



PRIVREDNA  
KOMORA  
SRBIJE



Република Србија  
МИНИСТАРСТВО НАУКЕ,  
ТЕХНОЛОШКОГ РАЗВОЈА И ИНОВАЦИЈА

# 11<sup>th</sup> International Conference on Renewable Electrical Power Sources



# PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023



# PROCEEDINGS

---

## 11th International Conference on Renewable Electrical Power Sources



2023

**PROCEEDINGS**  
**11th International Conference**  
**on Renewable Electrical Power Sources**

Chamber of Commerce and Industry of Serbia,  
Belgrade, November 2 and 3, 2023

**Publisher**

Union of Mechanical and  
Electrotechnical Engineers and  
Technicians of Serbia (SMEITS)  
Society for Renewable Electrical  
Power Sources  
Kneza Miloša str. 7a/II,  
11000 Beograd

**President to the Society**  
**for Renewable Electrical**  
**Power Sources**  
**within the SMEITS**

Prof. dr Zoran Lazarević

**Editor**

Dr Milica Vlahović

Tiraž  
50 primeraka

CD umnožava  
MT-KOMEX doo, Beograd

**ISBN**  
978-86-85535-16-1

CIP - Каталогизacija u publikaciji - Narodna biblioteka Srbije, Beograd

MEĐUNARODNA konferencija o obnovljivim izvorima električne energije (11 ; 2023 ; Beograd)

Zbornik radova pisanih za 11. Međunarodnu konferenciju o obnovljivim izvorima električne energije [Elektronski izvor]: [Beograd, 2. i 3. novembar 2023.] / [urednik Milica Vlahović] = Proceedings / 11th International Conference on Renewable Electrical Power Sources : [Belgrade, October 2 and 3, 2023] ; [editor Milica Vlahović]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije SMEITS, Društvo za obnovljive izvore električne energije = Union of Mechanical and Electrotechnical Engineers and Technicians of Serbia (SMEITS), Society for Renewable Electrical Power Sources, 2023.

Sistemska zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 50. - Bibliografija uz svaki rad.

ISBN 978-86-85535-16-1

a) Энергетски извори - Одрживи развој - Зборници

COBISS.SR-

## Organizer

Savez mašinskih i elektrotehničkih  
inženjera i tehničara Srbije (SMEITS),  
**Društvo za obnovljive izvore  
električne energije**

## Co-organizer

Institut za arhitekturu i urbanizam Srbije,  
Beograd



Privredna komora Srbije,  
Beograd



## Sponsors

Interplast, Greece



MS Kablovi, Paraćin



## Endorsement

MT-KOMEX, Beograd



Održavanje 11. MKOIEE finansijski je pomoglo  
Ministarstvo nauke, tehnološkog razvoja i inovacija  
Republike Srbije



Република Србија

МИНИСТАРСТВО НАУКЕ,  
ТЕХНОЛОШКОГ РАЗВОЈА И ИНОВАЦИЈА

## **International Scientific Committee**

Prof. Dr. Mohamed Salah **Aggoun**, Algeria  
Prof. Dr. Slađana **Alagić**, Serbia  
Dr. Ana **Alil**, Serbia  
Assist. Prof. Dr. Marina **Aškrabić**, Serbia  
Dr. Valentin **Birdeanu**, Romania  
Prof. dr Gordana **Broćeta**, Bosnia and Herzegovina  
Prof. Dr. Oleksandr **Bondarenko**, Ukraine  
Dr **Aleksandar Devečerski**, Serbia  
Dr. Silvana **Dimitrijević**, Serbia  
Dr. Stevan **Dimitrijević**, Serbia  
Dr. Nataša **Đorđević**, Serbia  
Prof. Dr. Mirko **Gojić**, Croatia  
Dr. Miroslav **Ignjatović**, Serbia  
Dr. Aleksandar **Ivančić**, Spain  
Prof. Dr. Revathi **Karunanithi**, India  
Prof. Dr. Borut **Kosec**, Slovenia  
Prof. Dr. Zoran **Lazarević**, Serbia  
Dr Filip **Ljubinković**, Portugal  
Prof. Dr. Nikolay **Mihaylov**, Bulgaria  
Dr. Marina **Nenković-Riznić**, Serbia  
Dr. Jovana **Perendija**, Serbia  
Dr. Sanja **Petronić**, Serbia  
Prof. Dr. Olena **Ponomaryova**, Ukraine  
Dr. Mila **Pucar**, Serbia  
Prof. Dr. Nikola **Rajaković**, Serbia  
Prof. Dr. Ivan **Rajšl**, Croatia  
Prof. Dr. Aleksandar **Savić**, Serbia  
Prof. Dr. Zoran **Stević**, Serbia  
Prof. Dr. Valeriy **Sytnikov**, Ukraine  
Prof. Dr. Dejan **Tanikić**, Serbia  
Prof. Dr. Dragan **Tasić**, Serbia  
Prof. Dr. Kong Fah **Tee**, Saudi Arabia  
Dr. Nataša **Tomić**, United Arab Emirates  
Dr. Milica **Vlahović**, Serbia (president)

## **Organizing Committee**

Borjan **Brankov**  
Vladan **Galebović**  
Dr Stevan **Dimitrijević**  
Dr Sanja **Petronić**  
Dr Mila **Pucar**  
Ilija **Radovanović**  
Assoc. Prof. Dr Aleksandar **Savić** (predsednik)  
Prof. dr Zoran **Stević**  
Žarko **Ševaljević**  
Dr Milica **Vlahović**  
Milica **Živanović**

## FOREWORD

*The conditions created by the development of technologies in which modern man lives have led to a complex and paradoxical effect: that by removing obstacles on the way to a more comfortable, simpler, faster and more efficient life and way of working, man also generates numerous misfortunes, attracting dark clouds of threats to the survival of the planet and humanity. The question that concerns and affects all of us - all people, all living beings, systems in which life takes place, large and small, strong and weak - boils down to the problem of the negative impact of man on the environment; this issue invites us to an urgent solution by looking at the causes, proposing solutions, evaluating them, changing approaches and ways of thinking, as well as drawing correct conclusions. Simply put, by adapting nature to one's own needs, man threatens and damages it. That is why, with the joint efforts of all of us, individuals, organizations and states, it is necessary to take all possible measures to immediately prevent the negative effects that are ahead of us.*

*The importance of renewable sources of electricity, which this international conference focuses on, is noticeable from two angles: the first - it is certain that fossil fuels as a resource will disappear and it is necessary to find alternative sources, the second - the use of renewable energy sources by its essence implies "clean" technology that significantly contributes to reducing CO<sub>2</sub> emissions and thus mitigating climate change and reducing pollution, while encouraging social and economic development in all spheres of life.*

*The 11th International Conference on Renewable Electrical Power Sources is organized by the Society for Renewable Electrical Power Sources (DOIEE) at SMEITS, with co-organizers: The Institute of Architecture and Urban & Spatial Planning of Serbia (IAUS) and the Chamber of Commerce and Industry of Serbia, with the support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.*

*The registered participants designed their papers according to the given conference topics:*

- Energy sources and energy storage;*
- Energy efficiency in the context of use of renewable energy sources (RES);*
- Environment, sustainability and policy;*
- Applications and services.*

*Eminent authors - scientists, teachers, experts in this field from fifteen different countries: Algeria, Belgium, Bosnia and Herzegovina, China, Croatia, Greece, Hungary, India, Portugal, Saudi Arabia, Serbia, Slovenia, Spain, the United Arab Emirates, and Ukraine, contributed to the conference through sixty-nine papers that were reviewed by the Scientific Committee of the Conference, and after the review process were accepted for presentation at the conference and for publication in the proceedings.*

*At the end of this short message and at the beginning of the proceedings I believe that it can be proudly said that scientists, researchers, policy makers and industry experts gathered in one place, in order to exchange experiences and knowledge with the aim of promoting scientific and professional ideas and results of research, technology improvement for the use of RES, promoting the rational use of electricity, affirming and proposing inventive solutions in the field of sustainable sources of electricity.*

