



Technical University of Moldova

**MISCANTHUS AS AN INNOVATIVE
PROSPECTING TECHNOLOGY FOR A
CIRCULAR BIOECONOMY**

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MBA thesis

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ADNOTARE

la teza de masterat în cadrul programului MBA Managementul Agrobusinessului „Miscanthus ca tehnologie inovativă de prospectare pentru o bioeconomie circulară”, realizată de Sandu Anatolii

Structura tezei. Teza de masterat este structurată conform cerințelor metodologice și cuprinde: adnotare, introducere, analiza situației actuale a cercetării, metodologia cercetării, rezultate și analize, studiu de fezabilitate tehnico-economică, plan de afaceri, analiza impactului asupra mediului, concluzii și recomandări, bibliografie și anexe.

Cuvinte-cheie: *Miscanthus × giganteus*, bioeconomie circulară, biomasă energetică, culturi energetice perene, energie regenerabilă, captarea carbonului, BECCS, bioenergie, securitate energetică, dezvoltare durabilă, lanț valoric, investiții în agrobusiness.

Domeniul de studiu: Managementul agrobusinessului, cu accent pe dezvoltarea și implementarea unor modele inovative de valorificare a culturilor energetice perene în cadrul bioeconomiei circulare, prin integrarea aspectelor tehnologice, economice, investiționale și de mediu.

Problematica studiului. Republica Moldova importă circa 96% din resursele energetice consumate, iar mixul de producere a energiei electrice și termice se bazează în proporție de peste 90% pe gazele naturale de import. În acest context, valorificarea biomasei energetice locale devine o direcție strategică pentru diversificarea aprovizionării cu energie, reducerea vulnerabilității climatice și decarbonizarea economiei naționale.

Scopul tezei constă în evaluarea și demonstrarea potențialului culturii energetice *Miscanthus × giganteus* ca tehnologie inovativă pentru dezvoltarea unei bioeconomii circulare, prin producerea sustenabilă a biomasei, utilizarea eficientă a resurselor naturale, reducerea emisiilor de gaze cu efect de seră și integrarea biomasei în sisteme moderne de producere a energiei și a bioproduselor.

Obiectivele tezei: evaluarea adaptabilității agrobiologice a culturii în condițiile Republicii Moldova; optimizarea tehnologiilor de înființare și gestionare a plantațiilor comerciale; determinarea productivității și a calității biomasei; evaluarea potențialului de captare și stocare a carbonului și a posibilităților de integrare în lanțul valoric BECCS; fundamentarea tehnico-economică și investițională a unei plantații pilot de 100 ha, cu scalare graduală la 500, 1500 și 2000 ha; elaborarea recomandărilor practice pentru autorități, investitori și fermieri.

Metodele de cercetare aplicate cuprind: metode agrobiologice de cercetare în câmp pe cultivarul Aphrodite; metode tehnico-economice (CAPEX, OPEX, cash-flow, ROI, analiza de sensibilitate); metode de evaluare a impactului asupra mediului (LCA, calculul emisiilor evitate, potențialul BECCS); metode de management al proiectelor și analiza matricei de risc conform ISO 31000:2018; sinteza documentelor instituționale, a literaturii științifice și a datelor din pilotul comercial lansat cu S.A. Termoelectrica în octombrie 2022.

Rezultatele obținute demonstrează viabilitatea tehnico-economică a unei plantații de 100 ha cu scalare progresivă până la 2000 ha, recuperarea investiției într-un orizont acceptabil, o contribuție netă negativă de aproximativ -28 t CO_2 pe hectar pe an prin cuplarea cu BECCS, precum și un impact social pozitiv exprimat prin locuri de muncă în zonele rurale. Rezultatele confirmă ipoteza cercetării și sunt aliniate cu Planul Național Integrat pentru Energie și Climă (NECP) al Republicii Moldova și cu Programul Național pentru Biomasă 2024-2030. Recomandările formulate se adresează autorităților publice, investitorilor și fermierilor pentru scalarea ordonată a lanțului valoric Miscanthus–BECCS în Republica Moldova.

ABSTRACT
of the Master's Thesis in MBA Management in Agribusiness “Miscanthus as an innovative prospecting technology for a circular bioeconomy”, prepared by Anatolii Sandu

The Master's Thesis is structured in accordance with the methodological requirements and comprises: abstract, introduction, literature review, research methodology, results and analyses, techno-economic feasibility study, business plan, environmental impact analysis, conclusions and recommendations, bibliography and annexes.

