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CHARACTERIZATION OF THE ENERGY POTENTIAL AND EMISSION PROPERTIES OF *SIDA HERMAPHRODITA*

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Abstract

Perennial industrial crops represent an important renewable resource for sustainable bioenergy production, providing high biomass yields with lower environmental impacts compared to conventional annual crops. *Sida hermaphrodita* (Virginia mallow) has attracted increasing attention as a promising biomass feedstock due to its high productivity, adaptability to diverse climatic and soil conditions, and ability to grow on marginal or degraded lands.

This study evaluates the energy potential and emission-related properties of *Sida hermaphrodita* biomass to assess its suitability for combustion-based bioenergy applications. Proximate and ultimate analyses were performed to determine moisture, ash, volatile matter, fixed carbon, and elemental composition (C, H, N, S, O). Higher and lower heating values (HHV and LHV) were measured using standard calorimetric methods. Emission factors for CO, CO₂, NO_x, SO₂, and particulate matter were estimated based on the physicochemical characteristics of the biomass.

The results indicate that *Sida hermaphrodita* exhibits favorable fuel properties, including satisfactory heating values and low ash content. The low nitrogen and sulfur concentrations suggest reduced NO_x and SO₂ emissions during combustion, while heavy metal contents in the ash remain below internationally accepted limits.

Overall, the findings confirm that *Sida hermaphrodita* represents an efficient, low-emission, and environmentally sustainable biomass source with strong potential for renewable energy production.

Keywords: *Sida hermaphrodita*, biomass characterization, energy crops, emission factors, calorific value, renewable energy

INTRODUCTION

In line with the objectives of the 2030 Climate and Energy Policy Framework, the Paris Agreement (COP 21), the ILUC Directive, and the Renewable Energy Directive (RED II) (EC Commission, 2010; EC Communication, 2014; COM, 2016; Paris Agreement, FCCC/CP/2015/, 2018), biomass and biofuels represent vital

components in Europe's transition toward a low-carbon and energy-independent society. Replacing fossil fuels with bioenergy offers both climate mitigation benefits and opportunities for rural development (Zhou & Thomson, 2009).

Thermochemical conversion processes are among the most widely used methods for utilizing biomass from dedicated energy crops and agricultural residues (Tanger et al., 2013). These technologies are generally considered environmentally friendly and support sustainable resource utilization (Mladenovic et al., 2017). For efficient application in energy systems, detailed knowledge of the biomass supply potential and fuel characteristics is required (Kumar et al., 2010).

Fuel properties - such as elemental composition, heating value, moisture content, volatile matter, and ash content - play a critical role in determining combustion efficiency and environmental performance (Barglowicz, 2014; Alvarez-Alvarez et al., 2018). Biomass quality is strongly influenced by plant genetics, environmental conditions, soil fertility, and harvest time.

Perennial energy crops are considered among the most promising biomass feedstocks due to their high productivity, low input requirements, and ability to be cultivated on marginal land (Demirbas, 2017). Among them, *Sida hermaphrodita* stands out for its high regrowth capacity, drought tolerance, and suitability for various soil types.

Originating from North America, *Sida hermaphrodita* was introduced to Europe in the 1930s and is currently cultivated across Central Europe for research and energy production purposes (Borkowska & Molas, 2012). The species produces tall, woody-herbaceous stems suitable for direct combustion and pellet production. Previous studies have highlighted its high calorific value, favorable chemical composition, and potential for phytoremediation of contaminated soils (Borkowska & Wardzinska, 2003; Borkowska, 2007; Tworkowski et al. 2014).

The aim of this study is to evaluate the energy potential of *Sida hermaphrodita*, focusing on fuel quality and emission performance, to assess its feasibility as a renewable energy crop for combustion applications.

MATERIALS AND METHODS

Field Experiment

Field trials were established using a randomized block design with four replications. Each plot measured 100 m². Seedlings were planted in May at a spacing of 0.75 m between and within rows. Biomass samples (three plants per replicate) were collected in mid-November prior to frost.

Sample Preparation

Plant material was dried at 105°C to constant mass and ground using a laboratory mill. Moisture, ash, and volatile matter were determined according to EN standards (BDS EN ISO 18134-3, 2015; BDS EN ISO 18122, 2015; BDS EN ISO 18123, 2015). Heating value (HHV) was measured following EN ISO 18125 (IKA C6000 calorimeter) (BDS EN ISO 18125, 2017). Total carbon, hydrogen, nitrogen, and sulphur contents were determined by dry combustion using a Vario Macro CHNS analyzer (Elementar GmbH, Germany) (BDS EN ISO 16948, 2015).

