



Synthesis :: Materials :: Corrosion :: Environment :: Energy

YuCorr

Analyse :: Discover :: Coat :: Green :: Protect :: Save :: Sustain

INTERNATIONAL CONFERENCE
MEĐUNARODNA KONFERENCIJA

MEETING POINT OF THE SCIENCE AND PRACTICE IN THE FIELDS OF
CORROSION, MATERIALS AND ENVIRONMENTAL PROTECTION

*STECIŠTE NAUKE I PRAKSE U OBLASTIMA KOROZIJE,
ZAŠTITE MATERIJALA I ŽIVOTNE SREDINE*

PROCEEDINGS

KNJIGA RADOVA

Under the auspices of the
MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL
DEVELOPMENT OF THE REPUBLIC OF SERBIA

Pod pokroviteljstvom
MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA
REPUBLIKE SRBIJE

May 16-19, 2022 :: Divčibare, Serbia

CIP - Каталогizacija u publikaciji
Narodna biblioteka Srbije, Beograd

620.193/.197(082)(0.034.2)
621.793/.795(082)(0.034.2)
667.6(082)(0.034.2)
502/504(082)(0.034.2)
66.017/.018(082)(0.034.2)

INTERNATIONAL Conference YUCORR (23 ; 2022 ; Divčibare)

Meeting point of the science and practice in the fields of corrosion, materials and environmental protection [Elektronski izvor] : proceedings = Stečište nauke i prakse u oblastima korozije, zaštite materijala i životne sredine : knjiga radova / XXIII YuCorr International Conference = XXIII YuCorr [Jugoslovenska korozija] Međunarodna konferencija, May 16-19, 2022, Divčibare, Serbia = [organized by] Serbian Society of Corrosion and Materials Protection ... [et al.]; [organizatori Udruženje inženjera Srbije za koroziju i zaštitu materijala ... [et al.]; [editors, urednici Miroslav Pavlović, Marijana Pantović Pavlović, Miomir Pavlović]. - Beograd : Serbian Society of Corrosion and Materials Protection UISKOZAM : Udruženje inženjera Srbije za koroziju i zaštitu materijala UISKOZAM, 2022 (Beograd : Serbian Society of Corrosion and Materials Protection UISKOZAM : Udruženje inženjera Srbije za koroziju i zaštitu materijala UISKOZAM). - 1 elektronski optički disk (CD-ROM) ; 12 cm
Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Radovi na engl. i srp. jeziku. - Tiraž 200. - Bibliografija uz većinu radova. - Abstracts.

ISBN 978-86-82343-29-5

a) Премази, антикорозиони -- Зборници б) Превлаке, антикорозионе -- Зборници в)
Антикорозиона заштита -- Зборници г) Животна средина -- Заштита -- Зборници д) Наука о
материјалима -- Зборници
COBISS.SR-ID 68624905

XXIII YUCORR – International Conference | Međunarodna konferencija

PUBLISHED AND CD BURNED BY | IZDAVAČ I NAREZIVANJE CD

SERBIAN SOCIETY OF CORROSION AND MATERIALS PROTECTION (UISKOZAM)

UDRUŽENJE INŽENJERA SRBIJE ZA KORZIJU I ZAŠTITU MATERIJALA (UISKOZAM),

Kneza Miloša 7a/II, 11000 Beograd, Srbija, tel/fax: +381 11 3230 028, office@sitzam.org.rs; www.sitzam.org.rs

FOR PUBLISHER | ZA IZDAVAČA Prof. dr MIOMIR PAVLOVIĆ, predsednik UISKOZAM

SCIENTIFIC COMMITTEE | NAUČNI ODBOR: Prof. dr M. G. Pavlović, Serbia – President

Prof. dr Đ. Vaštag, Serbia; Dr M. M. Pavlović, Serbia; Prof. dr D. Vuksanović, Montenegro;
Prof. dr D. Čamovska, North Macedonia; Prof. dr M. Antonijević, Serbia; Prof. dr S. Stopić, Germany;
Prof. dr R. Zejnilović, Montenegro; Prof. dr L. Vrsalović, Croatia; Dr N. Nikolić, Serbia;
Dr I. Krastev, Bulgaria; Prof. dr B. Grgur, Serbia; Prof. dr M. Gvozdrenović, Serbia;
Prof. dr S. Hadži Jordanov, North Macedonia; Prof. dr R. Fuchs Godec, Slovenia;
Prof. dr J. Stevanović, Serbia; Dr V. Panić, Serbia; Dr M. Mihailović, Serbia;
Prof. dr V. Marić, Bosnia and Herzegovina; Prof. dr J. Jovičević, Serbia; Prof. dr D. Jevtić, Serbia;
Dr F. Kokalj, Slovenia; Prof. dr M. Gligorić, Bosnia and Herzegovina; Prof. dr A. Kowal, Poland;
Prof. dr M. Tomić, Bosnia and Herzegovina; Prof. Dr B. Arsenović, Bosnia and Herzegovina

ORGANIZING COMMITTEE | ORGANIZACIONI ODBOR: Dr Miroslav Pavlović – president

Dr Nebojša Nikolić – vice president; Dr Marija Mihailović – vice president

Prof. dr Miomir Pavlović; Dr Vladimir Panić; Jelena Slepčević, B.Sc.;
Prof. dr Milica Gvozdrenović; Zagorka Bešić, B.Sc.; Gordana Miljević, B.Sc.;
Miomirka Anđić, B.Sc.; Dr Marija Matić; Dr Marijana Pantović Pavlović; Dr Dragana Pavlović;
Dr Sanja Stevanović; Lela Mladenović – secretary

EDITORS | UREDNICI: Dr Miroslav Pavlović, Dr Marijana Pantović Pavlović, Prof. dr Miomir Pavlović

SCIENTIFIC AREA | OBLAST: CORROSION AND MATERIALS PROTECTION | KORROZIJA I ZAŠTITA MATERIJALA

PAGE LAYOUT | KOMPJUTERSKA OBRADA I SLOG: Dr Marijana Pantović Pavlović

CIRCULATION | TIRAŽ: 200 copies | primeraka

PUBLICATION YEAR | GODINA IZDANJA: 2022

ISBN 978-86-82343-29-5



Ovaj PDF fajl sadrži elektronsku Knjigu radova prezentovanih u okviru Međunarodne konferencije **XXIII YuCorr**. U knjizi su **plavom bojom** obeleženi aktivni linkovi ka pojedinim njenim delovima, iz Sadržaja do naznačenih stranica.

This PDF file contains Proceedings presented on the **XXIII YuCorr** International Conference. It can be easily navigated through the book contents by a single click on the appropriate links in Contents (**showed in blue**).

Autori snose punu odgovornost za sadržaj, originalnost, jezik i gramatičku korektnost sopstvenih radova.

Authors bear full responsibility for the content, originality, language and grammatical correctness of their own works.

