Sustainable Bioenergy Production - An Integrated Approach

Hans Ruppert • Martin Kappas • Jens Ibendorf
Editors

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Hans Ruppert
Department of Sedimentology
and Environmental Geology
University of Göttingen
Göttingen, Germany

Martin Kappas
Department of Cartography, GIS and
Remote Sensing
Institute of Geography
University of Göttingen
Göttingen, Germany

Jens Ibendorf
Interdisciplinary Centre for Sustainable
Development
University of Göttingen
Göttingen, Germany

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Preface

This volume, entitled *Sustainable Bioenergy Production: An Integrated Approach*, focuses primarily on the advantages and implications of sustainable bioenergy production in terms of ensuring a more sustainable world despite its growing energy demands.

This book addresses a new concept that focuses on the interactions between different uses of agricultural land (e.g., agriculture for food, forage or energy and nature conservation) and their ecological, economic and societal impacts. This research concept provides new insights into the competition for resources and the synergies between different land uses. It seeks to improve people's understanding of bioenergy's potentials and the future of land use management and biomass management. To date, the transition towards renewable energy has been misunderstood as only an economic demand, rather than as a means to gain various societal and ecological advantages. Today, biomass is produced to generate energy and renewable raw materials, while simultaneously benefitting soil resources, water resources and biodiversity. The transition to a 'greener' economy is an important precondition to achieve the sustainable development of societies.

Chapter 1, *Sustainable bioenergy production: An integrated perspective,* by Ruppert, Kappas and Ibendorf provides an overview of the controversial issue of sustainable bioenergy production and sets the background for the subsequent chapters.

Chapter 2, *Bioenergy villages in Germany: Applying the Göttingen Approach of Sustainability Science to promote sustainable bioenergy projects,* by Schmuck, Eigner-Thiel, Karpenstein-Machan, Sauer, Ruppert and Roland provides a retrospective overview of the early development of sustainable bioenergy projects in Germany. Bioenergy villages such as Jühnde serve as best practice examples. This approach points the way to the development of a future sustainable energy supply. By means of integrated research, a holistic perspective is provided of the issues concerning sustainable bioenergy production.

The future use of biomass as an energy type needs to be assessed comprehensively and will require careful management of natural land resources such as soil and water. Unsustainable biomass use would undermine bioenergy's climate-related advantages. Precise estimations of the planet's bioenergy potentials are needed on a global, regional and local scale.

Chapter 3 by Kappas provides a short review of global bioenergy potentials and their contribution to the world's future energy demand. While there are many estimations of the future biomass potential, it is clear that bioenergy will play an important part in our future energy supply if we compare the average global bioenergy production potential in 2050 with the highest predictions of global primary energy consumption in 2050. This chapter provides a framework for further estimations of the bioenergy potentials in a region (Germany as a whole) and in a specific site (the local perspective).

State-of-the-art knowledge of the biomass potentials in Germany can be provided by using the process-based vegetation model as described by Tum, Günther and Kappas in Chap. 4. The chapter also presents an approach to estimate sustainable straw energy potentials by means of a modelled Net Primary Productivity (NPP) product, which has been validated by empirical data on the managed area and mean yields of the main crops in Germany. The Biosphere Energy Transfer Hydrology Model (BETHY/DLR) is the theoretical framework to estimate the NPP of the agricultural areas in Germany. The regional estimations of the bioenergy potentials throughout Germany provide a basis to assess the bioenergy potentials on a local scale (site-specific biomass potentials).

Chapter 5, *Modelling site-specific biomass potentials* by Bauböck, offers a new tool to assess local-scale biomass potentials. For the assessment of site-specific and larger area biomass potentials in Lower Saxony, a carbon-based crop model – BioSTAR – was developed at the University of Göttingen. The first validations of the model by means of measured agricultural harvest data from different farms in Lower Saxony are providing convincing results. Chapter 5 concludes the topic of bioenergy potentials and shows that the tools and estimations used to assess bioenergy potentials are already available and that they deliver robust results for future planning.

The next topic – the environmentally sound optimisation of bioenergy production – is addressed in Chaps. 6 and 7.

Chapter 6, *Integrative energy crop cultivation as a way to a more nature-orientated agriculture* by Karpenstein-Machan, focuses on the vision of integrative energy cultivation concepts, which contribute to a more diverse and sustainable rural landscape, keep nature in balance and conserve ecosystems. Integrated cultivation concepts are introduced that should harmonise the relationship between utilisation/production and landscape protection. This integrated concept shows convincing ways to prevent monocultures (e.g., of maize) through a diversified energy crop cultivation system.