*Belgrade,  
November 2023*

*Milica Vlahović*

# SADRŽAJ / CONTENTS

## Plenarna predavanja:

- 1. IZAZOVI U ELEKTROHEMIJSKOM SKLADIŠTENJU**  
ENERGIJE CHALLENGES IN THE ELECTROCHEMICAL ENERGY STORAGE  
Branimir N. GRGUR..... 1
- 2. POLIANILIN: PROVODNI POLIMER U UREĐAJIMA ZA SKLADIŠTENJE ENERGIJE**  
POLYANILINE: CONDUCTIVE POLYMER IN ENERGY STORAGE SYSTEMS  
Aleksandra JANOSEVIC LEZAIC ..... 11
- 3. ISPITIVANJE KVALITETA EKSPLOZIVNO ZAVAREN OG SPOJA RAZNORODNIH METALA ZA POTENCIJALNU PRIMENU U OBNOVLJIVIM IZVORIMA ENERGIJE**  
TESTING THE QUALITY OF EXPLOSIVELY WELDED JOINTS OF DISSIMILAR METALS POTENTIALLY APPLICABLE IN RENEWABLE ENERGY SOURCES  
Ana ALIL, Milos LAZAREVIC, Danica BAJIC, Nada ILIC, Tihomir KOVACEVIC, Bogdan NEDIC..... 23
- 4. METODE BEZ RAZARANJA I UNAPREĐENJE POUZDANOSTI RADA KULE ZA HLAĐENJE, KAO ASPEKT TEMATIZACIJE OBNOVLJIVIH IZVORA ENERGIJE**  
NON-DESTRUCTIVE METHODS AND IMPROVEMENT OF THE COOLING TOWER OPERATION RELIABILITY, AS AN ASPECT OF RENEWABLE ENERGY SOURCES THEMATIZATION  
Marko JARIC, Sanja PETRONIC, Nikola BUDIMIR, Zoran STEVIC, Suzana POLIC..... 35

## Energetski izvori i skladištenje energije:

- 1. ELEKTRIČNA SVOJSTVA TANKIH FILMOVA GO I GO/WPA NA INTERDIGITALNIM ELEKTRODAMA**  
ELECTRICAL PROPERTIES OF GO AND GO/WPA THIN FILMS ON INTERDIGITAL ELECTRODES  
Zeljko MRAVIK, Milica PEJCIC, Sonja JOVANOVIC, Darija PETKOVIC, Misa STEVIC, Zoran STEVIC, Zoran JOVANOVIC..... 45
- 2. MODELOVANJE I SIMULACIJA UREĐAJA ZA NAVODNJAVANJE KAP-PO-KAP**  
MODELING AND SIMULATION OF A DEVICE APPLIED FOR LOW-FLOW DRIP IRRIGATION  
Nouredine BENSEDIRA, Abdessmad MILLES, Mohammed-Salah AGGOUNE ..... 53
- 3. UTICAJ SENKE USLED DENIVELACIJE KROVA NA PROIZVODNJU KROVNE SOLARNE ELEKTRANE IZLAZNE SNAGE 400KW**  
THE INFLUENCE OF THE SHADOW CAUSED BY THE SLOPE OF THE ROOF ON THE PRODUCTION OF A ROOF-TOP SOLAR POWER PLANT WITH AN OUTPUT POWER OF 400KW  
Marko S. DJUROVIC, Zeljko V. DESPOTOVIC ..... 61

<b>4. PROJEKTOVANJE I IZVOĐENJE SOLARNE ELEKTRANE IZLAZNE SNAGE 400KW NA KROVU FABRIČKE HALE "EP BELT"-LOZNICA</b>	
DESIGN AND REALISATION PV ROOF-TOP POWER PLANT 400KW IN THE FACTORY "EP BELT"-LOZNICA	
Zeljko V. DESPOTOVIC, Marko S. DJUROVIC .....	<b>67</b>
<b>5. PRENAMENA NAPUŠTENIH ILI STARIH NAFTNIH POLJA ZA IZGRADNJU GEOTERMALNIH ELEKTRANA</b>	
THE CONVERSION OF ABANDONED OR MATURE OIL FIELDS INTO GEOTHERMAL POWER PLANT LOCATIONS	
Ivan RAJSL, Sara RAOS .....	<b>79</b>
<b>6. POBOLJŠANJE SPOSOBNOSTI SAMOIZLEČIVANJA I ŽILAVOSTI MIKROKAPSULA SA TUNG ULJEM DODATKOM GRAFENSKIH NANOPLOCICA I NJIHOVA PRIMENA U EPOKSI SISTEMU</b>	
THE IMPROVEMENT OF SELF-HEALING CAPABILITY AND TOUGHNESS OF MICROCAPSULES WITH TUNG OIL BY THE ADDITION OF GRAPHENE NANOPATELETS AND THEIR APPLICATIONS IN EPOXY SYSTEM	
Natasa TOMIC, Abdullah MUSTAPHA, Maitha ALMHEIRI, Mohamed Nasr SALEH .....	<b>87</b>
<b>7. MODEL SOLARNOG PANELA SA SOLARNIM TRAGAČEM, UPRAVLJAN POMOĆU ARDUINO UNO MODULA</b>	
MODEL OF THE SOLAR PANEL WITH SOLAR TRACKER CONTROLLED BY THE ARDUINO UNO BOARD	
Ivan TODORIC, Djordje DIHOVICNI, Dragan KRECULJ, Sanja JEVTIC, Nada RATKOVIC KOVACEVIC .....	<b>93</b>
<b>8. TERMoeLEKTRIČNI EFEKAT KAO IZVOR ENERGIJE U PRUŽNIM ŽELEZNIČKIM APLIKACIJAMA</b>	
THERMOELECTRIC EFFECT AS A SOURCE OF ENERGY IN RAILWAY TRACKSIDE APPLICATIONS	
Sanja JEVTIC, Milesa SREČKOVIĆ, Dragan KRECULJ, Nada RATKOVIĆ KOVACEVIC.....	<b>101</b>
<b>9. POREĐENJE RAZNOVRNIH TIPOVA ENERGIJE OD POKRETNIH VODA</b>	
COMPARISON OF VARIOUS TYPES OF ENERGY FROM MOVING WATERS	
Djordje DIHOVICNI, Dragan KRECULJ, Olga JAKSIC, Nada RATKOVIC KOVACEVIC .....	<b>107</b>
<b>10. ISPITIVANJE LIF/B SISTEMA KORIŠĆENJEM NEGATIVNOG MODA LDI MS: MOGUĆI SISTEM ZA SKLADIŠTENJE VODONIKA</b>	
INVESTIGATION OF LIF/B SYSTEM USING THE NEGATIVE MODE LDI MS: A POSSIBLE HYDROGEN STORAGE SYSTEM	
Filip VELJKOVIC, Bojan JANKOVIC, Ivana STAJCIC, Milovan STOJILJKOVIC, Marija JANKOVIC, Djordje KAPURAN, Suzana VELICKOVIC .....	<b>115</b>
<b>11. UŠTEDA ENERGIJE PRILIKOM ELEKTROLITIČKOG DOBIJANJA VODONIKA-POREĐENJE DVOKOMPONENTNIH I TROKOMPONENTNIH JONSKIH AKTIVATORA</b>	
ENERGY SAVINGS IN ELECTROLYTIC HYDROGEN PRODUCTION – COMPARISON OF BINARY AND TERNARY ACTIVATORS	
Sladjana MASLOVARA, Dragana VASIC ANICIJEVIC, Snezana BRKOVIC, Vladimir NIKOLIC, Milica MARCETA.....	<b>119</b>