Keywords: *Miscanthus × giganteus*, circular bioeconomy, energy biomass, perennial energy crops, renewable energy, carbon capture, BECCS, bioenergy, energy security, sustainable development, value chain, investments in agribusiness.

Field of study: Agribusiness Management, with a focus on the development and implementation of innovative models for the valorisation of perennial energy crops within the circular bioeconomy, through the integration of technological, economic, investment and environmental aspects.

Aim and objectives of the thesis

*The aim of this thesis is to assess and demonstrate the potential of the energy crop *Miscanthus × giganteus* as an innovative technology for the development of a circular bioeconomy through the sustainable production of biomass, the efficient utilisation of natural resources, the reduction of greenhouse gas emissions, and the integration of biomass into modern energy and bioproduct production systems.*

For the purpose of achieving this aim, the following objectives were formulated:

- assessment of the crop's agrobiological adaptability under the conditions of the Republic of Moldova;
- Optimisation of technologies for establishing and managing commercial plantations;
- Determination of biomass productivity and quality;
- assessment of the potential for carbon capture and storage and the possibilities for integration into BECCS systems;
- techno-economic feasibility analysis and the development of an investment model for value-chain development;
- assessment of the economic, social and environmental impact of implementing the crop;
- development of an integrated circular bioeconomy model applicable to the Republic of Moldova.

The scientific novelty and originality of the results obtained consist in the development of an integrated model for the use of *Miscanthus × giganteus* within the circular bioeconomy, by correlating biomass production, carbon capture, renewable energy production and the obtaining of value-added bioproducts. The thesis proposes the integration of the BECCS concept under the conditions of the Republic of Moldova and, for the first time, establishes a techno-economic model intended for the commercial implementation of *Miscanthus* energy plantations and their utilisation in centralised energy production systems.

The theoretical significance of the thesis lies in the systematisation and development of the conceptual framework concerning the role of perennial energy crops in the circular bioeconomy, the interdisciplinary analysis of the relationship between agriculture, energy and environmental protection, and the scientific substantiation of the use of *Miscanthus × giganteus* as an instrument for strengthening energy security and achieving climate neutrality objectives.

The applied value of the research is determined by the development of a techno-economic feasibility study and a business plan concerning the establishment of a commercial plantation of *Miscanthus × giganteus*, with the vertical integration of biomass and thermal energy production. The results may be used by public authorities, investors, farmers and operators in the energy sector to underpin investment decisions, develop bioenergy projects, utilise marginal land and implement sustainable development and green economy policies in the Republic of Moldova.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANRE	National Agency for Energy Regulation of the Republic of Moldova
BECCS	Bioenergy with Carbon Capture and Storage
CAPEX.....	Capital Expenditure
CBE	Circular Bio-based Europe
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide Equivalent
EBRD	European Bank for Reconstruction and Development
EU.....	European Union
EUR.....	Euro
GEFF	Green Economy Financing Facility
GHG	Greenhouse Gases
ha	Hectare
HHV	Higher Heating Value
IBERS.....	Institute of Biological, Environmental and Rural Sciences (Aberystwyth University, UK)
IEA	International Energy Agency
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
LCA.....	Life-Cycle Assessment
LHV.....	Lower Heating Value
MDL	Moldovan Leu
MWh.....	Megawatt-hour
NECP.....	National Integrated Energy and Climate Plan
OPEX	Operational Expenditure
PV	Photovoltaic
R&D	Research and Development
RED III.....	Renewable Energy Directive (EU) 2023/2413
ROI.....	Return on Investment
SOC	Soil Organic Carbon
SRL.....	Limited Liability Company (Societate cu Răspundere Limitată)
t.....	Metric Tonne

UNDP United Nations Development Programme
UTM Technical University of Moldova
VCS Verified Carbon Standard

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INTRODUCTION

The energy context of the Republic of Moldova lends this topic particular urgency. The country imports approximately 96% of the energy resources it consumes, while its heat and electricity generation mix is based to an extent of over 90% on imported natural gas, making it, according to the conclusions of the event “National Security Council decision on the Energy Security of Moldova” held in April 2022, one of the most vulnerable countries in Europe to gas price shocks. The energy crisis of 2021–2022 led to an eightfold increase in the gas import price compared with the previous year, with the price reaching USD 1,170/1000 m³ in April 2022, while energy bills accounted for more than 25% of the income of one quarter of the population (Government Decision of the Republic of Moldova No. 86/2025). This situation necessitated a strategic rethinking of national energy security and placed local biomass sources, including *Miscanthus × giganteus*, at the centre of the debate on diversifying energy supply.