Chapter 7 by Saathoff, von Haaren and Rode focuses on the *scale-relevant impacts of biogas crop production: A methodology to assess environmental impacts and farm management capacities*. Typical research questions are: To what extent can the ecological impacts of local biogas crop production be solved by integrated farm management at the farm level? Can potential obstacles to species-friendly and climate-friendly land management be reduced by providing optimal site-specific information about the potential advantages and disadvantages of implemented conservation measures? The outcomes of Chaps. 6 and 7 are a view of the environmentally sound optimisation of bioenergy production, which is important for economic and social linkages.

Environmental and social costs are part of the economic system and include external environmental costs. External diseconomies should be considered when pursuing sustainable consumption and production. Hence the next topic "The economic optimisation of bioenergy production." For example, Chap. 8 by Daub, Uhlemair, Ruwisch and Geldermann optimises *bioenergy villages' local heat supply networks* and provides important advice for a more decentralised energy supply.

According to the examination of the current and future bioenergy potentials (Chaps. 3, 4 and 5), the environmentally and ecologically sound optimisation of bioenergy production (Chaps. 6 and 7) and the economic optimisation of a heat distribution network relying on wood and crops (Chap. 8), the next contemporary issue is the socially acceptable optimisation of bioenergy production (Chaps. 9, 10, 11 and 12).

Chapter 9 by Granozewski, Reise, Spiller and Musshoff first considers the *growth of biogas production in German agriculture by providing an analysis of farmers' investment behaviour*. In German agriculture, renewable energy production from biogas has undergone a dynamic expansion over the past years, which is still continuing. However, with regard to biogas plants, farmers differ in their investment behaviour. A better understanding of farm-level decision-making structures is particularly important for policy-makers and local authorities to estimate biogas production's future investment potential. This chapter also analyses the conflicts in German agriculture regarding land rate leases and land use competition.

The question of willingness to invest in future bioenergy production is coupled with the *social acceptance of bioenergy use and the success factors of communal bioenergy projects* in Chapter 10 by Wüste and Schmuck. This chapter provides insights into the highly dynamic development of bioenergy production facilities in Germany, which are not all in line with sustainability criteria. A growing number of people in Germany's rural areas are directly or indirectly affected by increased bioenergy utilisation. In many cases, bioenergy plants are mainly built for economic considerations, without involving the local population and other stakeholders. Growing fears caused by the local population's lack of information often lead to conflicts, resistance and lower acceptance of bioenergy projects. Chapter 10 addresses potential avenues to sustainable bioenergy projects that local populations will support.

Chapter 10's results lead to the central challenge of *applying the sustainability science principles of the Göttingen approach to initiate renewable energy solutions in three German districts* as Schmuck, Karpenstein-Machan and Wüste describe in Chapter 11. This chapter summarises an interdisciplinary and transdisciplinary action research project that reports on the application of sustainability science principles to convert the energy supply in three German districts of Lower Saxony into renewables.

Finally, different bioenergy concepts regarding sustainable development are evaluated by Eigner-Thiel, Schmehl, Ibendorf and Geldermann in Chapter 12. This chapter focuses on a sustainability assessment of different concepts of biomass energy use in order to provide decision support that takes environmental, economic, social and technical perspectives into consideration. Bioenergy concepts in rural areas are of particular interest; possible technical and organisational concepts can, for example, be a biogas plant operated by electric service providers, or a single biogas plant owned by one farmer or a bioenergy village owned by a village cooperative. This chapter describes the development of suitable ecological, economic, social and technical criteria with which to assess the sustainability of different concepts and the adaptation of existing indicator systems to the special requirements of sustainable biomass use for energy. The results of this sustainability assessment illustrate different biomass concepts' advantages and disadvantages according to multi-criteria decision analysis methods. This decision support tool will facilitate mayors, district administrators, farmers and investors' decision process regarding the most sustainable concept for a certain area.

Two specific topics – the combustion of wood and straw and producing bioenergy on degraded soils – are addressed to complete the book's holistic perspective.

Chapter 13 by Seidel, Orasche, Ruppert and Schnelle-Kreis examines the organic and inorganic emissions during the burning of wood and straw in heat systems. The hazardous potential of the emitted pollutants' particulate matter is not at all well-known and is important for future acceptance of solid biomass sources such as wood and straw.