**XXIII YUCORR IS ORGANIZED BY
*ORGANIZATORI XXIII YUCORR-a***



SERBIAN SOCIETY OF CORROSION AND MATERIALS PROTECTION

Udruženje Inženjera Srbije za Koroziju i Zaštitu Materijala



**INSTITUTE OF CHEMISTRY, TECHNOLOGY AND METALLURGY,
UNIVERSITY OF BELGRADE**

*Institut za Hemiju, Tehnologiju i Metalurgiju,
Univerzitet u Beogradu*



UNION OF ENGINEERS AND TECHNICIANS OF SERBIA, BELGRADE

Savez Inženjera i Tehničara Srbije



ENGINEERING ACADEMY OF SERBIA

Inženjerska Akademija Srbije

**XXIII YUCORR IS ORGANIZED UNDER THE AUSPICES OF THE
MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL
DEVELOPMENT OF THE REPUBLIC OF SERBIA**



***XXIII YUCORR JE FINANSIJSKI POMOGLO
MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA
REPUBLIKE SRBIJE***

SPONSORS | SPONZORI

INTERNATIONAL SOCIETY OF ELECTROCHEMISTRY, Switzerland

SAVEZ INŽENJERA I TEHNIČARA SRBIJE, Beograd

INŽENJERSKA KOMORA SRBIJE, Beograd

HELIOS SRBIJA a.d., Gornji Milanovac

METAL CINKARA d.o.o., Inđija

SURTEC ČAČAK d.o.o., Čačak

ALFATERM d.o.o., Čačak

INSTITUT ZA PREVENTIVU d.o.o., Novi Sad

EKP ELKER a.d., Prijedor, Republika Srpska, B&H

EKO ZAŠTITA d.o.o., Bijeljina, Republika Srpska, B&H

IPIN d.o.o., Bijeljina Republika Srpska, B&H

HEMIPRODUKT d.o.o., Novi Sad

INSTITUT ZA OPŠTU I FIZIČKU HEMIJU, Beograd

SZR "GALVA", Kragujevac

NOVOHEM d.o.o., Šabac

Table of Contents

PLENARY LECTURES	1
Obtaining the new substance from waste blood biohazard for the treatment of anemia in piglets <i>Održivi razvoj u saniranju biohazarda na primeru otpadne klanične krvi</i> Branko Bugarski^{1,*}, Vesna Ilić², Ivana Drvenica², Stefan A. Bošković³, Radoslava Stojanović¹	2
Immune System as a Target of Xenobiotics Toxicity <i>Imunski sistem kao meta toksičnog delovanja ksenobiotika</i> Ivana Mirkov^{1,*}, Aleksandra Popov Aleksandrov¹, Dina Tucović¹, Jelena Kulaš¹, Dušanka Popović¹, Anastasija Malešević¹, Milena Kataranovski¹	7
Probing and Modelling the Relaxation Processes in "filled" and "empty" Lead-Free Electroceramic Materials Andrei Rotaru^{1-4*}, Jason A. McNulty³, Michael A. Carpenter⁴, Finlay D. Morrison³	14
Consideration of Energy Flows in the Life Cycle of Energy Production from Biogas <i>Razmatranje energetske tokova u životnom ciklusu proizvodnje energije iz biogasa</i> Slobodan Cvetković^{1*}, Mina Popović¹, Jovana Perendija¹	16
CFD analysis of Renewable Solid Fuel Combustion <i>CFD analiza sagorevanja obnovljivih čvrstih goriva</i> Filip Kokalj^{1,*}, Niko Samec¹	25
Traditional and new approaches in metal corrosion protection <i>Tradicionalni i novi pristupi u zaštiti metala od korozije</i> Đeđi Vaštag	35
INVITED LECTURES	36
Chemocompatibility of fluorapatite-based antibacterial nanophosphorus prepared by precipitation method for biomedical applications <i>Hemokompatibilnost antibakterijskih nanofosfora na bazi fluorapatita pripremljenog metodom precipitacije za biomedicinsku primenu</i> Dusan Milojkovic^{1,*}, Vaso Manojlovic², Branislav Nastasijevic³, Miroslav Sokic¹	37
Ecologically friendly corrosion inhibitor for low alloy steels and aluminium alloys <i>Ekološki prihvatljiv inhibitor korozije za nisko legirane čelike i aluminijumske legure</i> Bojana Radojković^{1,*}, Dunja Marunkić¹, Jovanka Pejić¹, Milena Milošević¹, Bore Jegdić¹, Aleksandar Marinković²	43
Extraction of novel exopolysaccharide as potential biosorbent for removal of Ni ²⁺ ions from contaminated water Verica Ljubic¹, Slobodan Cvetkovic¹, Jovana Perendija¹, Aleksandra Djukic-Vukovic², and Mina Popovic^{1*}	52
Tailoring of MgO/Mg(OH) ₂ structures by molten salt electrolysis <i>Formiranje MgO/Mg(OH)₂ struktura elektrolizom iz rastopa</i> Nataša M. Vukićević*	60
Hardness and morphology analysis of electrolytically produced copper coatings <i>Analiza tvrdoće i morfologije elektrolitički dobijenih bakarnih prevlaka</i> Ivana O. Mladenović^{1,*}, Nebojša D. Nikolić¹	66
Influence of internal corrosion of steel pipelines and replacement of old ones with new ones	