<b>12. KINETIKA TERMALNE DEGRADACIJE LIGNOCELULOZNOG OTPADA NA BAZI KOŠTICA BRESKVE</b> THERMAL DEGRADATION KINETICS OF LIGNOCELLULOSIC PEACH STONE WASTE Zorica LOPIČIĆ, Anja ANTANASKOVIĆ, Slobodan CVETKOVIC, Vladimir ADAMOVIĆ, Tatjana SOSTARIC, Jelena AVDALOVIC, Mirjana KIJEVCANIN .....	<b>125</b>
<b>13. THERMAL PROPERTIES OF RAPIDLY SOLIDIFIED Cu-Al-Ni-Mn SHAPE MEMORY ALLOY</b> <b>Borut KOSEC</b> , Milan BIZJAK, Mirko GOJIC, Ales NAGODE, Ivana IVANIC, Blaž KARPE .....	<b>133</b>
<b>14. PROCENA POTENCIJALA POLJOPRIVREDNO-FOTONAPONSKIH SISTEMA U SRBIJI</b> ASSESSMENT OF THE AGRIVOLTAIC POTENTIAL IN SERBIA Aleksandar IVANCIC, Melita ROGELJ, Bora OBRADOVIC, Slaviša JELISIC.....	<b>139</b>

### Energetska efikasnost u kontekstu primene RES:

<b>1. ULOGA KUPCA-PROIZVOĐAČA (PROZJUMERA) U PRIMENI OIEE</b> <b>U SRBIJI: PRE-PREKE I MOGUĆNOSTI</b> THE ROLE OF THE BUYER-PRODUCER (PROSUMER) IN THE IMPLEMENTATION OF RES IN SERBIA: OBSTACLES AND OPPORTUNITIES Marina NENKOVIC-RIZNIC, Borjan BRANKOV, Mila PUCAR, Ana STANOJEVIC.....	<b>147</b>
<b>2. PRIMENA SERIJSKE VEZE KOMPONENTI FREKVENTNO ZAVISNIH KOMPONENTI ISTOG</b> <b>TIPA U SISTEMIMA SA OBNOVLJIVIM IZVORIMA ENERGIJE</b> APPLICATION OF A SERIES CONNECTION OF THE SAME TYPE BANDPASS FREQUENCY DEPENDENT COMPONENTS IN SYSTEMS WITH RENEWABLE ENERGY SOURCES Tykhon SYTNIKOV, Igor PEREKRESTOV, Andrey CHMELECKSKY, Pavlo STUPEN, Valerii SYTNIKOV.....	<b>159</b>
<b>3. SMANJENJE GUBITAKA U DISTRIBUTIVNOJ MREŽI UVAŽAVAJUĆI NESIGURNOST</b> <b>SNAGE OPTEREĆENJA I DISTRIBUIRANE PROIZVODNJE IZ OBNOVLJIVIH IZVORA</b> REDUCTION OF LOSSES IN THE DISTRIBUTION NETWORK CONSIDERING THE UNCERTAINTY OF LOAD AND RENEWABLE DISTRIBUTED GENERATION POWER Nikola KRSTIC, Dragan TASIC, Teodora DENIC.....	<b>165</b>
<b>4. TEHNOLOGIJE ZA PRAĆENJE POLJOPRIVREDNIH ZASADA POMOĆU BESPILOTNIH LETILICA</b> TECHNOLOGIES FOR MONITORING AGRICULTURAL CROPS USING UAV Njegos DRAGOVIC, Milovan VUKOVIC, Snezana UROSEVIC .....	<b>173</b>
<b>5. MIKRO STEP ELEKTROMOTORNI POGON KONTROLISAN MIKROKONTROLEROM</b> MICRO STEP ELECTRIC DRIVE CONTROLLED BY MICROCONTROLLER Misa STEVIC, Zoran STEVIC, Predrag STOLIC, Ilija RADOVANOVIC, Dejan ILIC, Zoran JOVANOVIĆ.....	<b>181</b>
<b>6. SMART MATERIJALI I SAVREMENI KONTEKST ZA FUNKCIONALIZACIJU OBNOVLJIVIH</b> <b>IZVORA ENERGIJE U GALERIJSKOM PROSTORU</b> SMART MATERIALS AND CONTEMPORARY CONTEXT FOR THE FUNCTIONALIZATION OF RENEWABLE ENERGY SOURCES IN THE GALLERY SPACE Suzana POLIC, Sanja PETRONIC, Marko JARIC.....	<b>185</b>

<b>7. BLOCKCHAIN I RANE VIZUELIZACIJE KORIŠĆENJA ENERGIJE VETRA U MUZEJSKIM KOLEKCIJAMA</b>	
BLOCKCHAIN AND EARLY VISUALIZATION OF THE USE OF WIND ENERGY IN MUSEUMS COLLECTIONS	
Suzana POLIC .....	<b>195</b>
<b>8. ENERGETSKA EFIKASNOST U ELEKTRIČNIM VOZILIMA – PREGLED</b>	
ENERGY EFFICIENCY IN ELECTRIC VEHICLES – AN OVERVIEW	
Zoran STEVIC, Ilija RADOVANOVIĆ, Predrag STOLIC, Sanja PETRONIC, Marko JARIC, Misa STEVIC, Dejan ILIC.....	<b>203</b>
<b>9. TOPOLOGIJE NEIZOLOVANIH DC-DC KONVERTORA SA POBOLJŠANIM KARAKTERISTIKAMA</b>	
NON-ISOLATED DC-DC CONVERTERS TOPOLOGIES WITH IMPROVED CHARACTERISTICS	
Oleksii YAMA, Zoran STEVIC, Oleksandr BONDARENKO .....	<b>209</b>
<b>10. MOGUĆNOST PRIMENE ULTRAZVUČNE KAVITACIJE U PROCESU PRERADE INDUSTRIJSKIH OTPADNIH VODA</b>	
POSSIBILITY OF USING ULTRASONIC CAVITATION IN THE PROCESS OF INDUSTRIAL WASTEWATER TREATMENT	
Sladjana JEZDIMIROVIC, Marina DOJCINOVIC .....	<b>219</b>
<b>11. ZNAČAJ DISTRIBUCIJE TOPLOTE U SAVREMENIM ENERGETSKI EFIKASNIM ELEKTRIČNIM VOZILIMA</b>	
IMPORTANCE OF HEAT DISTRIBUTION IN MODERN ENERGY EFFICIENT ELECTRICAL VEHICLES	
Zoran STEVIC, Borivoje BEGENISIC, Dušan MURGASKI, Luka STAJIC, Sanja PETRONIC, Ilija RADOVANOVIĆ, Suzana POLIC .....	<b>227</b>
<b>12. PRIMERI PRIMENE VIŠEKRITERIJUMSKOG ODLUČIVANJA U OBLASTI OBNOVLJIVIH IZVORA ENERGIJE</b>	
EXAMPLES OF THE APPLICATION OF MULTI-CRITERIA DECISION-MAKING IN THE FIELD OF RENEWABLE ENERGY SOURCES	
Zoran STIRBANOVIC, Dragiša STANUJKIC, Jovica SOKOLOVIC.....	<b>233</b>

### **Životna sredina, održivost i politika:**

<b>1. RAZMATRANJE PRISUSTVA FENANTRENA U OPŠTINI BOR NA BAZI NJEGOVOG SADRŽAJA U LIŠĆU I STABLJKAMA HEDERA HELIX L.</b>	
A CONSIDERATION OF PHENANTHRENE PRESENCE IN BOR'S MUNICIPALITY BASED ON ITS CONTENT IN LEAVES AND STEMS OF HEDERA HELIX L.	
Aleksandra D. PAPLUDIS, Slađana C. ALAGIC, Snezana M. MILIC, Jelena S. NIKOLIC, Dragana V. MEDIĆ, Zoran M. STEVIC, Vesna P. STANKOV JOVANOVIĆ.....	<b>239</b>
<b>2. PERSPEKTIVE GRADSKOG VAZDUŠNOG SAOBRAĆAJA U BEOGRADU, SRBIJA</b>	
PROSPECTS OF URBAN AIR MOBILITY IN BELGRADE, SERBIA	
Jelena SVORCAN, Djordje CANTRAK, Jelena ANDRIC, Andrea IANIRO.....	<b>245</b>