Emission Factor Calculations

Emission factors for CO, CO₂, CH₄, NO_x, SO₂, and particulate matter were calculated using standard stoichiometric equations (1–7) described in the methodology section (Borycka, 2008). The calculations were based on the elemental composition of the biomass (C, H, N, S, O) and incorporated oxidation coefficients, molar mass ratios, and ash release factors. For reference, equivalent emission factors for coal were also included to provide a comparative assessment of combustion performance.

CO emission factor

$$CO = \frac{28}{12} \times Ec \times (C_CO/C) \quad (1)$$

where: CO – Carbon monoxide emission factor (kg/kg); 28/12 – Molar mass ratio of carbon monoxide to carbon; Ec – Emission factor of chemically pure coal (kg/kg); C_CO/C – Proportion of carbon emitted as CO (for biomass: 0.06).

Emission factor of chemically pure coal

$$Ec = c \cdot uc \quad (2)$$

where: c – Carbon content in biomass (kg/kg); uc – Proportion of carbon oxidized during combustion (for biomass: 0.88).

CO₂ emission factor

$$CO_2 = \frac{44}{12} \times (Ec - \frac{12}{28} \times CO - \frac{12}{16} \times ECH_4 - \frac{26.4}{31.4} \times ENMVOC) \quad (3)$$

where: CO₂ – Carbon dioxide emission factor (kg/kg); 44/12 – Molar mass ratio of carbon dioxide to pure coal; 12/28 – Molar mass ratio of carbon to carbon monoxide; 12/16 – Molar mass ratio of carbon to methane; ECH₄ – Methane emission factor; ENMVOC – Non-methane VOC emission index (for biomass: 0.009).

Methane emission factor:

$$ECH_4 = \frac{16}{12} \times Ec \times (C_CH_4/C) \quad (4)$$

where: ECH₄ – Methane emission factor (kg/kg); 16/12 – Molar mass ratio of methane to carbon; C_CH₄/C – Proportion of carbon emitted as CH₄ (for biomass: 0.005).

NO_x emission factor

$$NO_x = \frac{46}{14} \times Ec \times N/C \times (N_NO_x/N) \quad (5)$$

where: NO_x – Emission factor for nitrogen oxides (kg/kg); 46/14 – Molar mass ratio of nitrogen dioxide to nitrogen (NO in air oxidizes to NO₂); N/C – Nitrogen to carbon ratio in biomass; N_NO_x/N – Proportion of nitrogen released as NO_x (for biomass: 0.122).

Emission factor of SO₂

$$SO_2 = \frac{2S}{100} \quad (6)$$

where: SO₂ – Sulfur dioxide emission factor (kg/kg); 2 – Molar mass ratio of SO₂ to sulfur; S – Sulfur content in the fuel (%).

Dust emissions:

$$Edust = 1,5 \times A \times \frac{100 - \eta_0}{100 - k} \quad (7)$$

where: E_{dust} – Dust emission factor (kg/Mg); 1.5 – Coefficient denoting 15% of ash released as volatile dust; A – Ash content in the fuel (%); η_0 – Dust removal efficiency (for biomass: 20%); k – Combustible component content in the dust (for biomass: 5%).

RESULTS AND DISCUSSION

Proximate Analysis

Table 1 shows that the moisture content of the November-harvested *Sida hermaphrodita* biomass was 7.4%, fully meeting the EN ISO 17225-6 requirement for non-wood pellets ($\leq 12\%$). Moisture content is a key parameter determining biomass quality for combustion and is strongly influenced by harvest time. Previous studies have reported moisture values ranging from 6.9% to 32.2% (Stolarski et al., 2014; Stolarski et al., 2018; Zachar et al., 2018; von Gehren et al., 2019; Jankowski et al., 2019). It is generally recommended that stems intended for combustion be harvested after late September or in early spring (Siaudinis et al., 2015), as natural field drying during winter reduces moisture from 28–40% in November to 14–20% in February–March (Bilandzija et al., 2018), thereby lowering drying costs.