<i>Uticaj unutrašnje korozije čeličnih cevovoda i zamena starih sa novim</i> Željko Krivačević, Dejan Grgić, Saša Stojanović, Aleksandar Pešić	76
Synthesis of chromium-tin red glazes under oxidative conditions <i>Sinteza hrom-kalajnih crvenih glazura u oksidacionim uslovima</i> Bojan Jokić^{1,*}, Biljana Babić²	83
ORAL PRESENTATIONS	36
High-temperature resistance of SiC-HfC multilayered ceramics <i>Visokotemperaturna otpornost SiC-HfC višeslojevite keramike</i> Branko Matović	37
The effect ultrasound sonification on nitric acid leaching of pyrolyzed printed circuit board powder <i>Uticaj ultrazvuka na luženje spraćenih i pirolizovanih štampanih ploča azotnom kiselinom</i> Gvozden Jovanović^{1,*}, Mladen Bugarić¹, Nela Petronijević¹, Srećko Stopić², Branislav Marković¹, Srđan Stanković³, Bernd Friedrich², Miroslav Sokić¹	38
Electrical properties of electrochemically co-polymerized aniline and sulphanilic acid <i>Električna svojstva elektrohemijski kopolimerizovanog anilina i sulfanilne kiseline</i> Nikola Novaković¹, Miloš Petrović¹, Branimir Jugović², Branimir Grgur¹, Milica Gvozdenović^{1,*}	47
POSTER PRESENTATIONS	36
Novel Calcium Phosphate Coatings with Selenium on Titanium Marijana R. Pantovic Pavlovic^{1,2,*}, Nenad L. Ignjatovic³, Vladimir V. Panic^{1,2,4}, Miroslav M. Pavlovic^{1,2}	37
The optimization of hydrothermally obtained hydroxyapatite deposition process on titanium by novel <i>in-situ</i> process Katarina Đ. Božić^{1,2,*}, Miroslav M. Pavlović^{1,2}, Stefan V. Panić¹, Đorđe N. Veljović³, Marijana R. Pantović Pavlović^{1,2}	38
Rare-earth / manganese oxide-based composites for oxygen reduction reaction Stefan V. Panić^{1,*}, Marijana R. Pantović Pavlović^{1,2}, Katarina Đ. Božić^{1,2}, Miroslava M. Varničić¹, Maja R. Stevanović³, Vojin M. Tadić⁴, Miroslav M. Pavlović^{1,2}	43
Green Corrosion Inhibitors with Cysteine and Cerium-Cysteine Complex on 7000 series Aluminum Alloy <i>Zeleni inhibitori korozije sa cisteinom i kompleksom cerijum-cisteina na 7000 seriji aluminijumske legure</i> Jovanka Pejić¹, Bojana Radojković^{*1}, Anđela Simović², Dunja Marunčić¹, Bore Jegdić¹, Miroslav Pavlović^{1,3}, Jelena Bajat⁴	48
Investigation of the Influence of Mg Content on Corrosion Behavior of Al Alloys of Al-Mg System <i>Ispitivanje uticaja sadržaja Mg na koroziono ponašanje Al legura sistema Al-Mg</i> Jelena Šćepanović[*], Dragan Radonjić, Darko Vuksanović	49
Waste Tires in Podgorica, Resource or Waste That Endangers the Environment <i>Otpadne gume u Podgorici, resurs ili otpad koji ugrožava životnu sredinu</i> Darko Vuksanović[*], Dragan Radonjić, Jelena Šćepanović	55
Use of Municipal Waste as a Resource <i>Iskorišćenje komunalnog otpada kao resursa</i> Dragan Radonjić[*], Jelena Šćepanović, Darko Vuksanović	67

Rosa Canina (Rosehip) as a corrosion inhibitor in acidic media <i>Regina Fuchs–Godec^{1*}, Marija Riđošić², Miomir G. Pavlović², Milorad. V. Tomić²</i>	72
The application of thin films to prevent corrosion <i>Regina Fuchs–Godec</i>	77
Magnetic properties of electrodeposited Ni-Co powders <i>Magnetna svojstva elektrohemijskih taloženih Ni-Co prahova</i> <i>Vesna Maksimović^{1*}, Nebojša Nikolić²</i>	83
Physical and mechanical properties of glass-ceramic-metal composite materials after sintering <i>Fizička i mehanička svojstva staklo-keramika-metal kompozitnih materijala nakon sinterovanja</i> <i>Vladimir Pavkov¹, Gordana Bakić², Vesna Maksimović^{1*}, Ivana Cvijović-Alagić¹, Branko Matović¹</i>	84
Titanium Aluminide Cyclic Oxidation Kinetics <i>Kinetika ciklične oksidacije titan aluminida</i> <i>Ivana Cvijović-Alagić[*], Milan T. Jovanović</i>	85
Capacitive properties of electrochemically synthesized polyaniline on graphite electrode <i>Kapacitivna svojstva elektrode na bazi elektrohemijski formiranog polianilina</i> <i>Jelena Gojgić, Miloš Petrović, Branimir Jugović, Branimir Grgur, Bojan Jokić, Milica Gvozdenović</i>	86
Electrochemical co-deposition of neodymium and praseodymium from oxyfluoride molten salts <i>Elektrohemijsko taloženje neodijuma i prazeodijuma iz oksifluoridnih rastopa</i> <i>Nataša M. Vukićević, Dominic Feldhaus, Vesna S. Cvetković, Bernd Friedrich, Jovan N. Jovićević</i>	87
Influence of Parameters and Regimes of the Electrodeposition on Morphology and Structure of Tin Dendrites <i>Uticaj parametra i režima elektrohemijskog taloženja na morfologiju i strukturu dendrita kalaja</i> <i>Nebojša D. Nikolić^{1*}, Jelena D. Lović¹, Vesna M. Maksimović²</i>	89
Platinum nanoparticles supported on bacterial nanocellulose for ethanol electrooxidation <i>Platinske nanočestice deponovane na bakterijskoj nanocelulozi za elektrooksidaciju etanola</i> <i>Sanja Stevanović^{1*}, Marijana Ponjavić¹, Jasmina Nikodinović Runić², Sanja Jeremić², Vladan Ćosović¹, Vesna Maksimović³</i>	90
Electrochemical impedance spectroscopy of oxygen evolution reaction in acidic conditions on Pt nanoparticles <i>Milica Košević^{1*}, Marija Mihailović¹, Srećko Stopić², Bernd Friedrich², Jasmina Stevanović^{1,3}, Vladimir Panić^{1,3,4}</i>	92
Anodic Linear Sweep Voltammetric Examination of Deposits from Ore Leaching Solutions Containing Ni, Co and Fe Ions <i>Milica Košević¹, Srećko Stopić², Bernd Friedrich², Vladimir Panić^{1,3,4}, Jasmina Stevanović^{1,3}, Sanja Krstić⁵, Marija Mihailović^{1, *}</i>	93
Corrosion behavior of copper in 3 % NaCl with addition of cynarae extract <i>Koroziono ponašanje bakra u 3% rastvoru NaCl sa dodatkom ekstrakta cynarae</i> <i>Bojan Jokić^{1,*}, Milica Gvozdenović², Marijana Jovanović², Branimir Jugović³, Branimir Grgur²</i>	94
Investigation of the possibility the Pb-Zn slag from "Topionica" -Veles quality improving using magnetic separation	