<b>3. ULOGA SINERGIJE RUDARSKIH I RAČUNARSKIH TEHNOLOGIJA U PROCESU TRANZICIJE KA OBNOVLJIVIM IZVORIMA ELEKTRIČNE ENERGIJE</b>	
THE ROLE OF THE SYNERGY OF MINING AND COMPUTER TECHNOLOGIES IN THE PROCESS OF TRANSITION TO RENEWABLE ELECTRICAL POWER SOURCES	
Predrag STOLIC, Ilija RADOVANOVIĆ, Zoran STEVIĆ, Dejan PETROVIĆ.....	<b>253</b>
<b>4. ODRŽIVOST REŠENJA ZASNOVANIH NA OBNOVLJIVIM IZVORIMA ELEKTRIČNE ENERGIJE – INFORMATIČKI PRISTUP</b>	
SUSTAINABILITY OF SOLUTIONS BASED ON RENEWABLE SOURCES OF ELECTRICITY - ICT APPROACH	
Predrag STOLIC, Ilija RADOVANOVIĆ, Zoran STEVIĆ .....	<b>261</b>
<b>5. CHATGPT, MATERIJALI I OBNOVLJIVI IZVORI ENERGIJE: JEDAN NEELABORIRANI PROSTOR</b>	
CHATGPT, MATERIALS AND RENEWABLE ENERGY SOURCES: ONE UNREALIZED SPACE	
Suzana POLIĆ, Sanja PETRONIĆ, Marko JARIĆ.....	<b>269</b>
<b>6. ANALIZA STRUKTURE OŠTEĆENJA GRAĐEVINSKIH KONSTRUKCIJA NA OSNOVU ODREĐIVANJA FRAKCIONOG SASTAVA OSTATAKA</b>	
ANALYSIS OF THE STRUCTURE OF BUILDING STRUCTURE FAILURES BASED ON THE DETERMINATION OF THE FRACTIONAL COMPOSITION OF DEBRIS	
Valeriia CHORNA, Elena PONOMARYOVA, Sergey SHATOV, Liliia DRUZHININA.....	<b>279</b>
<b>7. UTICAJ EFEKTA STAKLENE BAŠTE NA KLIMATSKE PROMENE</b>	
THE INFLUENCE OF THE GLASS GARDEN EFFECT ON CLIMATE CHANGES	
Sladjana JEZDIMIROVIĆ, Marina DOJCINOVIĆ .....	<b>287</b>
<b>8. PRIMENA TEHNOLOGIJE 3D ŠTAMPE BETONA U REPUBLICI SRBIJI</b>	
APPLICATION OF 3D CONCRETE PRINTING TECHNOLOGY IN SERBIA	
Stefan Z. MITROVIĆ, Ivan IGNJATOVIĆ.....	<b>295</b>
<b>9. ULOGA VODOPROPUSNIH PROIZVODA U POPLOČAVANJU URBANIH SREDINA U SVETLU ODRŽIVOG KORIŠĆENJA RESURSA</b>	
THE ROLE OF PERMEABLE PRODUCTS IN THE PAVING OF URBAN ENVIRONMENT IN THE LIGHT OF SUSTAINABLE USE OF RESOURCES	
Marina ASKRABIĆ, Aleksandar RADEVIĆ, Aleksandar SAVIĆ .....	<b>301</b>
<b>10. OTPADNO STAKLO KATODNIH CEVI U PRIPREMI BETONA – POVEĆAVANJE ODRŽIVOSTI</b>	
CATHODE RAY TUBE WASTE GLASS IN CONCRETE PREPARATION – INCREASING SUSTAINABILITY	
Ivana JELIĆ, Aleksandar SAVIĆ, Tatjana MILJOJČIĆ, Marija SLJIVIĆ-IVANOVIĆ, Marija JANKOVIĆ, Slavko DIMOVIĆ, Dimitrije ZAKIĆ, Dragi ANTONIJEVIĆ .....	<b>309</b>
<b>11. DOPRINOS STUDIJI VEGETACIJSKOG POKRIVAČA: STUDIJA SLUČAJA ZELENIH POVRŠINA U GRADU HRAOUA (ALŽIR)</b>	
CONTRIBUTION TO THE STUDY OF VEGETATION COVER: A CASE STUDY OF GREEN SPACES IN THE CITY OF HRAOUA (ALGERIA)	
Mostafia BOUGHALEM .....	<b>317</b>

<b>12. TRANZICIJA KA OBNOVLJIVIM IZVORIMA ENERGIJE, DEKARBONIZACIJA I PROMENE U ENERGETSKOM SEKTORU KOJE UTIČU NA RADNIKE U TRADICIONALNIM INDUSTRIJAMA</b> TRANSITION TO RENEWABLE ENERGY SOURCES, DECARBONIZATION, AND CHANGES IN THE ENERGY SECTOR AFFECTING WORKERS IN TRADITIONAL INDUSTRIES Miloš CURCIC .....	<b>323</b>
--	------------

### **Aplikacije:**

<b>1. IMPLEMENTACIJA SOLARNE ELEKTRANE SNAGE 200 KWP NA RAVNOM KROVU U PARAĆINU</b> IMPLEMENTATION OF 200 KWP SOLAR POWER PLANT ON A FLAT ROOF IN PARAĆIN Bosko IVANKOVIC, Zoran LAZAREVIC, Ilija RADOVANOVIC, Misa STEVIC, Predrag STOLIC, Dejan ILIĆ, Zoran STEVIC .....	<b>329</b>
<b>2. FIZIČKO-HEMIJSKA KARAKTERIZACIJA ŠTAMPANIH PLOČA</b> PHYSICO-CHEMICAL CHARACTERIZATION OF PCBs Silvana B. DIMITRIJEVIC, Aleksandra T. IVANOVIC, Srdjana MAGDALINOVIC, Stefan S. DJORDIJEVSKI, Stevan P. DIMITRIJEVIC .....	<b>333</b>
<b>3. DEALLOYING PDNI5 LEGURE U 0.5M SULFATNOJ KISELINI</b> DEALLOYING OF PDNI5 ALLOY IN 0.5M SULFURIC ACID Stevan P. DIMITRIJEVIC, Silvana B. DIMITRIJEVIC, Aleksandra T. IVANOVIC, Renata KOVACEVIC .....	<b>341</b>
<b>4. SAGOREVANJE OTPADNOG TERMOBARIČNOG EKSPLOZIVA POD KONTROLISANIM USLOVIMA KAO IZVOR ENERGIJE</b> COMBUSTION OF WASTE THERMOBARIC EXPLOSIVE UNDER CONTROLLED CONDITIONS AS A SOURCE OF ENERGY Danica BAJIC, Mirjana KRSTOVIC, Mladen TIMOTIJEVIC, Bojana FIDANOVSKI .....	<b>351</b>
<b>5. INTERAKCIJE LASERA OD INTERESA ZA MATERIJALE U SISTEMIMA I KOMPONENTAMA U TRANSFORMACIJI ENERGIJE U LINEARNOM I NELINEARNOM OPSEGU</b> LASER INTERACTION OF INTEREST FOR MATERIALS IN SYSTEMS AND COMPONENTS IN ENERGY TRANSFORMATION IN LINEAR AND NONLINEAR RANGES Milesa SRECKOVIC, Aleksandar BUGARINOVIC, Milanka PECANAC, Zoran KARASTOJKOVIC, Milovan JANIĆIJEVIC, Aleksander KOVACEVIC, Stanko OSTOJIC, Nenad IVANOVIC .....	<b>359</b>
<b>6. DETEKCIJA MELASE LAŽNIH DATULA INFRACRVENOM SPEKTROKOPIJOM PRIMENOM HIJERARHIJSKE KLASIFIKACIJE</b> DETECTION OF DATE MOLASSES ADULTERATED BY INFRARED SPECTROSCOPY USING ASCENDING HIERARCHICAL CLASSIFICATION Samir CHERIGUI, Ilyes CHIKHI, Hadj FAYÇAL DERGAL, Ferial CHELLALI, Hanane CHAKER .....	<b>369</b>
<b>7. DETEKCIJA FALSIFIKOVANJA MELASE GROŽĐA FIZIKO-HEMIJSKIM PARAMETRIMA</b> DETECTION OF ADULTERATION OF GRAPE MOLASSES BY PHYSICO-CHEMICAL PARAMETERS Samir CHERIGUI, Ilyes CHIKHI, Hadj FAYÇAL DERGAL, Ferial CHELLALI, Hanane CHAKER .....	<b>373</b>

