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# UPOREDNA TEHNO-EKONOMSKA ANALIZA PRIMENE POSTUPKA ODLAGANJA PEPELA I ŠLJAKE IZ TERMOELEKTRANA, TOPLANA I METALURŠKIH POSTROJENJA KONVENCIONALNIM POSTUPCIMA I VRAĆANJEM ISTIH «NA MESTO NASTANKA» ODNOSNO U PROSTORE NAPUŠTENIH RUDNIKA UZ PRETHODNU PRIPREMU I UZ UPOTREBU SAVREMENIH TEHNOLOGIJA ODLAGANJA, REKULTIVACIJE I REMEDIJACIJE I NAJSAVREMENIJIH METODA ZAŠTITE

***Izvod***

*Dosadašnja iskustva u proizvodnji i preradi metala, nemetala i ugljeva, ukazala su na ozbiljnost problema odlaganja otpadnih materija na površini terena, sa svim pratećim posledicama po poljoprivredno zemljište i ukupan ekosistem kao celinu. Obzirom da se radi o godišnjim količinama od nekoliko miliona $m^3$ ovog materijala, koji je gotovo uvek u izvesnoj meri otrovan, a ne retko i kancerogen, pitanje njegovog odlaganja u prirodi (najčešće na poljoprivrednom zemljištu ili neposredno uz njega u blizini postrojenja u kojima se stvara) i samim tim narušavanje ukupnog ekosistema mora biti tretirano sa odgovarajućom pažnjom. Stoga, odlaganje ovih materija predstavlja ozbiljan problem, koji zahteva ekološki prihvatljiva i ekonomski održiva rešenja.*

***Ključne reči:*** *Ekologija, ekonomija, održivi razvoj, rudarstvo, industrijske štete*

## 1. UVOD

Obzirom da je danas u svetu poznat veliki broj otrovnih jedinjenja, moguće ih je detaljno studijski ispitati da bi smo ih uspešno primenjivali (izbegavajući stvaranje, razlaganje, upotrebu i uništavanje) i stoga u krajnjoj instanci zaštitili životnu sredinu. Istovremeno velika grupa visoko toksičnih jedinjenja (VTJ), od kojih izdvajamo diokside i ostale, koji su relativno malo ispitani do sada zavređuju odgovarajuću pažnju tek od nedavno.

Na slici 1. data je uslovna šema ciklusa (VTJ) u prirodi kao refleksija stvarnih

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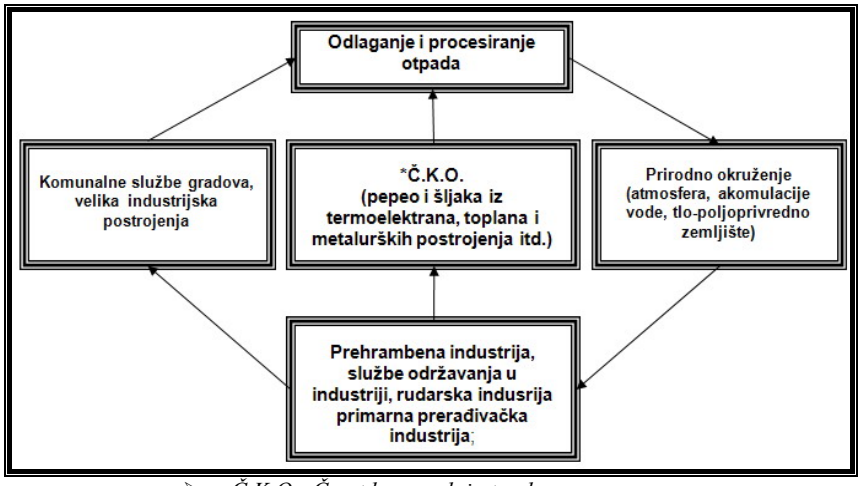
zbivanja u ovom trenutku. Kao što se uočava, emisija otrovnih materija učestvuje u tom lancu infiltrirajući se u okruženje, a potom u proces prerade, hranu, povrće i voće, razne proizvode životinjskog porekla (mleko, meso, jaja itd.) i tako se na ovaj ili onaj način vraćaju u ljudski organizam sa primerenim pripadajućim posledicama. Prirodno, najracionalniji pristup rešenju ovog problema nije eliminisan prihvatanjem i akumuliranjem (VTJ), već stremljenjem ka eliminisanju dobijenih toksičnih materija.Takođe, sasvim je prirodno, na taj način izbegavanje stvaranja (VTJ), odnosno razbijanje recirkulacionog ciklusa koji je šematski prikazan na slici 1. [Dimovski, 2003., Grechko, Denisov, 2001.], a rešenja za ovo nalaze se u procesiranju otpada primenom metoda korišćenja koje iz otpada istovremeno likvidiraju diokside (VTJ).