<i>Ispitivanje mogućnosti poboljšanja kvaliteta Pb-Zn šljake iz "Topionica" -Veles primenom magnetne separacije</i>	
Dejan Todorović, Vladimir Jovanović, Branislav Ivošević, Dragan Radulović, Sonja Milićević	100
Possibility of "Topionica" - Veles Pb-Zn slag valorization by gravity concentration procedure <i>Mogućnost valorizacije Pb-Zn šljake "Topionica"-Veles postupkom gravitacijske koncentracije</i>	
Dragan Radulović, Vladimir Jovanović, Dejan Todorović, Branislav Ivošević, Sonja Milićević	108
Cu, Mn, Pb and Zn concentrations in bark of different tree species as indicator of atmospheric pollution	
Dragana Pavlović*, Marija Matić, Olga Kostić, Dimitrije Sekulić, Natalija Radulović, Miroslava Mitrović, Pavle Pavlović	117
Human health risk assessment of PTEs in soil originating from urban parks in Serbia	
Marija Matić*, Dragana Pavlović, Veljko Perović, Milica Marković, Dimitrije Sekulić, Miroslava Mitrović, Pavle Pavlović	125
<i>Thymus Serpillum</i> and <i>Origanum Minutiflorum</i> as green corrosion inhibitors	
Marija Riđošić¹, Regina Fuchs-Godec², Milorad Tomić^{1*}, Miomir Pavlović¹	133
Determination of Corrosion Resistance of Aluminium after Anodization in Sulfuric Acid and Post-Processing	
Milorad Tomić^{1*}, Marija Riđošić¹, Milena Milovanović², Stana Stanišić³, Dubravka Banjac³, Dragan Tošković¹, Vladan Mičić¹, Miomir G. Pavlović¹	140
Carbon-based Polymer Nanocomposites as Indispensable Sensing Elements in Different Sensing Applications	
Marija Riđošić*, Milorad Tomić	141
Testing of Chemical Composition of Materials Using a Portable Handmade Device for X-Ray Fluorescent Analysis-XRF. Part I <i>Ispitivanje hemijskog sastava materijala primjenom prenosnog ručnog uređaja za rendgensku fluorescentnu analizu-XRF. Dio I</i>	
Zorica Ristić, Stana Stanišić, Božidarka Arsenović	142
Ecosystem Sustainability From the Aspect of the Role of Green and Blue Water <i>Održivost ekosistema sa aspekta uloge zelene i plave vode</i>	
Božidarka Arsenović	148
New Heteropolynuclear Systems Obtained Using 3d-4f Nodes	
Adina-Elena Neacsu,¹ Robert-Alin Pelle,¹ Catalin Maxim,¹ Delia-Laura Popescu,¹ Marius Andruh,¹ and Traian-Dinu Pasatoiu^{1,*}	156
Luminescent Materials Based on 3d-4f Nodes	
Traian-Dinu Pasatoiu,^{1,*} Augustin Madalan,¹ and Marius Andruh¹	157
Ash radioactivity level and ambient dose equivalent rate in the vicinity of TPP Kosovo B Obilić <i>Nivo radioaktivnosti u pepelu i jačina ambijentalnog doznog ekvivalenta u okolini TE "Kosovo B" Obilić</i>	
Ljljana Gulan¹, Stanimirka Jovanović¹, Marija Mitrović^{2,*}, Jelena M. Stajić³	158
Radon concentration in dwellings in the mining area of "Trepča" complex <i>Koncentracija radona u stanovima u rudarskom području "Trepča" kompleksa</i>	
Marija Mitrović^{1,*}, Aleksandra Lempic², Ljljana Gulan²	164
Corrosion costs for oil and gas industry	
Nikola Kostić^{1,*}, Živče Šarkoćević¹, Ivica Čamagić¹, Dragan Lazarević¹, Jasmina Dedić¹	170

The role of drainage systems in the prevention of material degradation of bridge structures

Uloga sistema za odvodnjavanje u prevenciji degradacije materijala konstrukcija mostova

Vujadin Aleksić^{1,*}, Bojana Zečević², Srđan Bulatović¹, Ana Maksimović², Ljubica Milović³ _____ 176

S P O N S O R S _____ **186**

Consideration of Energy Flows in the Life Cycle of Energy Production from Biogas

Razmatranje energetske tokove u životnom ciklusu proizvodnje energije iz biogasa

Slobodan Cvetković^{1*}, Mina Popović¹, Jovana Perendija¹

¹University of Belgrade, Institute of Chemistry, Technology and Metallurgy (ICTM), Njegoseva 12, 11000 Belgrade, Serbia

*Corresponding author: slobodan.cvetkovic@ihm.bg.ac.rs

Abstract

The aim of this paper is to present the energy flows in the life cycle of the biogas cogeneration system, as well as their mutual relations, starting from providing of feedstock materials (corn silage and cow manure), anaerobic digestion, cogeneration up to the digestate as fertilizer on agricultural land. The cogeneration process has been considered according to the performance of the biogas plant located on the Mirotin dairy farm in Vrbas (Serbia). For evaluation of energy flows in this work were used four energy indicators. According to the Life Cycle Energy Assessment approach, results obtained in this study have shown that the biogas cogeneration process has positive energy balances and this process is energy sustainable. The applied approach in this research can be adjusted to any biogas power plant since it complies with the main material and energy balances.

Keywords: Life Cycle Energy Analysis; Biogas; Cogeneration; Energy balance; Energy efficiency

Izvod

Cilj ovog rada je da prikaže tokove energije u životnom ciklusu biogas kogeneracionog sistema, kao i njihove međusobne odnose, počev od obezbeđivanja sirovine (kukuruzna silaža i kravli stajnjak), anaerobne digestije, kogeneracije, pa do digestata, kao đubrivo na poljoprivrednom zemljištu. Proces kogeneracije je razmatran prema performansama biogas postrojenja koje se nalazi na farmi mleka Mirotin u Vrbasu (Srbija). Za evaluaciju energetske tokove u ovom radu korišćena su četiri energetska indikatora. Prema LCEA pristupu, rezultati dobijeni u ovoj studiji su pokazali da proces kogeneracije biogasa ima pozitivan energetske bilans i da je ovaj proces energetske održiv. Primenjeni pristup u ovom istraživanju može se prilagoditi bilo kojoj elektrani na biogas jer je u skladu sa osnovnim materijalnim i energetske bilansima.

Glavne reči: Energetska analiza životnog ciklusa; Biogas; Kogeneracija; Energetske bilans; Energetske efikasnost

Introduction

Nowadays, coal, crude oil, and natural gas are the most important resources for energy supply. It was estimated that about 85% of the total world's primary energy consumption has been provided by fossil fuels in 2018[1]. Environmental protection, global warming, and the reduction of greenhouse gas (GHG) emissions are located on many political agendas (United Nations, European Union, etc). Greater use of biogas as renewable energy sources could be one of the solutions for the mitigation of these problems. The most important sources of biogas production include agriculture and food waste; organic waste from the industry; municipal solid waste in form of fermentable fractions and sludge from municipal wastewater treatment plants. The major components in biogas as a gas mixture are CH₄, CO₂, and impurities (such as O₂, H₂S, N₂, siloxanes, and water). The biogas can be used as a source for heat and electricity production, in the natural gas grid, as well as a fuel for traffic.

The Republic of Serbia is a region rich in biomass that can be used for biogas production. According to Energy Treaty with European Union, Serbia introduced feed-in tariffs as a supporting measure for

electricity produced from biogas. The primary energy production from biogas in Serbia in the period 2015-2020 is presented in Figure 1[2].