<b>8. SENZOR SALINITETA ZASNOVAN NA HEKSAGONALNOM FOTONOM KRISTALNOM VLAKNU</b> SALINITY SENSOR BASED ON A HEXAGONAL PHOTONIC CRYSTAL FIBER Ilhem MIREL, Hicham CHIKH-BLED.....	<b>377</b>
<b>9. NAPREDAK U FOTONSKIM KRISTALNIM VLAKNAMA: METODE PROIZVODNJE I PRIMENA ŠIROKOG SPEKTRA</b> ADVANCEMENTS IN PHOTONIC CRYSTAL FIBER: FABRICATION METHODS AND BROAD-SPECTRUM APPLICATIONS Mohammed DEBBAL, Hicham CHIKH-BLED, Mouwefeq BOUREGAA, Mohammed CHAMSE EDDINE OUADAH .....	<b>385</b>
<b>10. ENERGETSKA EFIKASNOST PREDIZOLOVANIH PLASTICNIH CEVI</b> ENERGY EFFICIENCIES OF PRE-INSULATING PLASTIC PIPES Vasilis ZOIDIS.....	<b>393</b>
<b>11. STATISTIČKO MODELOVANJE NEKIH EKOLOŠKI PRIHVATLJIVIH LEGURA NA BAZI BAKRA</b> STATISTICAL MODELING OF SOME ENVIRONMENTALLY-FRIENDLY COPPER-BASED ALLOYS Aleksandra T. IVANOVIC, Silvana B. DIMITRIJEVIC, Stevan P. DIMITRIJEVIC, Branka B. PETKOVIC.....	<b>403</b>
<b>12. SPEKTROSKOPSKA ANALIZA NATRIJUM KARBONATA</b> SPECTROSCOPY ANALYSIS OF ACTIVATED SODIUM CARBONATE Natasa DJORDJEVIC, Milica VLAHOVIC, Slavica MIHAJLOVIC, Nenad VUSOVIC, Srdjan MATIJASEVIC .....	<b>409</b>
<b>13. ANALIZA PERFORMANSI KRUŽNOG FOTONSKOG KRISTALNOG VLAKNA ZA TERAHERC APLIKACIJE</b> PERFORMANCE ANALYSIS OF CIRCULAR PHOTONIC CRYSTAL FIBER FOR TERAHERTZ APPLICATIONS Mohammed CHAMSE EDDINE OUADAH, Mohammed DEBBAL, Assia AHLEM HARRAT, Hicham CHIKH-BLED, Mouwefeq BOUREGAA .....	<b>415</b>
<b>14. POSTUPAK IZRADE POLIMERNOG KALUPA ZA ISPITIVANJE NA ISTEZANJE BIOKOMPOZITNIH MATERIJALA</b> POLYMER MOULD MANUFACTURING FOR TENSILE TESTING OF BIOCOMPOSITE MATERIALS Marija BALTIC, Milica IVANOVIC, Igor STAMENKOVIC, Miloš VORKAPIC, Aleksandar SIMONOVIC .....	<b>421</b>
<b>15. HABANJE Ti-6Al-4V NANOKOMPOZITA SA DISPERGOVANIM ZrO<sub>2</sub> DOBIJENOG MEHANIČKIM LEGIRANJEM I SPARK PLAZMA SINTEROVANJEM</b> WEAR BEHAVIOR OF ZrO <sub>2</sub> DISPERSED Ti-6Al-4V ALLOY NANOCOMPOSITES PREPARED BY MECHANICAL ALLOYING AND SPARK PLASMA SINTERING R. KARUNANITHI, M. PRASHANTH, M. KAMARAJ, S. SIVASANKARAN .....	<b>427</b>
<b>16. PROIZVODNJA NISKOLEGIRANOG Cr-Mo-Ni ČELIKA U ELEKTROLUČNOJ PEĆI</b> PRODUCTION OF LOW ALLOY Cr-Mo-Ni STEEL IN ELECTRIC ARC FURNACE M. GOJIC, M. DUNDJER, S. KOZUH, I. IVANIC, D. DUMENCIC .....	<b>435</b>
<b>17. NUMERIČKA SIMULACIJA I DIZAJN SPOJNICA OD FOTONSKIH KRISTALNIH VLAKNA ZA SEPARACIJU TALASNIH DUŽINA</b> NUMERICAL SIMULATION AND DESIGN OF A PHOTONIC CRYSTAL FIBER COUPLER	

FOR WAVELENGTH SEPARATION Assia AHLEM HARRAT, Mohammed CHAMSE EDDINE OUADAH, Mohammed DEBBAL.....	445
<b>18. FOTOKATALITIČKA DEGRADACIJA KONGO CRVENE BOJE KORIŠĆENJEM KOMPOZITA UIO-66 METALO-ORGANSKIH MREŽNIH STRUKTURA I METALNIH OKSIDA</b> PHOTOCATALYTIC DEGRADATION OF CONGO RED DYE USING UIO-66 MOF-METAL OXIDES COMPOSITES Dimitrije PETROVIC, Marija EGERIC, Radojka VUJASIN, Yi-nan WU, Fengting LI, Ljiljana MATOVIC, Aleksandar DEVECERSKI .....	451
<b>19. EKSPERIMENTALNA OPTIČKA ANALIZA OTPORNOSTI NA LOM NERĐAJUĆEG ČELIKA</b> EXPERIMENTAL OPTICAL ANALYSIS OF STAINLESS STEEL FRACTURE BEHAVIOUR Katarina COLIC .....	461
<b>20. OPTIMIZOVANI PRORAČUN ČELIČNIH HALA NA DEJSTVO POŽARA</b> OPTIMIZED FIRE DESIGN FOR STEEL PORTA-FRAMED SHEDS Filip LJUBINKOVIĆ, Luís LAÍM, Aldina SANTIAGO .....	469
<b>21. HIDROFOBIZACIJA KALCITA STEARINSKOM KISELINOM MOKRIM POSTUPKOM</b> HYDROPHOBIZATION OF CALCITE BY WET METHOD USING STEARIC ACID Slavica MIHAJLOVIC, Nataša DJORDJEVIC, Vladan KASIC, Srdjan MATIJASEVIC.....	479
<b>22. INDEX ZA PROCENU STRUKTURALNE EFIKASNOSTI ČELIČNIH RAMOVA</b> INDEX FOR THE ASSESSMENT OF STRUCTURAL EFFICIENCY OF STEEL PORTAL FRAMES Filip LJUBINKOVIC, Luís Simões da SILVA .....	485
<b>23. RAZVOJ APARATURE ZA IN SITU ISPITIVANJE ANKERA NOSACA SOLARNIH PANELE</b> DEVELOPMENT OF THE APPARATUS FOR IN SITU TESTING OF SOLAR PANEL RACKING ANCHORS Gordana BROČETA, Aleksandar SAVIC, Milica VLAHOVIC, Sanja MARTINOVIC, Tatjana VOLKOV HUSOVIC.....	495
<b>24. POVEĆANJE EFIKASNOSTI DOBIJANJA BIOGASA I NJEGOVOG KORIŠĆENJA U POSTROJENJU ZA TRETMAN KOMUNALNIH OTPADNIH VODA</b> INCREASING THE EFFICIENCY OF BIOGAS PRODUCING AND ITS UTILIZATION IN THE MUNICIPAL WASTEWATER TREATMENT PLANT Darja ZARKOVIC, Milica VLAHOVIC, Bilyana ISZITY.....	503
<b>25. ISPITIVANJE MORFOLOGIJE SUMPOR-POLIMERNOG KOMPOZITA MORPHOLOGY</b> INVESTIGATION OF SULFUR-POLYMER COMPOSITE Milica VLAHOVIC, Kong FAH TEE, Aleksandar SAVIC, Nataša DJORDJEVIC, Slavica MIHAJLOVIC, Tatjana VOLKOV HUSOVIC, Nenad VUSOVIC .....	513
<b>26. PRIMENA VARENJA, TVRDOG I MEKOG LEMLJENJA U IZRADI SOLARNIH SISTEMA</b> APPLICATION OF WELDING, BRAZING AND SOLDERING IN SOLAR SYSTEMS MANUFACTURING Zoran KARASTOJKOVIC, Milesa SRECKOVIC, Misa STEVIC .....	521
<b>27. ŠTETNI EFEKTI LEGURA ZA LEMLJENJE IZ ŠTAMPANIH KOLA PRILIKOM ZAJEDNIČKOG TOPLJENJA SA GVOZDENIM I ČELIČNIM DELOVIMA</b> HARMFULL EFFECTS OF SOLDERING ALLOYS FROM PRINTED CIRCUITS WHEN MELTED TOGETHER WITH IRON&STEEL COMPONENTS Zoran KARASTOJKOVIC, Ognjen RISTIC, Misa STEVIC .....	529

