 kwam hij als Onderzoeker in Opleiding bij de Sectie Natuurwetenschap en Samenleving, Universiteit Utrecht. Dit onderzoek, naar de mogelijkheden om de kansen voor energieteelt in Nederland te vergroten door meervoudig landgebruik, heeft geleid tot dit proefschrift. Tijdens het onderzoek participeerde hij in het maken van een handleiding voor recreatieschappen over de mogelijkheden voor duurzame energie in recreatieterreinen. Daarnaast werkte hij samen met Nico Haselager bij de Chemiewinkel aan een uitgebreide brochure over meten bij lokale milieuproblemen, ‘Een naald in een hooiberg’, die in 2001 uitkwam.

Sinds februari 2002 is hij werkzaam bij KDO Advies, een adviesbureau dat lokale en regionale projecten ondersteunt op het gebied van duurzame ontwikkeling en meervoudig landgebruik.

Publicaties:

Wetenschappelijke artikelen:

Londo, M., J. Dekker and H. de Graaf: *Willow Short Rotation Coppice in multiple land use systems: evaluation of three combination options*. Submutted to Biomass and Bioenergy.

Londo, .M., J. Dekker and W. ter Keurs: *Willow Short Rotation Coppice for energy and breeding birds: An exploration of potentials in relation to management*. Submitted to Biomass and Bioenergy.

Londo, M., J. Dekker, P. Verweij and H. de Graaf: *Multiple land use on land unit level in rural areas: Towards operationalisation*. Submitted to Land Use Policy.

Londo, M., L. Vleeshouwers, J. Dekker and H. de Graaf: *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation*. Biomass and Bioenergy 20 (2001), 337-350.

Londo, M., M.I. Bakker and S.M. Schrap: *Measurements on water containing dissolved and suspended matter from natural sediments*. Chemosphere 32 (1996) no 9, 1699-1708.

Rapporten en boeken:

Schulte, B., H.M. Londo en E.J. Bruls: *Duurzame energie in recreatiegebieden*. Ecofys, Universiteit Utrecht, Stichting Recreatie, Utrecht 2001.

Haselager, N. en M. Londo: *Een naald in een hooiberg; over meten bij lokale milieuproblemen*. Chemiewinkel Utrecht en VNG Uitgeverij, Utrecht/Den Haag, 2001.

Londo, M., L. Vleeshouwers, J. Dekker and H. de Graaf: *Energy farming in Dutch desiccation abatement areas: effects on break-even biomass price*. Report no. 99.045, Vakgroep Natuurwetenschap en Samenleving, Universiiteit Utrecht, 1999.

Bruijn, P.J., A.B.M. Stax, H. M. Londo en L.L.M Absil: *Stappen bij onderzoek en sanering*. In: Veul, M.F.X.W., A.S.F. van Asseldonk, C. de Boer, P.J. de Bruijn, C.A. Janssen, M.J.H. Langenhuijsen: *Leidraad Bodembescherming*. Sdu uitgevers, Den Haag 1997.

Londo, H.M.: *Basisboek Bodem; over verontreiniging, onderzoek en sanering van de bodem*. Chemiewinkel Utrecht, Utrecht 1996.

Londo, M.: *Speurtocht naar het kritisch effect bij beroepsmatige blootstelling aan chemicalien*. Vakgroep Natuurwetenschap en Samenleving, Universiteit Utrecht, 1994.

Londo, M.: *Handleiding leeflaagsaneringen*. Chemiewinkel, Universiteit Utrecht, 1993.

Conferentie-proceedings:

Londo, M.: *Willow Short Rotation Coppice in Multiple Land Use Systems: a survey of potentials in the Netherlands*. Accepted for the 5th Biomass Conference of the Americas, Orlando, 2001.

Londo, M., J. Dekker and W. ter Keurs: *Willow Short Rotation Coppice for energy and birdlife: an exploration of potentials in relation to management*. Accepted for the 5th Biomass Conference of the Americas, Orlando, 2001.