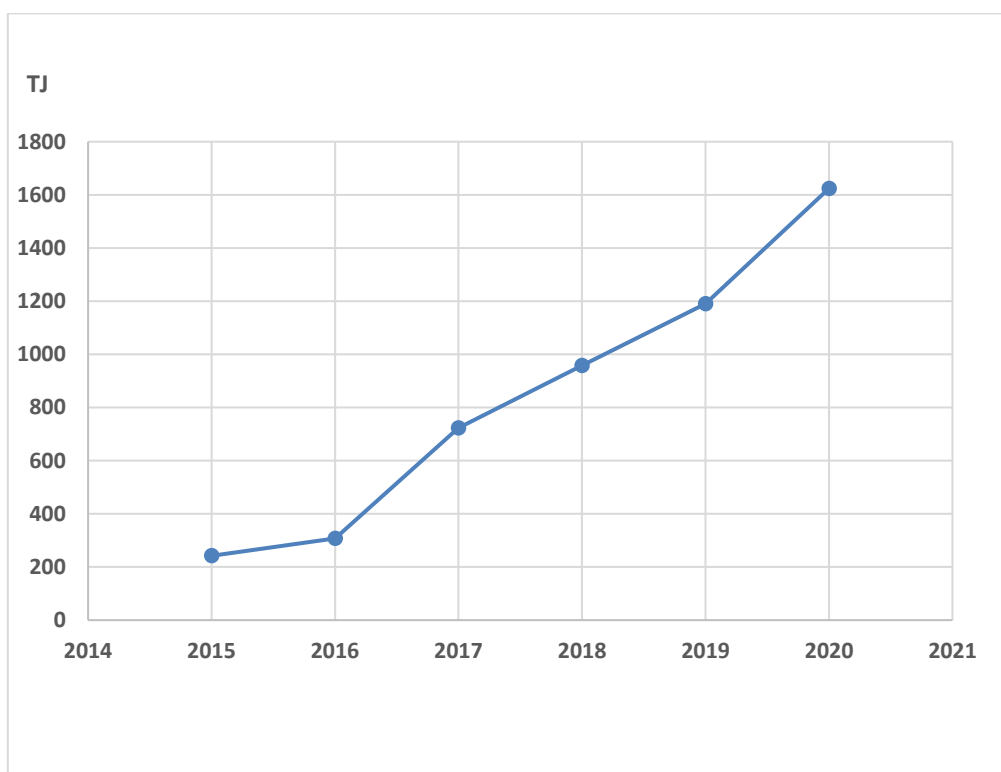


Figure 1. Primary energy production from biogas in Serbia in the period 2015 to 2020[2]

Energy analysis of biogas systems according to the Life Cycle Assessment (LCA) approach has been a focus of scientific research over the past two decades. Analyzing materials and energy flows, LCA estimates the influence of biogas processes on the environment. The phases of LCA (Figure 2) involve:

- Definition of the objective and the scope of the study;
- Inventory, in which the inputs of the life cycle are collected and the outputs determined and presented;
- Environmental impact assessment of the life cycle, where the impact is evaluated and quantified;
- Interpretation of the results, where the implications on the environment are described and the recommendations for decision-makers are provided.

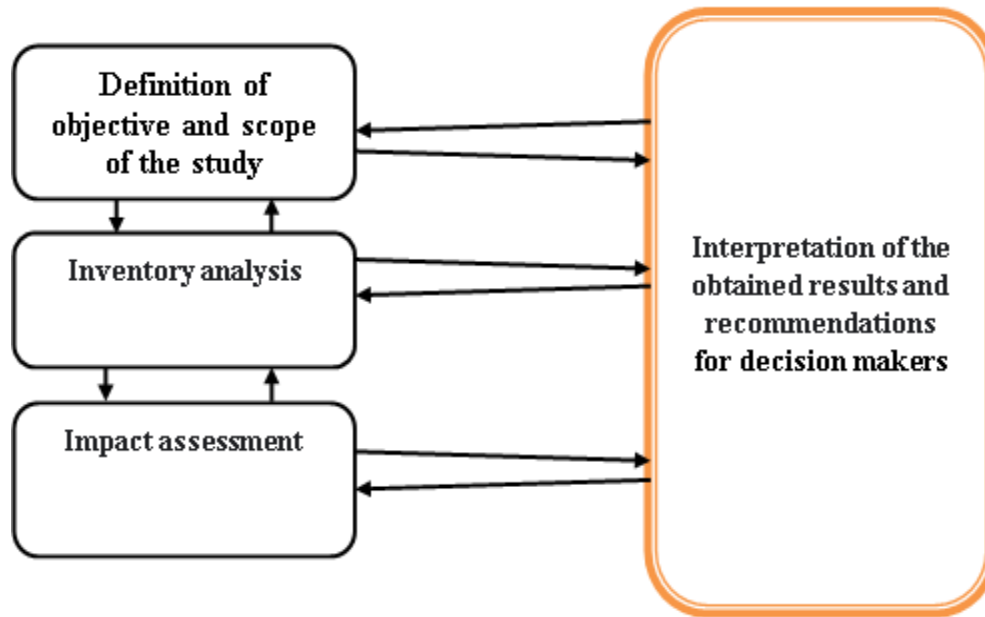


Figure 2. The phases of LCA

This approach involves feedstock supply, production process, transport, distribution, utilization, recycling, and product disposal or end of the biogas production process. The objectives of the biogas LCA studies are diverse. These studies were considered various resources for anaerobic digestion and biogas production [3,4] or the specific biogas technologies [5-7]. In studies [8,9], biogas was compared with other energy sources in the LCA analysis. LCA methodology is the base for conducting the life cycle energy assessment (LCEA) for different biogas utilization pathways. LCEA in an environmental context is implemented for consideration of fossil fuel needs or energy efficiency and characterization of biogas renewability. Scientific methodology for estimating the energy performance of biogas plants in LCEA has not yet been established. The production of biogas and the other types of energy that can be produced from biogas covers various energy flows: (i) from the production of materials for anaerobic digestion, (ii) via the process of anaerobic digestion (iii) to the use of the produced energy, and (iiii) the utilization of the produced digestate. The objective of this study is an analysis of the energy flows in the life cycle of the biogas cogeneration system, as well as their mutual relation, starting from the supply of the resources necessary for anaerobic digestion, heat, and electricity production up to the digestate on the agricultural soil as fertilizer. The analysis was performed using the data from the biogas plant Mirotin in Serbia.

Materials and Methods

In this work, the methodology of LCEA analysis was conducted according to ISO 14000 series standards [10,11].

Description of the system for LCEA

In this study, the Mirotin biogas plant was analyzed. The biogas power plant was built in 2011 and is situated in Vrbas (Serbia). On this farm, corn silage and cow manure are used as a substrate for anaerobic digestion. Cultivation of corn silage includes different operations such as soil preparation, sowing, plant protection, harvesting, and ensilage which use material and energy resources. The cow manure is stored in tanks and transferred to the digester by an electric pump. During the process of anaerobic digestion, it is necessary to provide a constant temperature in the range of 37- 40 °C. Produced biogas contains 50-55% of methane. The cogeneration unit (CHP unit) has an installed capacity of 1 MWe. In this unit, biogas energy is converted into heat and electricity using gas motors.