The National Integrated Energy and Climate Plan of the Republic of Moldova (NECP), approved by Government Decision No. 86/2025, establishes quantified targets for the period 2025–2030: a minimum share of 30% of energy from renewable sources in gross final energy consumption and a 68.5% reduction in greenhouse gas emissions compared with the 1990 reference-year level. The document is aligned with the National Biomass Programme 2024–2030, which provides for an estimated allocation of 3.8 billion EUR for the development of biomass-based value chains, as well as with access to the European Union's 2025–2027 Reform and Growth Facility, which makes approximately 1.9 billion EUR available for reform and investment projects compatible with European climate objectives (Government Decision of the Republic of Moldova No. 86/2025). Perennial energy crops such as *Miscanthus × giganteus* are among the solutions eligible for funding under these instruments, owing to their direct contribution to both NECP targets.

GOVERNMENT POLICY ALIGNMENT & FUNDING ELIGIBILITY		
NECP 2025-2030 (GD 86/2025)	RE target 30% by 2030 68.5% GHG reduction vs 1990	✓
Biomass Programme 2024-2030	EUR 3.8B infrastructure Local biomass market	✓
EU RED III Sustainability	Criteria met — ANSA pre-approved Boiler compatibility confirmed	✓
EBRD GEFF Moldova	Green Economy Facility EUR 2M Phase I eligible	✓
EU Reform Facility 2025-2027	EUR 1.9B total EUR 270M pre-financing released Jul 2025	✓
UNDP / GEF	Carbon verification grants Capacity building support	✓
ANRE Heat Tariff	EUR 35-45/MWh regulated 15-25% savings vs gas	✓
Verra VCS Carbon Market	PRIMARY stream EUR 10-28/t Immediate access — active	✓

Figure 2.1. Governmental Alignment & Funding Eligibility: 8 national and international programmes underpinning the Miscanthus BECCS Moldova project

A relevant aspect underpinning the strategic basis of this research is the fact that the authorities of the Republic of Moldova have included BECCS (Bioenergy with Carbon Capture and Storage) technologies in the deliberations of the Security Council on national energy security, recognising the potential of perennial energy crops to contribute simultaneously to reducing dependence on gas imports and achieving internationally committed climate objectives. The conclusions of government-level events on energy security emphasise the need to diversify local energy sources and reduce pressure on forest resources, in which context dedicated biomass produced on marginal agricultural land becomes a strategic resource for the national energy system (Government Decision of the Republic of Moldova No. 86/2025).

In this context, perennial energy crops have become a major area of interest in international research. Among these, *Miscanthus* × *giganteus* occupies a distinct position owing to its agrobiological, energetic and ecological performance. As a perennial species with C4 photosynthesis, *Miscanthus* efficiently utilises solar radiation and atmospheric carbon dioxide, exhibiting higher

photosynthetic efficiency than the majority of agricultural crops in the temperate zone. The biomass produced annually may exceed 15–25 tonnes of dry matter/ha under favourable cultivation conditions, while the economic lifespan of plantations may exceed two decades without re-establishment.

Numerous studies conducted in the United Kingdom, Germany, Denmark, Poland, Italy and the United States have demonstrated that *Miscanthus* requires low inputs of fertilisers and pesticides, has high water-use efficiency, and contributes to reducing soil erosion and improving organic matter content.

These experimental results, accumulated over more than three decades of European research, have been synthesised in numerous publications reviewed by scientific committees and in technical guidelines intended for farmers and investors, providing a solid knowledge base transferable to regions with similar soil and climatic conditions, such as the Republic of Moldova. The transfer of this knowledge to the local context, through a strengthened collaborative network involving British, Moldovan and Romanian institutions, constitutes one of the essential methodological premises of the present research. In addition, the deep root system promotes carbon accumulation in the soil, thereby transforming this crop into an important instrument for climate change mitigation and enhancing the resilience of agricultural ecosystems.

Miscanthus biomass exhibits favourable energy characteristics, such as high calorific value, low sulphur and ash content, and properties suitable for use in modern thermal and electrical energy generation facilities. At the same time, it can serve as feedstock for the manufacture of advanced biofuels, biochar, insulating materials, biocomposites, cellulose, paper, biodegradable packaging and other products characteristic of the circular bioeconomy.

In recent years, research has focused on the development of integrated value chains based on the biorefinery concept, in which the entire biomass is successively valorised to obtain several categories of products, thereby maximising economic efficiency and reducing the quantity of waste generated. In this model, *Miscanthus* cultivation represents not merely a source of renewable energy, but a multifunctional biological platform capable of supporting the development of innovative industrial sectors.