# ULOGA SINERGIJE RUDARSKIH I RAČUNARSKIH TEHNOLOGIJA U PROCESU TRANZICIJE KA OBNOVLJIVIM IZVORIMA ELEKTRIČNE ENERGIJE

## THE ROLE OF THE SYNERGY OF MINING AND COMPUTER TECHNOLOGIES IN THE PROCESS OF TRANSITION TO RENEWABLE ELECTRICAL POWER SOURCES

Predrag STOLIĆ<sup>1\*</sup>, Ilija RADOVANOVIĆ<sup>2,3</sup>, Zoran STEVIĆ<sup>1,3</sup>, Dejan PETROVIĆ<sup>1</sup>

<sup>1</sup>University of Belgrade, Technical Faculty in Bor

<sup>2</sup>University of Belgrade, Innovation Center of the School of Electrical Engineering

<sup>3</sup>University of Belgrade, School of Electrical Engineering

pstolic@tfbor.bg.ac.rs (\*Correspondence)

*Kada se govori o povezivanju rudarstva i savremenih informaciono-komunikacionih tehnologija, do sada se uglavnom ta povezanost odnosila na osavremenjavanje određenih postupaka u rudarstvu upotrebom odgovarajućih računarskih rešenja. Ranije su to uglavnom bila određena rešenja namenjena ostvarivanju određenog stepena automatizacije u raznim tradicionalnim postupcima u rudarskim objektima, dok danas ta rešenja dostižu svoju punu snagu od primene raznih vrsti inteligentnih i pametnih senzora u podzemnoj eksploataciji, preko raznih analitika i predikcija zasnovanih na najnovijim algoritmima veštačke inteligencije, pa na primer sve do razvoja potpunog autonomnog transporta u površinskoj eksploataciji. Dakle, kao što je spomenuto, radi se ekskluzivno o primeni informaciono-komunikacionih tehnologija u domenu rudarstva. Međutim, postavlja se pitanje, da li se može postići i drugačije dejstvo, odnosno primena rudarskih metoda, tehnologija i rešenja u računarskom domenu i kakve se pogodnosti mogu ostvariti ovim obrnutim smerom primene. U radu će se predstaviti primer iz svetske prakse, odnosno kako je jedan napušteni rudarski objekat transformisan i primenjen za razvoj jednog savremenog produkcijskog rešenja u domenu informaciono-komunikacionih tehnologija. Zatim će se analizirati potencijalna primenljivost ovakvog rešenja u jednom širem smislu na rudarskim objektima na teritoriji Republike Srbije, a posebno će se ukazati na mogućnosti primene rešenja ne samo u napuštenim rudarskim objektima, već i u aktivnim rudarskim objektima u kojima se trenutno ostvaruje proizvodnja. Na kraju predstavljenih analiza posebno će se dati osvrt kakvi se potencijali i dodatne mogućnosti ostvaruju primenom ovakvih rešenja u energetsom domenu sa posebnim osvrtom na benefite koja ovakva rešenja ostvaruju u području primene i razvoja rešenja zasnovanih na upotrebi obnovljivih izvora električne energije.*

**Ključne reči:** rudarski objekti; rudarstvo; informaciono-komunikacione tehnologije; obnovljivi izvori električne energije

*Connection of mining and modern information and communication technologies, until now, mainly referred to the modernization of certain procedures in mining using appropriate computer solutions. Previously, these were mainly certain solutions aimed at achieving a certain degree of automation in various traditional procedures in mining facilities, while today these solutions reach their full strength from the application of various types of intelligent and smart sensors in underground exploitation, through various analytics and predictions based on the latest artificial intelligence algorithms, to development of fully autonomous transport in surface exploitation and similar applications. So, as mentioned, it is exclusively about the application of information and communication technologies in the field of mining. However, the question arises whether a different effect can be achieved, that is, the application of mining methods, technologies and solutions in the ICT domain, and what benefits can be realized by this reverse direction of application. The paper will present an example from world practice, that is, how an abandoned mining facility was transformed and applied for the development of a modern production solution in the field of*

*information and communication technologies. Then, the potential applicability of such a solution in a broader sense to mining facilities on the territory of the Republic of Serbia will be analyzed, and the possibility of applying the solution not only in abandoned mining facilities, but also in active mining facilities where production is currently being realized will be pointed out. At the end of the presented analysis, there will be an overview of the potential and additional opportunities realized by the application of such solutions in the energy domain, with a special focus on the benefits that such solutions achieve in the area of application and development of solutions based on the use of renewable electrical power sources.*

**Key words:** *mining facilities; mining; information and communication technologies; renewable electrical power sources*

## 1 Introduction

With the progress of information and communication technologies, a significant part of the world's electricity production is beginning to be spent precisely on achieving the goals that are provided with the help of the aforementioned technologies. Two key factors are responsible for this increase. The first factor is directly related to the direction of society at the global level towards an information-oriented society. This means that all decisions, all actions, and all processes are based on timely, quality and adequate information, and as is already known, information is directly dependent on data. Society's orientation towards the information society and the processes of digital transformation, which are ongoing at many levels, have significantly increased the world volume of data, which in recent years has been measured in tens of zettabytes, with estimates that in the period 2022-2023 the limit of 100 zettabytes will be broken, and, already in 2024, that limit will approach the amount of 150 zettabytes of data at the world level [1].

The mentioned large volume of data should be accompanied by appropriate infrastructural changes. Therefore, in accordance with this, the number of data centers is constantly increasing worldwide, the goal of which is to provide an adequate response to the needs of the entire data processing process, starting from their collection and storage, through processing, to the storage of the obtained results. Many large companies own a large number of data centers in different locations, and even countries that build their own infrastructure capacities and open their own data centers are involved in the process. For example, the Republic of Serbia opened its own state data center in Kragujevac [2], which is in the process of further expansion.

Data centers represent extremely complex and advanced infrastructure projects. Complexity can vary significantly depending on the size of the data center, type, purpose, fulfillment of certain conditions for certification according to various parameters, the environment in which the data center is located and many other parameters. So, for example, dark data centers [3] will have greater complexity due to the requirement to enable complete management without the presence and intervention of humans in all possible conditions, except in certain, extraordinary conditions. Data centers that meet the highest Tier standards [4] will have greater complexity than those built in accordance with lower standards and similar. What should be noted when considering a data center is its complexity in terms of the equipment it includes. Although the purpose of the center is the realization of various operations in the field of ICT, it includes not only ICT equipment, but also other equipment of various purposes and constructions, power supply equipment, equipment for humidity regulation, air conditioning equipment, firefighting equipment, lighting and others.