Ash content reached 6.53%, which falls within the acceptable range for non-wood pellets (6–10%). High ash content may reduce combustion efficiency, but the measured values are comparable to or better than those reported in previous studies. Fixed carbon content was 14.27%, contributing positively to fuel quality. Volatile matter was high (79.2%), consistent with typical biomass values (75–90%) (Garcia et al., 2012). The lower heating value (LHV) reached 17.02 MJ/kg, exceeding the EN ISO 17225-6 minimum requirement (≥ 14.5 MJ/kg) and aligning with literature data (14–17.7 MJ/kg) (Borkowska et al., 2009; Wroblewska et al., 2009; Szyszlak-Barglowicz et al., 2012; Siaudinis et al., 2017; Jablonowski et al., 2017).

Overall, the proximate and ultimate analysis results presented in Tables 1 and 2 confirm that the biomass harvested in late autumn exhibits favorable characteristics for direct combustion, comparable to biomass produced in other countries and compliant with international solid fuel standards.

Table 1. Proximate analyses and lower heating value of *Sida hermaphrodita* biomass

Parameter	Moisture, %	Ash, %	FC, %	VM, %	LHV, MJ/kg
Sida	7.4	6.53	14.27	79.2	17.02
Reference	6.9-32.2	1.57-6.07	9.28	77.45	14.0-17.7
Standard	≤ 12	≤ 6	-	-	≥ 14.5

Ultimate Analysis

The ultimate analysis of *Sida hermaphrodita* biomass confirmed that its elemental composition falls within the typical ranges reported for this species. The carbon content (45.9%) corresponds well to literature values (44.1–48.5%) [33–37], while the hydrogen content (5.7%) is also consistent with previously published findings (5.9–7.22%). The oxygen level (46.03%) indicates good combustibility, as oxygen-rich biomass tends to burn efficiently.

Nitrogen (0.658%) and sulfur (0.0909%) were low and below the maximum allowable limits specified for solid fuels, indicating a reduced potential for NO_x and SO₂ formation during combustion. The chlorine content (0.156%) was slightly above the EN ISO 17225-6 threshold (<0.1%) but remained comparable to values observed in similar biomass materials grown under various soil conditions.

Ash content is a key indicator of biomass quality because ash has no calorific value and negatively affects combustion efficiency. The measured ash content of 6.53% complies with the EN ISO 17225-6 standard for non-wood pellets (6–10%). Similar values were reported for biomass harvested in autumn (Siaudinis et al., 2015). The fixed carbon reached 14.27%, further contributing to the heating value and burn stability of the fuel.

Volatile matter content, which typically ranges between 75% and 90% for lignocellulosic biomass (Garcia et al., 2012), reached 79.2%, aligning well with expected values. The lower heating value (LHV) of 17.02 MJ/kg exceeds the minimum requirement for solid biofuels (14.5 MJ/kg) and corresponds to previously published ranges for *Sida hermaphrodita* (14.0–17.7 MJ/kg) [29–32]. Studies have shown that harvest timing can influence energy parameters; for example, Franzaring et al. (2015) observed a decrease in LHV from 17.4 to 15.8 MJ/kg when stems were harvested in early December rather than mid-April.

Carbon is the most important element determining fuel quality, and its consistent concentration across studies highlights the species' stability as an energy crop. Reported values typically range from 44.10% to 48.5% (Wroblewska et al., 2009; Werle, 2019; von Gehren et al., 2019; Jablonowski et al., 2020), closely matching the value obtained in this study (45.9%). Hydrogen levels were similarly consistent, and the calculated oxygen fraction aligns with the literature range (41.96–45.80%).

From an environmental perspective, low nitrogen and sulfur contents are highly desirable, as they reduce the formation of harmful gaseous emissions. The measured values are comparable to those in other studies (0.14–0.75% N; 0.003–0.23% S). Although chlorine content (0.156%) exceeded the recommended limit (Table 2), it remained within the range reported for this species, particularly under conditions of soil contamination or nutrient variation.