Londo, M., L. Vleeshouwers, J. Dekker and H. de Graaf: *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation*. In: Kyritsis, S., A.A.C.M. Beenackers, P. Helm, A. grassi and D. Chiarmonti (Eds.): *Proceedings of the 1st World Conference on Biomass for Energy and Industry*, Seville, 2000, 300-304.

Londo, M. and M.E. Roose: *Willow cultivation in multiple land use systems; Evaluation of two combinations of willow farming and another function*. In: Kyritsis, S., A.A.C.M. Beenackers, P. Helm, A. grassi and D. Chiarmonti (Eds.): *Proceedings of the 1st World Conference on Biomass for Energy and Industry*, Seville, 2000, 305-307.

Marc Londo, Jos Dekker, Pita Verweij and Hans de Graaf: *Multiple land use: operationalisation of a concept*. In: Ierland, E. van, A. Oude Lansink and E. Schmieman (Eds): *Sustainable Energy: New challenges for agriculture and implications for land use*. Conference Proceedings, Wageningen 2000.

Marc Londo and Michelle E. Roose: *Willow cultivation in multiple land use systems; Evaluation of two combinations of willow farming and another function*. In: Ierland, E. van, A. Oude Lansink and E. Schmieman (Eds): *Sustainable Energy: New challenges for agriculture and implications for land use. Conference Proceedings*, Wageningen 2000.

Marc Londo, Leo Vleeshouwers, Jos Dekker, and Hans de Graaf: *Energy farming in Dutch desiccation abatement areas: Yields and benefits compared to grass cultivation*. In: Ierland, E. van, A. Oude Lansink and E. Schmieman (Eds): *Sustainable Energy: New challenges for agriculture and implications for land use*. Conference Proceedings, Wageningen 2000.

Londo. M., L Vleeshouwers, J. Dekker en H. de Graaf: *Energieteelt in buffergebieden tegen verdroging: Effecten op de kostprijs van biomassa*. Proceedings Nederlandse Duurzame Energie Conferentie, Noordwijkerhout 1999, 198-199.

Roose, M.E., en M. Londo: *Wilgenteelt in Multifunctioneel Landgebruik: Evaluatie van enkele combinaties van energieteelt met andere functies*. Proceedings Nederlandse Duurzame Energie Conferentie, Noordwijkerhout 1999, 208-209.

Londo, M., and J. Dekker: *Enhancement of biodiversity in energy farming: Towards a functional approach*. In: *Proceedings of the Third Biomass Conference of the Americas*, Montreal, 1997, 1525-1532.

Londo, M.: *Biodiversiteit en de teelt van biomassa voor energieproductie*. In: *Proceedings van de eerste Nederlandse Duurzame Energie Conferentie*, pp. 179-180. Ede, 17-18 november, 1997.

Kleine artikelen / ingezonden brieven:

Bruls, E., B. Schulte en M. Londo: *Duurzame energie betaalt zich terug voor groenbeheerders*. Groen, vakblad voor groen in stad en landschap, 57 nr 12, december 2001.

Londo, M. en M. Louwes: *Communicatie na rampen: juist, volledig én vooral snel*. Milieutijdschrift Arena 7 nr 6, oktober 2001.

Haselager, N. en M. Londo. *Een poldermodel voor milieumetingen*. Dossier Milieutijdschrift Arena 7 nr 5, september 2001.

Haselager, N. en M. Londo: *Weet wat je meet!* Gastredactioneel in Chemisch (2) Weekblad, 4 juni 2001.

Londo, M.: *Paralympics geen topsport*. De Volkskrant, 12 september 2000.

Hamelinck, C., M. Londo en J. van der Sluijs: *CO_2-opslag niet raadselachtig*. Technisch Weekblad no 42, 1999.

Dankwoord

Na dertien jaren bij de Alma Mater
Maak ik het testament op van die tijd.
Promoveren voert haast tot de psychiater
Omdat men zich voor 'n hongerloon kastijdt.