The heat from the cogeneration unit is used for heating digesters and buildings. The produced electricity is delivered to the national electric grid and the company is a part feed-in tariff system in Serbia. After the process of separation, a digestate is obtained as a solid and a liquid phase. The digestate is further used as fertilizer on agricultural land for corn silage production.

System boundaries in LCEA

In this study system boundary for the biogas cogeneration process was defined for LCEA which is given in Figure 3. The biogas cogeneration system was analyzed using the data of the Mirotin biogas plant. The system boundary in Figure 3, is as follows: corn silage production using digestate as fertilizer, all electricity is imported, heat energy for the anaerobic digestion unit is used from the cogeneration unit, electricity and the remaining part of the heat from the CHP unit is exported (PC1 process).

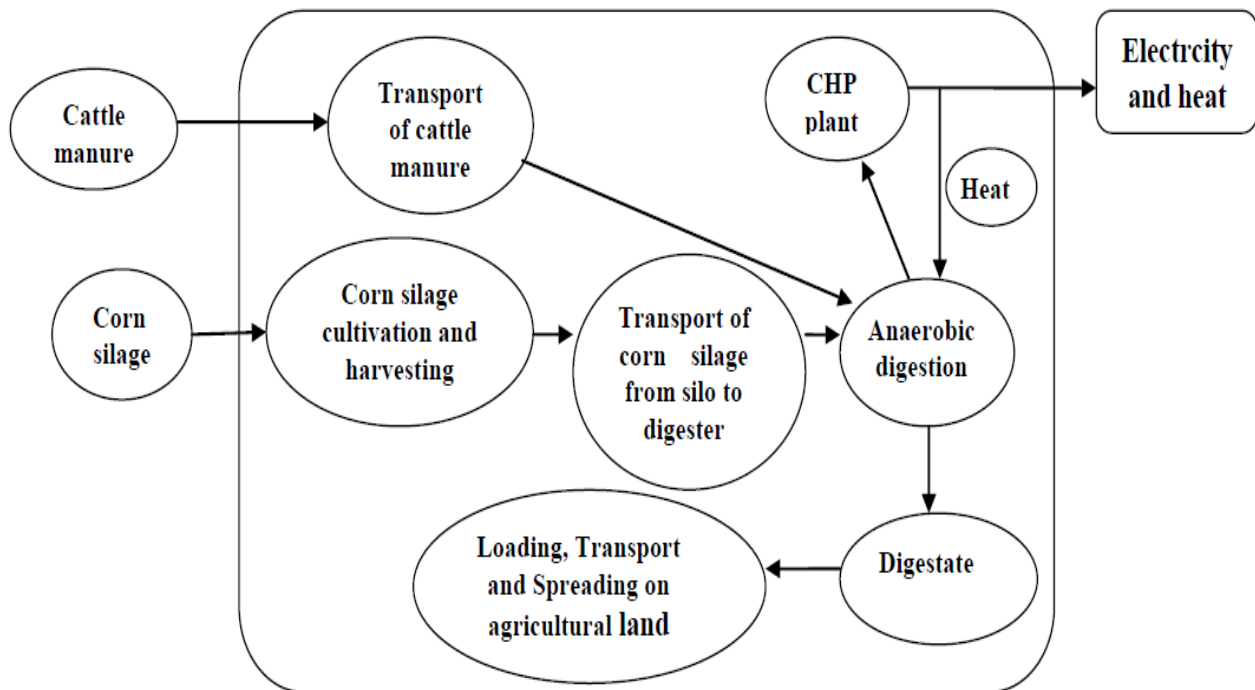


Figure 3. System boundary in Life Cycle Energy Assessment for PC1 process on a farm in Serbia

Mass flows in a biogas plant

Mass flows in Mirotin biogas plant were determined as follows : MF_1 - Cow manure flow (26,800 t/year); MF_2 - Corn silage flow (10,363 t/ year); MF_3 - Total digestate flow (30,930 t/ year); MF_4 - Liquid digestate flow (24,470 t/year); MF_5 - Solid digestate flow (6,434 t/year) and MF_6 - Biogas flow (3,903,163 m³_N/year).

Based on on-site data, dry matter (DM) in corn silage was 32% with volatile matter 93% of DM in corn silage, while DM in cow manure was 22%, with 80% of volatile matter in DM of cow manure. The content of methane in biogas was 53.5% (average value). In the PC1 process was assumed that the mineral fertilizer for the corn silage cultivation process was replaced by the solid digestate. The yield of corn silage of 40 t/ha was assumed.

Calculation of energy input

The energy performance of the PC1 process was considered by the following indicators [12,13]

- The difference between energy output and total primary energy input (energy balance), where energy output was heat and electricity produced in the CHP unit, while energy input was the sum of primary energy input inside the boundary of the system for the LCEA.
- Energy output/energy input ratio (energy efficiency)
- The ratio of energy output and the sum of parasitic electricity and parasitic heat energy used for biogas production (μ_p). Parasitic electricity and parasitic heat energy represent energy that was provided out of the boundary of the biogas system in LCA.
- Ratio ($E_{F/TS}$) of energy balance and the dry matter (DM) mass of feedstock material (corn silage and cow manure).
- Energy inputs that were analyzed in this study are:
 - The energy input for corn silage production, (F_c), in GJ. The mineral fertilizer in corn silage cultivation is replaced by solid digestate and based on this fact, the energy input for corn production per hectare was adopted by the value of 8.3 GJ/ha [14].
 - The energy input for the transport of corn silage, ($F_{transil}$), in MJ. The distance for transport of corn silage in this study was 200 m.
 - The energy input for transport of cow manure, ($F_{tranman}$), to the digester and according to on-site measurements, $F_{tranman}$, was 3500 kWh/year.
 - The energy input for anaerobic digestion, (F_d), in MJ according to on-site data measurements
 - The energy input for the CHP unit, (F_{cog}), was used 207 MWh/year of heat and 244.5 MWh/year of electricity (on-site data measurement).
 - The energy input for digestate separation, (F_{dsep}), in MJ
 - The energy input for using liquid digestate, (F_{ldig}), in MJ (loading, transport, spreading). The distance for transportation of liquid digestate was 7 km in this work.
 - The energy input for using solid digestate, (F_{sdig}), in MJ (loading, transport spreading). The distance for the transport of solid digestate was assumed as 3 km in this study.

Energy inputs were determined according to mass balance in the Mirotin biogas plant, on-site data, and specific energy inputs which are given in Table 1.