Table 2. Ultimate analysis of *Sida hermaphrodita* biomass

	N, %	C, %	S, %	H, %	O, %	Cl, %
Sida	0.658	45.9	0.0909	5.7	46.03	0.156
Reference	0.14-0.75	44.10-48.5	0.003-0.23	5.9-7.22	41.96-48.5	0.005-0.054
Standard	≤1.5	-	≤0.2	-	-	≤0.1

Previous research (Stolarski et al., 2014; Bilandzija et al., 2018) indicates that spring-harvested biomass often contains lower moisture, ash, and sulfur levels, resulting in improved combustion characteristics. However, the biomass harvested in late November in the present study still demonstrates high quality—characterized by elevated carbon and hydrogen levels and low concentrations of ash, nitrogen, sulfur, and chlorine—making it suitable for direct combustion.

Overall, the results confirm that *Sida hermaphrodita* biomass harvested in late autumn exhibits excellent fuel properties and strong energy potential, positioning it as a promising perennial crop for sustainable bioenergy production.

Emission Factors

Table 3 presents the emission factors for carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfur dioxide (SO₂), and particulate matter (dust) obtained from the combustion of *Sida hermaphrodita* biomass, with coal used as a reference fuel. The results clearly demonstrate the environmental advantages of this species as a bioenergy feedstock.

Table 3. Emission factors (kg/Mg) for analysed plant and coal

	CO	CO ₂	NO _x	SO ₂	Edust
Sida	56.55	1480.76	0.23	0.12	8.25
Hard coal	82.01	1969.00	4.09	5.20	23.57

The emission factors show that SO₂ emissions were very low, consistent with the low sulfur content measured in the biomass. NO_x emissions were significantly lower than those typically reported for straw pellets, sunflower stalks, corn stalks, and wood pellets (Krugly et al., 2014), as well as *Eucalyptus globulus* (Mateos & Ormaetxea, 2019). CO and CO₂ emissions were comparable to those observed for mint waste (Maj et al., 2020), larch needles (Maj, 2018), and hazelnut biomass (Maj, 2018; Borkowska et al., 2024), indicating clean and stable combustion behavior. Dust emissions were considerably lower than those associated with coal, highlighting the superior air-quality performance of the biomass.

The overall emission profile of *Sida hermaphrodita* aligns closely with other herbaceous and woody plant-based fuels such as mint waste (Maj et al., 2020), *Eucalyptus globulus* (Mateos & Ormaetxea, 2019), and larch needles (Maj, 2018). Notably, the low SO₂ and NO_x values confirm the low environmental burden associated with the combustion of this species, while the moderate CO and CO₂ emissions are typical for well-performing lignocellulosic fuels.

These findings clearly indicate that *Sida hermaphrodita* is a cleaner-burning fuel compared with conventional solid biomass sources and dramatically cleaner than fossil fuels. In addition, the methodology used for emission factor determination provides an efficient and accessible approach for environmental assessment. Because it does not require advanced analytical instrumentation, this method serves as a practical tool for rapid evaluation of biofuel emissivity—an important but often overlooked aspect of biomass suitability for energy use.

CONCLUSIONS

1. *Sida hermaphrodita* biomass harvested in late autumn exhibits excellent fuel characteristics, including low moisture content, moderate ash percentage, and high carbon and hydrogen levels.
2. The obtained lower heating value (17.02 MJ/kg) confirms the crop's strong energy potential, comparable to other leading perennial biomass species.
3. Low nitrogen and sulfur contents result in reduced emissions of NO_x and SO₂, supporting environmentally sustainable combustion.

4. Estimated emission factors indicate that *Sida hermaphrodita* produces significantly fewer pollutants than coal and performs competitively with other herbaceous biomass sources.

5. The species demonstrates high suitability for renewable energy production, especially within sustainable agriculture systems and bioeconomy strategies.

6. *Sida hermaphrodita* can be recommended as a dual-purpose crop for both biomass energy and potential phytoremediation applications, enhancing land-use efficiency and contributing to circular economy models.