Dit dankwoord moet eigenlijk beginnen met een kort excuus aan onder meer Nico en Jethro. Ik had beloofd een dankwoord te schrijven op rijm, en in het voorbijgaan een aantal bekende vaderlandse gedichten door de persiflagemolen te halen. Maar in dit geval bleek er een stevig writers-block in de weg te staan. Bovendien was ik natuurlijk doodsbenauwd dat Jethro mijn gerijmel de eerstvolgende NeWS (het interne blaadje van de sectie Natuurwetenschap en Samenleving) genadeloos zou persifleren…
Deze anekdote zegt wel iets over de sfeer waarin ik in de afgelopen jaren dit proefschrift geschreven heb. Die sfeer is natuurlijk deels bepaald door de mensen die inhoudelijk hebben bijgedragen aan het onderzoek, maar minstens zo belangrijk is de totale groep mensen van de sectie Natuurwetenschap en Samenleving. Een groep die barst van de spirit, creativiteit en een tegenwoordig bijna ouderwetse ambitie de wereld een beetje beter te maken. Een groep waar ik me dan ook bijzonder thuis heb gevoeld. Mensen noemen is andere mensen tekort doen, maar toch wil ik een paar personen naar voren halen. Heleen, je combinatie van humor en een 'niet lullen maar poetsen'-mentaliteit maakte jou tot een ideale kamergenoot. Omdat je inhoudelijk met heel ander onderzoek bezig was, kon je af en toe van een prettige afstand commentaar geven op wat ik aan het doen was, ook al zaten we al die jaren met z'n tweeën in een hokje van nog geen tien vierkante meter. Carlo, je observatievermogen en licht filosofische aard leidden vaak tot opmerkelijke opmerkingen, maar het was ook bijzonder om na een conferentie in Sevilla nog twee weken lang samen Spanje onveilig te maken. Silvia, met je 'calor humano', Dirk-Jan, die in dezelfde periode als ik verliefd over de wereld zweefde, Esther, Monique, Jethro, Kay (*&^Y%$!!), Jaklien, Arlette, Günther, Roni, André, Penny, Louise, en ik vergeet er gegarandeerd een paar: stuk voor stuk zijn jullie mensen die een bijdrage hebben geleverd aan de opwarming van de atmosfeer in de sectie.

Maar prettig werken lukt uiteindelijk alleen wanneer het ook de met inhoudelijke supervisie wel goed zit. Promotor Hans de Kruijf, ik heb het erg gewaardeerd dat jij de inhoudelijke begeleiding op hoofdlijnen hebt gehouden, te meer omdat ik al zoveel eigenwijze begeleiders had. Bovendien was je begeleiding van het proces uitstekend. Co-promotor Hans de Graaf, je creativiteit en associatievermogen lijken onuitputtelijk. Zeker nadat ik gevonden had waar de 'regelknoppen' van je tomeloze energie zitten, heb ik daar erg veel aan gehad. Jos Dekker, als dagelijks begeleider had je natuurlijk verreweg het meest contact met me. Ik ken weinig mensen die zo zorgvuldig en gewetensvol met het begeleiden van mensen omgaan als jij. Daar heb ik als promovendus veel baat bij gehad, maar ik heb ook veel kunnen leren over het geven van onderwijs en het werken met afstudeerders. Wim ter Keurs, je hebt niet alleen een belangrijke bijdrage geleverd aan hoofdstuk 5, maar in het hele onderzoek heb je constructief meegedacht, en je lette er vooral op dat onze wilde onderzoeksideeën ook nog eens ‘met de voetjes aan de grond’ konden komen. Pita Verweij, jouw komst bij NW&S leidde ertoe dat een tot dan toe half uitgewerkt verhaal kon uitgroeien tot een volwaardig hoofdstuk 2, en bovendien ben jij ook al zo’n sociale verrijking van de sectie.

In de loop der jaren heb ik het biomassa-groepje onder leiding van André Faaij zien groeien. In de eerste jaren had ook Richard van den Broek daar een belangrijke rol in. En dan was er natuurlijk nog Leo Vleeshouwers, onze ‘hangende spits’ in Wageningen, die onder meer heeft geholpen bij hoofdstuk 4. Het nieuwe onderzoek van Iris en Roni is een logisch en interessant vervolg op zaken waar ik mee bezig geweest ben. De studenten in dit groepje zijn mijns inziens onmisbaar, en dat vind ik helemaal van mijn ‘eigen’ studenten. Floor, Irma, Hans, Ulrich, Monique en Michelle: het was erg boeiend om te zien hoe jullie al doende aan het leren waren, en te merken hoe ik door jullie werk ook nieuwe ideeën kreeg.