Table 1. Specific energy inputs are used for the determination of different energy inputs in the biogas cogeneration system [12,13]

Specific energy input	Value	References
SE_1	8.3 GJ/ha	[14]
SE_2	12.6 MJ/t·km	[15,16]
SE_3	78.6 MJ/t	[17,18]
SE_4	0.63 MJ/t	[16,19]
SE_5	2.84 MJ/t·km	[16,19]
SE_6	20.16 MJ/t	[20]
SE_7	3.78 MJ/t	[20]
SE_8	3.15 MJ/t·km	[20]
SE_9	25.83 MJ/t	[20]

Where is: SE_1 is the specific energy input for corn production (GJ/ha); SE_2 is the specific energy input for transport of corn silage (MJ/t·km); SE_3 is the specific energy input for digestate separation (MJ/t);

SE_4 is the specific energy input for liquid digestate loading (MJ/t); SE_5 is the specific energy input for liquid digestate transport (MJ/t·km); SE_6 is the specific energy input for liquid digestate spreading (MJ/t); SE_7 is the specific energy input for solid digestate loading (MJ/t); SE_8 is the specific energy input for solid digestate transport (MJ/t·km); SE_9 is the specific energy input for solid digestate spreading (MJ/t);

Calculation of energy performance of PC1 process

All equations necessary for the determination of energy indicators used in this work are summarized below:

The energy balance for PC1, E_{b2} , was calculated as:

$$E_{b2} = E_{out2} - E_{in2} \tag{1}$$

$$E_{in2} = F_c + F_{transil} + F_{tranman} + F_d + F_{dsep} + F_{ldig} + F_{sdig} + F_{chp} \tag{2}$$

$$E_{out2} = 8,839 \text{ MWh/year (heat energy)} + 8,149.5 \text{ MWh/year (electricity)} = 16,998.5 \text{ MWh/year} \tag{3}$$

In this process the efficiency of the electric energy generation ($\mu_{CHP, el}$) and heat generation ($\mu_{CHP, H}$) in cogeneration were calculated according to the equations (4-6) proposed by the Eastern Research Group [21]:

$$\mu_{CHP, el} = E_{el, prod} / E_{bg, biogas} \tag{4}$$

$$\mu_{CHP, H} = E_{H, prod} / E_{bg, biogas} \tag{5}$$

$$E_{bg, biogas} = 0.535 \cdot MF_6 \cdot HV_{CH4} \tag{6}$$

where $E_{el, prod}$ and $E_{H, prod}$ are the electricity and heat generated in the CHP unit (see equation 3); $E_{bg, biogas}$ is the energy content of biogas input to the CHP; HV_{CH4} is the lower heating value of methane (35.8 MJ/m³_N).

μ_p was obtained in this process as:

$$\mu_p = E_{out2} / (F_{tranman} + F_d + F_{dsep} + F_{chp \text{ electricity}}) \tag{7}$$

CHP electricity was 244.5 MWh/year.

$E_{F/TS}$ was obtained in this process as:

$$E_{F/TS} = E_{b2} / M_{F/TS} \tag{8}$$

Results and Discussion

The obtained energy inputs for the PC1 process are given in Table 2.

Table 2. The energy inputs for the PC1 process

Energy input	Value
F_c	2,149.7 GJ
$F_{transil}$	26.1 GJ (on-site data)
$F_{tranman}$	3,500 kWh/year (on-site data)
F_d	1,587.6 GJ/year (on-site data)
F_{cog}	207 MWh/year of heat and 244.5 MWh/year of electricity (on-site data)
F_{dsep}	2,431.1 GJ
F_{ldig}	995.2 GJ
F_{sdig}	251.3 GJ

The calculated total energy input for the PC1 process was 9,081.1 GJ. In this process, the thermal energy for the digester is provided from a CHP unit in the amount of 1,356 MWh per year. The dominant energy inputs in this process are the energy inputs required for digestate separation (26.76%) and corn silage production (23.67%).

The energy balance in the PC1 process was 52,114 GJ (surplus energy), while the energy efficiency (μ) amounted to 6.74 (Table 3).

Table 3. Energy efficiency in a life cycle of biogas cogeneration in different studies

[20,21]	[22]	[23]	[24]	This study
3-7.5	2.5-7	3.5-8.2	5.5-6.8	6.74

The results in this study were in good agreement with the values (Table 3) for the energy efficiency (3.-7.5) determined in the studies of Eastern Research Group [21] and Pöschl et al. (2010) [20], as well as, the values of 2.5-8.2 calculated by Berglund and Börjesen (2006) [22], Seppälä et al. (2008) [23], and Navickas et al., (2012) [24].

The values of the energy efficiencies of electricity and heat generation in the cogeneration unit calculated for the system investigated in this paper were $\mu_{CHP, el.}=0.39$ and $\mu_{CHP, H}=0.42$. These results are in good agreement with the values obtained for modern CHP units [25-27]. The total energy efficiency in the CHP unit obtained as the sum of $\mu_{CHP, el.}$ and $\mu_{CHP, H}$ was 0.81. This value for total energy efficiency was higher than the value of 0.6 obtained by Blengini et al. (2011) [28] and also it was higher than the value of 0.66 obtained by Havukainen et al. (2014) [29].

The parasitic energy in this process involved energy input for the transport of cow manure, the energy input for anaerobic digestion, the energy input for digestate separation, and energy input for CHP unit in the form of electricity. In the PC1 process, μ_p was calculated as 10.81 and parasitic energy represented 9.25% of energy output. The determined result was in good agreement with the values of the parasitic energy reported by Gropgen (2007) of 8.5% [30]. The energy input for digestate separation contributed the most to the parasitic energy input. This is electricity necessary for motors in the process of digestate separation. Implementation of the measures for rational use of electricity in the process of digestate separation (adjustable-speed drive equipment, voltage optimization, etc) can contribute significantly to the reduction of parasitic energy in this process.

$E_{F/TS}$ in the PC1 process amounted to 7.23 MJ/kg DM of input substrate. This result means that processing of 138.31 g DM of input substrate under the conditions in this process can achieve up to 1 MJ of positive energy balance.

According to Arodudu et al. (2014) [31], the bioenergy systems whose energy efficiency is below 3 are not sustainable and represent potential hazards to the environment primarily in land degradation, water pollution, and loss of biodiversity. According to that indicator, the system investigated in this paper is sustainable.

Determination of energy outputs according to the agricultural practice in Serbia, assumed distance of transport for the liquid and solid digestate to agricultural areas, technology for biogas production, and assumed lower calorific value of biogas may involve uncertainties in the estimation of energy output in biogas cogeneration process.

Conclusions

The objective of this study was energy analysis and determination of energy characteristics in the biogas cogeneration process (heat and electricity production) during the life cycle. Evaluation of energy flows was carried out according to the performances of the Mirotin biogas plant in Serbia and literature data. Four energy indicators were used to determine energy flows in this work. The obtained results show that the biogas gas cogeneration process has a positive energy balance ((52,114 GJ) and an energy efficiency of 6.74 in the life cycle and it is sustainable from an energy point of view. The obtained results can serve to the improvement of energy management on biogas power plants in Serbia. Also, this paper is conducted on data obtained in the real biogas system and it provides an

extension of the existing database for further environmental and energy analysis of the other biogas energy systems.