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REFERENCES

- Alvarez-Alvarez, P., Pizarro, C., Barrio-Anta, M., Cámara-Obregón, A., Bueno, J.L.M., Alvarez, A., Gutiérrez, I., & Burslem, D.F. (2018). Evaluation of Tree Species for Biomass Energy Production in Northwest Spain. *Forests*, 9,160.
- Barglowicz, J. (2014). Content of chosen macroelements in biomass of Virginia mallow (*Sida hermaphrodita* Rusby). *J. Cent. Eur. Agric.*, 15.
- BDS EN ISO 16948 (2015). Solid biofuels. Determination of total content of carbon, hydrogen and nitrogen.
- BDS EN ISO 18122 (2015). Solid biofuels. Determination of ash content.
- BDS EN ISO 18123 (2015). Solid biofuels. Determination of the content of volatile matter.
- BDS EN ISO 18123 (2015). Solid biofuels. Determination of the content of volatile matter.
- BDS EN ISO 18125 (2017). Solid biofuels. Determination of calorific value.
- BDS EN ISO 18134-3 (2015). Solid biofuels. Determination of moisture content. Oven dry method. Moisture in general analysis sample.
- Bilandzija, N., Kricka, T., Matin, A., Leto, J., Grubor, M. (2018). Effect of harvest season on the fuel properties of *Sida hermaphrodita* (L.) Rusby biomass as solid biofuel. *Energies*, 11, 3398.
- Borkowska A., Klimek, K.E., Maj, G., & Kapłan, M. (2024). *Energies*, 17, 3899.
- Borkowska, H. & Molas, R. (2012). Two extremely different crops, *Salix* and *Sida*, as sources of renewable bioenergy. *Biomass Bioenergy*, 36, 234–240.
- Borkowska, H. & Wardzinska, K. (2003). Some effects of *Sida hermaphrodita* R. cultivation on sewage sludge. *Pol. J. Environ. Stud.*, 10, 119–122.
- Borkowska, H. (2007). Yields of Virginia fanpetals and willow on good wheat soil complex. *Fragm. Agron.*, 2, 7–41.
- Borkowska, H., Molas, R., & Kupczyk, A. (2009). Virginia fanpetals (*Sida hermaphrodita* Rusby) cultivated on light soil; height of yield and biomass productivity. *Polish J Environ Stud.*, 18(4), 563–568.

- COM (2016) 767 Final/2 Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources (Recast); European Commission: Brussels, Belgium, 2017.
- Demirbas, A. (2017). Higher heating values of lignin types from wood and non-wood lignocellulosic biomasses. *Energy Sources Part A*, 39, 592–598.
- EC. Communication (2014) 0015 from the Commission to the European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions. A Policy Framework for Climate and Energy in the Period from 2020 to 2030, COM/2014/015 Final. Available online: <https://www.eea.europa.eu/policy-documents/com-2014-15-final> (accessed on 22 November 2018).
- EC. Report from the Commission on Indirect Land-Use Change Related to Biofuels and Bioliquids; European Commission: Brussels, Belgium, 2010.
- EN ISO 17225-6. Solid biofuels. Fuel specifications and classes. Part 6: Graded non-woody pellets (2014).
- Franzaring, J., Holz, I., Kauf, Z., & Fangmeier, A. (2015). Responses of the novel bioenergy plant species *Sida hermaphrodita* (L.) Rusby and *Sida* L. to CO₂ fertilization at different temperatures and water supply. *Biomass and Bioenergy*, 81, 574–583.
- Garcia, R., Pizarro, C., Lavín, A.G., & Bueno, J.L. (2012). Characterization of Spanish biomass wastes for energy use. *Biore. Technol.*, 103 (1), 249–258.
- Jablonowski, N. D., Kollmann, T., Nabel, M., Damm, T., Klose, H., Müller, M. & Schurr, U. (2017). Valorization of *Sida* (*Sida hermaphrodita*) biomass for multiple energy purposes, *GCB Bioenergy*, 9(1). 202–214.
- Jablonowski, N.D., Kollmann, T., Meiller, M., Dohrn, M., Müller, M., Nabel, M., Zapp, P., Schonhoff, A. & Schrey, S.D. (2020). Full assessment of *Sida* (*Sida hermaphrodita*) biomass as a solid fuel, *GCB Bioenergy*, 12, 618–635.
- Jankowski, K.J., Dubis, B., Sokolski, M.M., Zaluski, D., Borawski, P., & Szemplinski, W. (2019). Biomass yield and energy balance of Virginia fanpetals in different production technologies in north-eastern Poland. *Energy*, 185, 612–623.
- Krugly, E., Martuzevicius, D., Puida, E., Buinevicius, K., Stasiulaitiene, I., Radziuniene, I., Minikauskas, A., Kliucininkas, L. (2014). Characterization of Gaseous- and Particle-Phase Emissions from the Combustion of Biomass-Residue-Derived Fuels in a Small Residential Boiler. *Energy Fuel*, 28, 5057–5066.
- Kumar, R., Pandey, K.K., Chandrashekar, N., & Mohan, S. (2010) Effect of tree-age on calorific value and other fuel properties of Eucalyptus hybrid. *J. For. Res.*, 21, 514–516.
- Maj, G. Najda, A., Klimek, K., Balant, S. (2020). Estimation of Energy and Emissions Properties of Waste from Various Species of Mint in the Herbal Products Industry. *Energies*, 13, 55.
- Maj, G. (2018). Emission Factors and Energy Properties of Agro and Forest Biomass in Aspect of Sustainability of Energy. *Energies*, 11, 1516.
- Mateos, A. & Ormaetxea, L. (2019). Sustainable Renewable Energy by Means of Using Residual Forest Biomass. *Energies*, 12, 13.