As can be assumed from the above, data centers are very energy-demanding solutions with a very significant share in the consumption of electricity at the world level. Huge efforts are being made to make data centers more energy efficient. In order to achieve energy efficiency, a combination of different approaches is used, new approaches are used in air conditioning, new, non-standard locations are used for the construction of data centers, energy efficient equipment is introduced and others. Also, there is a transformation of data centers from the point of view of providing the necessary electrical energy. The carbon footprint created by data centers is not negligible and it is necessary to make significant changes in this regard as well. In recent years, many companies have focused on clean sources of electrical energy, so in accordance with that, efforts are being made to ensure the

largest percentage of electrical energy from renewable sources. There are also cases where the transformation to renewable electrical power sources has been completed.

In these efforts, better conditions should be provided for a higher percentage of transformation to renewable electrical power sources. In addition, existing solutions based on renewable electrical power sources should be made sustainable. In the following, some existing solutions from practice will be considered, but some new potential solutions will also be pointed out.

## 2 Existing solutions

As already mentioned, in order to improve the work of data centers, non-traditional approaches are used in order to achieve even more efficient work of data centers. Information about some projects is not publicly available, some projects are presented to the public with a limited amount of information, while much more detailed information can be obtained about some projects, and some can even be visited in person with prior notice. Three projects will be considered here as an example of modern approaches without going into the detailed technical aspects of the projects themselves.

The first such project is Microsoft's Natick project [5]. The goal of the project is to consider the possible implementation of data centers in the water environment instead of the traditional one on land. The project consisted of two phases with different test objectives and different test locations [6]. In the first phase, an examination was made as to whether it is possible to operate the data center in underwater conditions and a comparative analysis of the data obtained from operational work in underwater conditions with the data obtained from operational work on land was carried out. In the second phase, it was considered whether it is possible to produce an underwater data center within a reasonable time frame, place it in the required location and make it economically acceptable. The success of the project was demonstrated in the achievement of several goals. Power usage effectiveness (PUE) [7] was 1.07 while Water usage effectiveness (WUE) was 0 [5] which represents exceptional values. To clarify, PUE represents the ratio of the total energy used by the data center with the total energy used by the IT equipment in that data center and in the ideal case it would be equal to 1 [7]. WUE represents water expressed in liters consumed per megawatt of power per minute and in the ideal case the value is 0. Here the ideal value is achieved due to no water consumption, while such a data center on land would show a water consumption of about 5 liters per kilowatt hour [5]. The entire supply of electricity is made using renewable electrical power sources using wind and solar energy (energy collected on land), as well as tidal and wave energy. This is an example of how breaking out of the traditional framework of thinking can lead to exceptional solutions in terms of energy efficiency and the application of renewable electrical power sources. In order to indicate the full potential of the solution obtained through the implementation of this project, it should be noted that in phase 2 of the project [6] it was proven that the complete solution can be produced, delivered and put into operational use in less than 90 days, as well as that the underwater data center during testing, used in real work by various Microsoft teams and others.

Another project that we would like to point out and which has been in use for many years is the project of an underground data center located in the Swiss Alps in several locations, better known as Swiss Fort Knox [8,9] consisted of two units Swiss Fort Knox I and Swiss Fort Knox II. The mentioned data center was created primarily from the need to build a data center with the highest level of security and is one of the most secure data centers in Europe. The data center was built by using the existing bunkers that were used by the Swiss army in earlier periods to make the facility safe from all kinds of threats. For this purpose, the data center was built according to the principles of complete independence in order to achieve a minimum of risks that may come from the outside environment. Thus, the data center has its own capacity for the production of electricity, as well as a special cooling system based on the natural resources of the Swiss Alps. Due to high security requirements, there is no availability of technical data for the systems located within the data center, so there is not enough data on the method of production and type of electricity. The cooling system used in the operation of the data center is known to use glacial water from an underground lake located at the location of the data center. It is assumed due to the very construction of the data center and due to some known characteristics that the data center achieves good energy efficiency, but due to the lack of appropriate

data, it is not possible to know how much PUE is actually achieved. We mention this data center here for the reason that they show how certain special purpose facilities can be used and transformed into high performance data centers. Also, here the primary vision of the data center was security, but it can be seen from the previous that along with the primary vision, the appropriate elements needed to achieve good energy efficiency can also be realized.

The next project, that is, a data center that is particularly worth considering, is the Lefdal Mine Datacenter (LMS) [10] realized within an abandoned mine [11] in just a few years after the end of mining production. It must be noted here that, since it is an underground data center as in the previous case, the previously described data center and LMS will share many similarities. In the description of the previous data center, it was mentioned that it was built as such due to the need for superior security. LMS was not built conceptually like the previously described data center, but it achieves high security because in this case it is also an underground facility and, in this case, it has a significant part of its own infrastructure, but it cannot, like the previously described data center, achieve complete independence from the outside world because it is conceptually different imagined. The guaranteed PUE is 1.15, however, it should be noted here that some parts of the data center achieve a lower PUE, which in some cases can be as high as 1.08. The WUE value is equal to 0 [12]. What makes LMS special is that it uses seawater for cooling purposes, which cools the closed circuit of fresh water to approximately 18 degrees Celsius using heat exchangers. This is feasible thanks to the proximity of the fjord, which contains extremely cold sea water thanks to the presence of several glaciers. It should also be noted that due to the difference in level (the mine is below sea level) there is no energy consumption because the water does not rise to a higher level [13]. Regarding the use of renewable sources of electricity, it is considered that the electricity used within the LMS is entirely electricity obtained from renewable sources. However, attention should be drawn here to two important factors. First, Norway, where the data center is located, is one of the leading countries in terms of generating electricity from renewable sources (98.5% of electricity). Second, the location of the data center itself is close to several electricity producers based on the use of renewable electrical power sources. We presented this data center in order to show how a mining facility can be transformed in a short time into an ICT facility and at the same time obtain a high-tech facility that meets the highest standards of energy efficiency.

### 3 New possibilities

#### 3.1 Using active mining facilities

In the previous chapter, some of the current, modern solutions that are applied in the construction of modern data centers that enable good energy efficiency and applicability of renewable electrical power sources are shown. Also, it has been shown that data centers can fulfill their role and even be more competitive when they are implemented in locations that were not primarily intended for the construction of data centers and that were not so much used for facilities of this purpose in some traditional sense. The question arises whether these are sporadic cases of application or whether this can be applied as a more universal rule. And can this kind of applicability be achieved in the territory of the Republic of Serbia? It is certain that underwater solutions for data centers will gain wider applicability in some future time, however, since they are still experimental and since their applicability in smaller water environments has yet to be confirmed, it will not be considered further. What should be pointed out and where there is a chance for a wider applicability are underground facilities, and the discussion will continue in that direction.

The previously considered cases of underground data centers used the existing capacities of facilities whose purpose was abandoned, so they became ideal candidates for conversion to other types of purposes, in this case in the field of ICT. This can be achieved if there are such facilities available, that is, if there are free underground facilities that can be brought to the purpose of data centers. It should be mentioned here that not every abandoned underground facility can be brought to the mentioned purpose since there may be various limiting factors in the given process. For example, there may have been a change in the configuration or characteristics of the terrain and the object is no longer stable and does not achieve this stability even with adaptive measures. Perhaps the object

contains flammable substances that cannot be neutralized or removed in any way, so electrical equipment used in the operation of data centers cannot be placed in it under any circumstances. There can be many such reasons, and accordingly, the number of usable underground facilities will be quite limited. The construction of a dedicated underground facility would require additional economic efforts, and waiting for the availability of a suitable abandoned underground facility cannot be considered a correct procedure because such realization can sometimes be predicted and sometimes not, sometimes it can occur in a short period of time, and sometimes it won't.