Acknowledgments

This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-68/2022-14/200026. The authors would like to thank the Mirotin Company, Vrbas, Republic of Serbia, for the help in the realization of this study.

References

1. S. Ghasemian, A. Faridzad, P. Abbaszadeh, A. Taklif, A. Ghasemi, R. Hafezi, An overview of global energy P1 process by 2040: identifying the driving forces using cross-impact analysis method, *Int.J.Sci. Environ.*, 1-24, 2020.
2. The Statistical Office of the Republic of Serbia 2020 (online). Available: <https://www.stat.gov.rs/media/346516/bilans-biogasa-2020.pdf>
3. N. I. H. A. Aziz, M. M. Hanafiah, Life cycle analysis of biogas production from anaerobic digestion of palm oil mill effluent, *Renew. Energ.*, 145, 847-857, 2020.
4. L. Ioannou-Ttofa, S. Foteinis, A.S. Moustafa, E. Abdelsalam, M. Samer, D. Fatta-Kassinou, Life cycle assessment of household biogas production in Egypt: Influence of digester volume, biogas leakages, and digestate valorization as biofertilizer, *J. Clean. Prod.*, 286, 125468, 2021.
5. P.Z Morsink-Georgali, A. Kylili, P.A. Fokaides, A.M. Papadopoulos, Compost versus biogas treatment of sewage sludge dilemma assessment using life cycle analysis, *J. Clean. Prod.*, 131490, 2022.
6. Y.K. Nugroho, L. Zhu, C. Heavey, Building an agent-based techno-economic assessment coupled with life cycle assessment of biomass to methanol supply chains, *Appl. Energ.*, 309, 118449, 2022.
7. H. Hahn, K. Hartmann, L. Bühle, M. Wachendorf, Comparative life cycle assessment of biogas plant configurations for a demand oriented biogas supply for flexible power generation, *Bioresour. Technol.*, 179, 348–358, 2015.
8. K.Y. Wang, H.G. Wang, Integrated Cost Dataset under the Whole Life Cycle of Biogas, Straw, and Coal Power Generation, *J. Global. Change Data Discovery.*, 1, 53-57, 2022.
9. G. San Miguel, B. Corona, Hybridizing concentrated solar power (CSP) with biogas and biomethane as an alternative to natural gas: Analysis of environmental performance using LCA, *Renew. Energ.*, 66, 580-587, 2014.
10. ISO14040: Environmental management - Life cycle assessment - Principles and framework. International Organization for Standardization; 2006.
11. ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines. International Organization for Standardization; 2006.
12. S. Cvetković, T. Kaluđerović Radoičić, B. Vukadinović, M. Kijevčanin, A life cycle energy assessment for biogas energy in Serbia. *Energy Sources A: Recovery Util. Environ. Eff.*, **38(20)**, 3095-3102, 2016.
13. S.M. Cvetković, T.K Radoičić, M. Kijevčanin, J.G. Novaković, Life Cycle Energy Assessment of biohydrogen production via biogas steam reforming: case study of biogas plant on a farm in Serbia, *Int. J. Hydrog. Energy*, **46(27)**, 14130-14137, 2021.
14. A. Salter, Crops for biogas productions; yields, suitability, and energy balance. In: 15th European Biomass Conference, Workshop 2–Biogas: Energy throughout the whole world, Berlin, 2007.
15. P.A. Gerin, F. Vliegen, J.M. Jossart, Energy and CO₂ balance of maize and grass as energy crops for anaerobic digestion, *Bioresour. Technol.*, 99, 2620–27, 2008.
16. KTBL, Association for Technology and Structures in Agriculture. Diesel fuel consumption during agricultural processes; 2008.
17. A. Lootsma, T. Raussen, Current practise for pre-treatment and utilization of digestate, *Kasseler Abfall- und Bioenergieforum*, Germany:Witzenhausen; 2008.
18. C. Becker, H. Döhler, H. Eckel, N. Fröba, T. Georgieva, J. Grube, Empirical values for biogas, 1st ed. Germany: Darmstadt, 2007.

19. KTBL, Association for Technology and Structures in Agriculture (KTBL). Business planning agriculture 2008/09 – data for business planning in agriculture. Germany: Darmstadt; 2009.
20. M. Pöschl, S. Ward, P. Owende, Evaluation of energy efficiency of various biogas production and utilization pathways. *Appl. Energ.*, 87, 3305–21, 2010.
21. Eastern Research Group, Protocol for quantifying and reporting the performance of anaerobic digestion systems for livestock manures, 2011.
22. M. Berglund, P. Börjesson, Assessment of energy performance in the life cycle of biogas production, *Biomass Bioenerg.*, 30, 254–66, 2006.
23. M. Seppälä, T. Paavola, A. Lehtomäki, O. Pakarinen, J. Rintala, J., Biogas from energy crops optimal pre-treatments and storage, co-digestion and energy balance in boreal conditions, *Water Sci. Technol.*, **58(9)**, 1857-1863, 2008.
24. K. Navickas, K. Venslauskas, A. Nekrošius, V. Župerka, T. Kulikauskas, Influence of different biomass treatment technologies on efficiency of biogas production, In *11th International Scientific Conference Engineering for Rural Development*, 24, 25, 2012.
25. S. Abanades, H. Abbaspour, A. Ahmadi, B. Das, M.A Ehyaei, F. Esmailion, E.H. Bani-Hani, A critical review of biogas production and usage with legislations framework across the globe, *Int.J.Sci. Environ*, 1-24, 2021.
26. A. Rafiee, K.R. Khalilpour, J. Prest, I. Skryabin, Biogas as an energy vector, *Biomass Bioenerg.*, 144, 105935, 2021.
27. M. Lantz, The economic performance of combined heat and power from biogas produced from manure in Sweden – A comparison of different CHP technologies, *Appl. Energ.*, 98, 502-511, 2012.
28. G.A. Blengini, E. Brizio, M. Cibrario, G. Genon, LCA of bioenergy chains in Piedmont (Italy): A case study to support public decision makers towards sustainability, *Resour. Conserv. Recycl.*, 57, 36-47, 2011.
29. J.V Havukainen, V. Uusitalo, A. Niskanen, V. Kapustina, M. Horttanai, Evaluation of methods for estimating energy performance of biogas production. *Renew. Energ.*, 66, 232-240, 2014.
30. Gropgen, An overall energy balance for energy production taking into account energy inputs associated with farming. University of Vienna; 2007.
31. O. Arodudu, E. Ibrahim, A. Voinov, I. van Duren, Exploring bioenergy potentials of built-up areas based on NEG-EROEI indicators, *Ecol. Indic.*, 47, 67-79, 2014.