- Mladenovic, M., Paprika, M., & Marinkovic, A. (2017). Denitrification techniques for biomass combustion. *Renew. Sustain. Energy Rev.*, 82, 3350–3364.
- Paris Agreement, FCCC/CP/2015/L.9/Rev.1. <https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf> (accessed on 3 December 2018).
- Siaudinis, G., Jasinskas, A., Sarauskis, E., Steponavicius, D., Karcauskiene, D., & Liaudanskiene, I. (2015). The assessment of *Sida hermaphrodita* (*Sida hermaphrodita* Rusby) and cup plant (*Silphium perfoliatum* L.) productivity, physico-mechanical properties and energy expenses, *Energy*, 9, 606–612.
- Siaudinis, G., Skuodiene, R., & Repsiene, R. (2017). The investigation of three potential energy crops: Common mugwort, cup plant and *Sida hermaphrodita* on Western Lithuania's albeluvisol, *Applied Ecology and Environmental Research*, 15(3), 611–620.
- Stolarski, M. J., Krzyzaniak, M., Śnieg, M., Stomińska, E., Piorkowski, M., & Filipkowski, R. (2014). Thermophysical and chemical properties of perennial energy crops depending on harvest period. *International Agrophysics*, 28(2), 201–211.
- Stolarski, M.J., Śnieg, M., Krzyzaniak, M., Tworkowski, J., Szczukowski, S., Graban, Ł., & Lajszner, W. (2018). Short rotation coppices, grasses and other herbaceous crops: Biomass properties versus 26 genotypes and harvest tim. *Ind. Crops Prod.*, 119, 22–32.
- Szyszlak-Bargłowicz, J., Zajac, G., & Piekarski, W. (2012). Energy biomass characteristics of chosen plants. *International Agrophysics*, 26(2), 175–179.
- Tanger, P., Field, J.L., Jahn, C.E., DeFoort, M.W., & Leach, J.E. (2013). Biomass for thermochemical conversion: Targets and challenges. *Front. Plant. Sci.*, 4, 218.
- Tworkowski, J., Szczukowski, S., Stolarski, M.J., Kwiatkowski, J., & Graban, Ł. (2014). Productivity and properties of Virginia fanpetals biomass as fuel depending on the propagule and plant density. *Fragm. Agron*, 3, 115–125.
- von Gehren, P., Gansberger, M., Pichler, W., Weigl, M., Feldmeier, S., Wopienka, E., & Bochmann, G. (2019). A practical field trial to assess the potential of *Sida hermaphrodita* as a versatile, perennial bioenergy crop for Central Europe. *Biomass and Bioenergy*, 122, 99–108.
- Werle, S., Khanh-Quang, T., Magdziarz, A., Sobek, S., Pogrzeba, M., & Løvas, T. (2019). Energy crops for sustainable phytoremediation—Fuel characterization. *Energy Procedia*, 158, 867–872.
- Wroblewska, H., Komorowicz, M., Pawłowski, J., & Cichy, W. (2009). Chemical and energetical properties of selected lignocellulosic raw materials. *Folia Forestalia Polonica*, 40, 67–78.
- Zachar, M., Lieskovsky, M., Majlingová, A., & Mitterová, I. (2018). Comparison of thermal properties of the fast-growing tree species and energy crop species to be used as a renewable and energy-efficient resource. *J. Therm. Anal. Calorim.*, 134, 543–548.
- Zhou, A. & Thomson, E. (2009). The development of biofuels in Asia. *Appl. Energy*, 86, 11–20.