Therefore, instead of using abandoned underground facilities, it is proposed to use active mining facilities, that is, to expand the purpose of active mining facilities. Active mining objects, as their name suggests, were realized for the purpose of mining works, however, the proposal here is to expand that purpose and put a part of the active mining object for ICT purposes, specifically for the purpose of realizing a data center. This approach to the mentioned solution is based on the use of abandoned mining rooms within active underground mining facilities.

This approach to the mentioned solution is based on the use of abandoned mining rooms within active underground mining facilities. There are different mining rooms, and which one will be able to be used for ICT purposes depends on many different factors. Of course, the mining rooms will not be used in their original form, but will be adapted and brought to their changed purpose. In some cases, several rooms will be used in the same location, sometimes several rooms will be used but in different locations, and sometimes there may be several sets of rooms in different locations. What will be the configuration of the targeted solution depends on the concrete mining facility, the situation on the ground, as well as on the real possibilities.

The justification for introducing such a solution lies in several facts. First, the already existing underground facilities are used, so there will be a significant reduction of the funds needed for the construction of the required facility. From the point of view of security, since it is about underground facilities, it can be said that an extremely high level of data center security can be achieved in a simpler way with less resources compared to some other security measures that would have to be implemented in the case of above-ground facilities. Furthermore, there is a real chance for the realization of very low PUE and WUE values, which is aimed for in the realization of today's data centers. Energy efficiency can be achieved thanks to the fact that these are underground facilities in which certain influences that exist during work in classic data centers are significantly reduced, such as significantly lower ambient temperatures and similar parameters. It should be mentioned here that in most cases there are systems that are already used in mining production, and which can be used in the operation of a data center at the same location with certain adaptations. For example, the ventilation system that exists in underground mining facilities can be used for the needs of data center operation, of course, with certain adaptation to the new purpose and specific requirements that data center operation requires. The infrastructure that accompanies such facilities can potentially be used for the needs of the data centers in those facilities.

If we look at the application from the point of view of renewable electrical power sources, this situation favors their introduction, since the energy requirements of the mentioned solution can be significantly reduced. There is a decrease in the participation of certain elements, and the participation of certain elements is completely abolished, which significantly opens up the space for the application of solutions based on the renewable electrical power sources because the total energy consumption is in the appropriate margins for sustainability of mentioned applications.

Let us also mention that many potential benefits are realized from the application of this solution. If we look at the introduction of ICT technologies into mining processes, the existence of a data center at the very location of the mine enables a simpler introduction of automation, predictive technologies and similar operations that involve the participation of ICT technologies, quick access to information and similar procedures. Such data centers can significantly increase the income of companies, but they can significantly improve the mining companies themselves, on the basis of these data centers, space is created for much greater action, for making more informed decisions, better process management, predicting risks and other things. This approach can give a great opportunity for development on various grounds.





*Figure 2. The immediate surroundings of the Bor mine suitable for building a solar power plant*

As can be seen from the previous, there is a possibility of realizing underground data centers in the territory of the Republic of Serbia, with the achievement of high energy efficiency and the application of renewable electrical power sources.

## 4 Conclusion

The paper shows some of the latest trends in the construction of data centers with high energy efficiency and the use of renewable electrical power sources. One underwater solution and two underground solutions are shown. The presented underground solutions were realized in abandoned objects of various purposes. This enabled a simpler, more efficient and more economical realization of the most modern European data centers that are competitive on a global level.

However, there is always a limit to the number of abandoned underground facilities that can be adequately transformed into data centers. Accordingly, the paper presents a view of the possible transformation of inactive parts of active underground mines into modern data centers as a potentially more sustainable solution. Such a proposal enables the implementation of energy-efficient data centers that are suitable for the use of renewable electrical power sources.

The solution, as conceptually presented in the paper, is potentially applicable on the territory of the Republic of Serbia. It must be noted here that in Serbia there are also certain abandoned underground mining facilities due to the end of mining production, but that these facilities are not applicable for the realization of data centers due to various factors. These are mostly dangers that can arise due to the use of electrical equipment. This is another indicator that thoughts should be focused on the possibilities of realizing modern data centers in active underground facilities as an expanded purpose of the same.

The goal of this work is only to point out certain open possibilities that could be realized, and accordingly conceptual solutions are presented throughout the work. Practical implementation was not considered due to the wide complexity that needs to be analyzed, mastered and which implies a multidisciplinary approach through different areas of mining, energy, ICT and others. However, it is expected that one day this complexity will be successfully overcome and that similar solutions will be implemented in practice on a smaller scale.

## 5 References

- [1] 53 Important Statistics About How Much Data Is Created Every Day, FinancesOnline - Reviews for Business, 2023. Available at <https://financesonline.com/how-much-data-is-created-every-day/>. Last accessed on 10<sup>th</sup> September 2023.
- [2] Državni data centar: Gradimo digitalno društvo, Kancelarija za informacione tehnologije i elektronsku upravu, Republika Srbija, 2023. Available at <https://www.ite.gov.rs/tekst/sr/5273/drzavni-data-centar.php>. Last accessed on 10<sup>th</sup> September 2023.
- [3] Liquori, T., Lights Out Data Centers Explained. DataSpan, 2020. Available at <https://dataspan.com/blog/lights-out-data-centers-explained/>. Last accessed on 10<sup>th</sup> September 2023.
- [4] Tier Classification System, Uptime Institute, LLC., 2023. Available at <https://uptimeinstitute.com/tiers>. Last accessed on 10<sup>th</sup> September 2023.
- [5] Project Natick, Microsoft, 2020. Available at <https://natick.research.microsoft.com/>. Last accessed on 11<sup>th</sup> September 2023.

- [6] Roach, J., Microsoft finds underwater datacenters are realible, practical and use energy sustainably, Microsoft Source, 2020. Available at <https://news.microsoft.com/source/features/sustainability/project-natick-underwater-datacenter/>. Last accessed on 11<sup>th</sup> September 2023.
- [7] Stolić, P., Stević, Z., Dimitrijević, S., Stanimirović, Z., Stanimirović, I. Data handling culture – A forgotten aspect of the integration of renewable electrical power sources. In Proceedings of the 10<sup>th</sup> International Conference on Renewable Electrical Power Sources, Belgrade, Serbia, 2022, pp. 175-180. ISBN: 978-86-85535-13-0
- [8] Factsheet – Swiss Fort Knox Housing, Version 7, SIAG Secure Infostore AG, 2023. Available at [https://www.schweizer-webhosting.ch/file/datacenter/mount10-Factsheet\\_Housing\\_EN.pdf](https://www.schweizer-webhosting.ch/file/datacenter/mount10-Factsheet_Housing_EN.pdf). Last accessed on 11<sup>th</sup> September 2023.
- [9] Swiss Fort Knox: Known as Europe’s safest data center, Mount 10, 2023. Available at <https://mount10.ch/en/about-us/swiss-fort-knox/>. Last accessed on 11<sup>th</sup> September 2023.
- [10] Lefdal Mine Datacenter, 2023. Available at <https://www.lefdalmine.com>. Last accessed on 11<sup>th</sup> September 2023.
- [11] Lefdal Olivine Mine, Mindat.org, 2019. Available at <https://www.mindat.org/loc-225043.html>. Last accessed on 11<sup>th</sup> September 2023.
- [12] Sustainability, Lefdal Mine Datacenter, 2023. Available at <https://www.lefdalmine.com/sustainability-3/>. Last accessed on 11<sup>th</sup> September 2023.
- [13] Cooling, Lefdal Mine Datacenter, 2023. Available at <https://www.lefdalmine.com/facility-2/cooling/>. Last accessed on 11<sup>th</sup> September 2023.
- [14] Planovi razvoja - nacionalni - regionalni - evropski, AD Elektromreža Srbije, 2023. Available at <https://ems.rs/planovi-razvoja/>. Last accessed on 12<sup>th</sup> September 2023.