Contaminated soils should not be used for the production of food or forage crops. In Chapter 14, Sauer and Ruppert argue that energy plants should be grown in these polluted areas. Since the process of the phytoremediation of soils contaminated by heavy metal to acceptable low values requires several thousand years, it is more feasible to leave the toxic elements in the soil. The metal transfer from the different polluted soils to different energy plants was tested to find crops with low transfer factors. The advantages of using such crops are that the fermentation process in the biogas plant will not be impaired by heavy metals and that the residues of the biogas production can be recycled in the fields from which the plants were harvested without exceeding the maximum permissible values for heavy metal.

Energy alternatives based on locally available renewable resources, such as bioenergy, are crucial to the creation of a new energy mix. At the same time, increasing the energy efficiency of the whole economy and of all energy alternatives is an essential precondition to transition to a renewable energy system and a society oriented to sustainability.

To develop a modern, forward-looking energy supply from biomass, such as biomass for heat and power generation and liquid biofuels for transport, there should be a balance between the amount of biomass required for food production and for material purposes. Crop types, production methods and conversion technologies need to be matched with local conditions within the different landscapes to establish a national transformation plan, to reduce the increasing land use competition between food/fodder and energy crop production as well as the use of forests for energy.

Rethinking the linkages between bioenergy, climate change (limiting global temperature change to 2 °C), land use and water requires an integrated assessment of the energy, land and water nexus.

The advantages of sustainable bioenergy production use should always outweigh the effect of its possible environmental damage. The current book is an outcome of ongoing research in Lower Saxony, Germany, to provide an integrated approach to sustainable bioenergy development.

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Martin Kappas
Hans Ruppert
Jens Ibendorf

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Hans Ruppert
Martin Kappas
Jens Ibendorf

Contents

Abbreviations

AHP	Analytic hierarchy process
BImSchG	German Bundes-Immissionsschutzgesetz
BioSTAR	Biomass Simulation Tool for Agricultural Resources
BioSt-NachV	German Biomasse-Strom-Nachhaltigkeitsverordnung
CED	Cumulative energy demand
CHE	Condensing heat exchanger
CHP	Combined heat and power plant
CSD	Commission on Sustainable Development
DPSIR	Driving force, Pressure, State, Impact, Response analysis
DSS	Decision support system
EC	Elemental carbon
EEG	German Renewable Energy Sources Act
EJ	Exajoule = 10^{18} Joule (J) = 1,000 Petajoule
ESP	Electrostatic precipitator
FFH EU	Flora and Fauna Habitat directive
GEMIS	Globales Emissions Modell Integrierter Systeme
GHG	Greenhouse gas emissions
GIS	Geographical information system
GPP	Global primary production
ha	hectare
LAI	Leaf Area Index
LCA	Life-cycle assessment
ICP-OES	Inductively coupled plasma optical emission spectrometer
ICP-MS	Inductively coupled plasma mass spectrometer
IPCC	Intergovernmental Panel on Climate Change
IZNE	Interdisciplinary Centre for Sustainable Development (Interdisziplinäres Zentrum für Nachhaltige Entwicklung)
MADM	Multi-attribute decision-making

MAVT	Multi-attribute value theory
MAUT	Multi-attribute utility theory
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision-making
MCDSS	Multi-criteria decision support system
MIP	Mixed integer program
MJ	Megajoule = 10^6 Joule
MODM	Multi-objective decision-making
MWh	MegaWatt hours
NPP	Net primary productivity
NPV	Net present value
NUTS	Nomenclature des Unites Territoriales Statistiques
OC	Organic carbon
PAH	Polycyclic aromatic hydrocarbon
PAR	Photosynthetically Active Radiation
PJ	Petajoule = 10^{15} Joule
PM	Particulate matter
RUE	Radiation use efficiency
SCOPE	Scientific Committee on Problems of the Environment
SETAC	Society of Environmental Toxicology and Chemistry
SOA	Secondary organic aerosol
TEQ	Toxic equivalent
TF	Transfer factor
TSP	Total suspended particulate matter (the total of all particles in the air)
TTC	Threshold of toxicological concern
UN	United Nations
UNCED	United Nations Conference on Environment and Development
WBGU	German Advisory Council Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen)
WCED	World Commission on Environment and Development
WP	Water productivity coefficient
WSOC	Water-soluble organic compounds