Het cliché dat een bestaan als Onderzoeker in Opleiding leidt tot monomanie en sociale isolatie geloofde ik al niet toen ik er aan begon, en dat is terecht gebleken. Er viel, zeker in de beginjaren, nog genoeg vrijwilligerswerk te doen bij de Chemiewinkel, waarbij werk en ontspanning dwars door elkaar liepen. Arjan, Marjan, Nico, Detlef, Petra, Michel, Monique, Ivo, Ingeborg: weg met de one-track mind! Al gingen de gesprekken met al die promovendi wel vaak over het onderzoek. En dan wil ik nog een paar vriendschappen noemen waar ik in een balorige bui een zeer politiek correct minderhedenrijtje van zou kunnen maken: Alex, Fatima, Meike, Corine, Rudie, Janneke: jullie zijn en blijven me dierbaar.

Ik vermoed dat iedereen van tevoren wel wist wie mijn paranimfen zouden worden: Gerard en Nico. Wie anders? Als ik twee mensen in de afgelopen jaren tot steun en toeverlaat heb gehad, zijn jullie het wel. Ik voel me werkelijk een gezegend mens met de band die ik met jullie beiden heb. Gerard, zo’n zestien jaar geleden was een geweldige rampvakantie zo ongeveer het begin, en sindsdien hebben tien jaar in één huis wonen, een gasexplosie, komen en gaan van vriendinnen en ons beider persoonlijke ontwikkeling onze vriendschap alleen maar versterkt. In zo’n context zijn promotieperikelen natuurlijk weinig meer dan kleine rimpelingen. Je directheid, die ik in de loop der jaren wat gedoseerder heb zien worden, is nog steeds inspirerend. Nico, je gekanker mag dan spreekwoordelijk zijn, als het erom gaat ben je betrokken en integer, nooit bang om de moeilijke onderwerpen aan te snijden als je vermoedt dat dat even nodig is. Je manier van in het leven staan, onbevangen, en met een fundamenteel vertrouwen in het goede, is een goede tegenhanger voor mijn neiging af en toe wel erg verstandelijk te zijn.

Ik las onlangs een oratie over inspirerend leiderschap. Ik weet niet of het inspirerend vaderschap al is uitgevonden, maar beste Pa, wat mij betreft zou je hoge ogen gooien. Dat je nu, na een bepaald enerverend en zeker niet altijd makkelijk leven, nog steeds de kracht hebt om ervan te genieten, betrokken te zijn bij je omgeving en je opinies over de wereld scherp te houden, bewonder ik. Broer, zussen, andere familie: ondanks jullie betrokkenheid heeft het schrijven van dit proefschrift zich natuurlijk goeddeels buiten jullie blikveld afgespeeld. Maar ik weet zeker dat ik zonder jullie steun een veel zwaardere periode zou hebben gehad tijdens de ziekte en het overlijden van Ma en tante Lien. Ook aan jou, Corine, denk ik wat dat betreft met veel dankbaarheid terug.

Ach lieve Mariëtte, dit boekje zou vast ook wel afgekomen zijn als wij elkaar vorig jaar niet tegen het lijf waren gelopen. Veel dingen in mijn leven zouden er in dat geval echter heel anders uitzien, en ik ben elk uur van dag en nacht blij en dankbaar met wat wij bij elkaar teweeg brengen. Maar als ik daarover zou gaan uitweiden zou ik waarschijnlijk nog een boekje vol moeten schrijven. En bovendien: het zou alleen voor jouw ogen bestemd zijn, en niet voor een commissie die erover mag opponeren!

Tenslotte, lezer die inmiddels een eerste kennismaking met dit proefschrift achter de rug heeft: ik wens u veel plezier met het lezen van de rest.

Utrecht, maart 2002.