In the Republic of Moldova, the development of energy crops represents a strategic opportunity in the context of the need to diversify energy sources, reduce dependence on imported fuels and utilise agricultural land with low productivity. The existing soil and climatic conditions permit the cultivation of *Miscanthus* in numerous regions of the country, while experiences conducted in recent years

demonstrate the crop's capacity to adapt to local conditions and produce significant quantities of energy biomass.

At the same time, the Republic of Moldova has adopted ambitious objectives concerning the development of renewable energy, the reduction of greenhouse gas emissions, and the implementation of circular economy principles through the National Integrated Energy and Climate Plan (NECP), the Energy Strategy 2050, and other strategic documents aligned with European Union policies. Within this framework, *Miscanthus* cultivation may become one of the important components of the future national energy mix.

However, in the Republic of Moldova, research into the integrated use of *Miscanthus* within the circular bioeconomy remains limited. Most existing studies focus on cultivation technology or energy biomass production, while aspects concerning the integration of the complete value chain, the assessment of the impact on carbon capture, life-cycle analysis, the development of BECCS models, and the evaluation of economic and social benefits remain insufficiently investigated. In addition, the economic performance of commercial plantations under the specific conditions of the Republic of Moldova, as well as the integration of biomass into centralised heat-generation systems, remains poorly studied.

Based on these considerations, the present study aims to provide a scientific and techno-economic foundation for the use of *Miscanthus × giganteus* as an innovative technology for the development of a circular bioeconomy. The research focuses on assessing the agronomic, energy, economic and ecological potential of this crop; developing sustainable models for the production and utilisation of biomass; and integrating it into value chains capable of contributing to the energy security, carbon emission reductions and sustainable development of the Republic of Moldova.

The novelty of the study lies in the integrated approach to the *Miscanthus* crop, not merely as an energy species, but as a biological platform for a circular bioeconomy, in which biomass production, carbon capture, energy utilisation, the production of bioproducts and the use of residues are analysed as parts of a single, efficient and sustainable system. This approach enables the development of an innovative green economy model, adapted to the conditions of the Republic of Moldova and aligned with European objectives concerning climate neutrality, energy security and the sustainable use of biological resources.

Goal: assessment and demonstration of the potential of the *Miscanthus × giganteus* energy crop as an innovative technology for the development of a circular bioeconomy, through the sustainable

production of biomass, efficient utilisation of natural resources, reduction of greenhouse gas emissions, and integration of biomass into modern energy and bioproduct production systems.

The Objectives

1. Assessment of the agrobiological adaptability of *Miscanthus* × *giganteus* genotypes under the soil and climatic conditions of the Republic of Moldova and identification of optimal cultivation technologies.
2. Development and optimisation of technologies for establishing and managing multiannual *Miscanthus* plantations to achieve stable and sustainable biomass production.
3. Determination of biomass productivity and quality, including assessment of energy yield, physicochemical properties, and potential for use in the energy and industrial sectors.
4. Evaluation of the contribution of *Miscanthus* cultivation to carbon capture and storage, quantification of the reduction in greenhouse gas emissions, and analysis of the potential for integration into BECCS-type systems (Bioenergy with Carbon Capture and Storage).
5. Analysis of the techno-economic feasibility of the *Miscanthus*-based value chain, including the production of planting material, cultivation, harvesting, logistics, processing and utilisation of the biomass.
6. Assessment of the impact on the circular bioeconomy through the full utilisation of biomass and by-products for the production of energy, bioeconomic materials, biofertilisers and other value-added bioproducts.
7. Estimation of the environmental, economic and social benefits generated by the implementation of *Miscanthus* cultivation, including job creation, rural economic development and the strengthening of energy security.
8. Development of an integrated circular bioeconomy model based on *Miscanthus* cultivation, enabling the efficient utilisation of biomass, the reduction of dependence on fossil fuels, and alignment with the objectives of the European Green Deal and national strategies concerning renewable energy and the circular economy.

The structure of this thesis reflects an integrated methodological approach, combining an in-depth review of the international scientific literature on *Miscanthus* × *giganteus*, the substantiation of the elements of novelty and the research hypothesis, a description of the original experimental methodology, the presentation of the results in the form of a techno-economic feasibility study for a specific 100-2.000 ha project, a detailed business plan for the vertical integration of the value chain, an analysis of risks and environmental impacts, an implementation schedule and, finally, conclusions and

strategic recommendations. This structure enables a progressive transition from general scientific foundations to immediate practical applicability for a real investment project in the Republic of Moldova.

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