➢ *Č.K.O.- Čvrst komunalni otpad*

**Sl. 1.** *Šema postojećeg ciklusa kretanja toksičnih materija u prirodi*

Poseban problem predstavljaju tzv. «neovlašćena» odlaganja koja su najčešći slučaj. Tako dolazi do odlaganja materija sa visokom temperaturom u trenutku odlaganja (600-900°C) koja pri tome i dalje sagoreva i stvara emisiju otrovnih dioksidnih gasova direkto u atmosferu, što predstvlja između 25-30% najvećih zagađivača. Analize referentnih informacija naučnih i tehnoloških istraživanja omogućuju definisanje glavnih uslova koji omogućuju rešenje razmatranih problema tokom tretmana odgovarajućih materijala (otpada). Ovi uslovi su:

- ❖ Prilično visoka temperatura procesa (t > 1250°C);
- ❖ Oksidirajuća atmosfera (oksidacioni faktor sagorevanja a > 1.05);
- ❖ Konačno trajanje procesiranja proizvoda u ovim uslovima (D > 2sec.);
- ❖ Termalna trenutnost procesa (TIP)[****]

Iz prethodne analize nameće se zaključak da rešavanje problema odlaganja otpadnih materijala u prirodi predstavlja složen i zahtevan zadatak. Pri rešavanju ove vrste problema mogući su razni pristupi. Za eksperimentalna testiranja i tehno-ekonomska modeliranja, namenjena rešavanju ovog problema u radu su izabrani sledeći postupci:

[****] *Thermal instantaneity of process*

1. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, na postojeći (konvencionalni) način, tj. na poljoprivrednom i drugom zemljištu postupcima i na način kojim se, bez prethodne pripreme, maksimalno degradira površina terena, i potom ista privodi prvobitnoj nameni, sa više ili manje uspeha.
2. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije.
3. Tretman pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite.

Ovakav pristup izabran je iz razloga što je potrebno do detalja rasvetliti stvarno stanje u ovoj oblasti, uzimajući u obzir zahteve održivog razvoja i ekonomsku dimenziju rešavanja svakog problem, sa ciljem da se uprednom ekološko-ekonomskom analizom dođe do najprihvatljivijeg rešenja ovog problema.

## 2. EKSPERIMENTALNI DEO

Kao objekti eksperimentalnih testiranja izabrani su pepeilište termoelektrane Nikola Tesla u obrenovcu tzv. TENT A, i otvoreni otkopani prostori površinskih kopova rudarskog basena «Kolubara», otvoreni otkopani prostori površinskih kopova rudarsko-topioničarskog basena Bor i otvoreni otkopani prostori u Jami rudnika bakra Bor. Da bi se stekao uvid u stepen uticaja odloženih otpadnih materija (pepela i šljake iz termoelektrana, toplana i metalurških postrojenja), bez prethodne pripreme na obradivom i dugom poljoprivrednom zemljištu, odnosno u prirodi u opšte, u radu su prezentirani određeni rezultati istraživanja, iz kojih je moguće utvrditi uticaj odloženih materija na pedološki sastav zemljišta posle odlaganja. Rovni lignit iz rudarskog basena "Kolubara", koji se sagoreva u termoelektrani «TENT» A, ima vrlo neujednačen kvalitet. [Dželetović i sar., 2001.] Učešće mineralnih materija koje prate ugljenu supstancu varira, te se sadržaj pepela u rovnom (sirovom) lignitu iz rudarskog basena "Kolubara" kreće od 22 do 40%, dok se u očišćenom lignitu on kreće od 9,5 do 20 %. Očišćen lignit ima izmenjen hemijski sastav pepela u odnosu na sastav pepela rovnog uglja. Hemijski elementi koji se nalaze u ugljevima imaju uglavnom dvojako poreklo. Većina elemenata koje danas nalazimo u ugljevima potiče uglavnom iz ostataka biljnih i drugih živih organizama, od kojih su postali ugljevi. Pojedini mikroelementi koje danas nalazimo u ugljevima su, osim toga, mogli dospeti u ugljene slojeve i iz okoline, iz okolnih stena ili preko cirkulišućih podzemnih voda, koje nose niz rastvorenih mineralnih supstanci. Pepeo koji nastaje sagorevanjem lignitskog uglja rudarskog basena "Kolubara" poseduje, u poređenju sa fizičkim osobinama prirodnih zemljišta, malu specifičnu masu i izrazito nisku zapreminsku masu i u zbijenom i u rastresitom stanju, čime se objašnjava njegova visoka podložnost raznim erozionim uticajima, (tabela 1.).

***Tabela 1.*** *Fizičke osobine letećeg pepela iz TE "Kolubara"*

| | | | | |
|---|---|---|---|---|
| Specifična masa (g/cm$^3$) | 1,93 | 1,93 | 1,86-2,06 | 2,5-2,6 |
| Specifična površina (cm$^2$/g) | 4020 | 4020 | | |
| Ostatak na situ od 0,0063mm (%) | 27,6 | 36,1 | | |
| Zapreminska masa u rastresitom stanju (kg/m$^3$) | 600 | 550 | 462-539 | 1000 |
| Zapreminska masa u zbijenom stanju (kg/m$^3$) | 760 | 760 | - | 1700 |

Sadržaji pojedinih teških metala u pepelu (Tabela 2) su povišeni za pojedine biljne vrste i mogu biti toksičnih koncentracija. Relativno su visoke koncentracije: Va, V, Cd i Al; i one mogu uticati ne samo na rast biljaka, nego i na kvalitet semena.

***Tabela 2.*** *Hemijska analiza pepela koji nastaje sagorevanjem lignitskog uglja iz rudarskog basena "Kolubara" u termoelektranama.*

| | **TENT - A** | **TENT - B** | **TEK - A** |
|---|---|---|---|
| **Sastav** | | **(%)** | |
| $SiO_2$ | 55,40 | 56,20 | 50,35 |
| $Fe_2O_3$ | 24,87 | 24,47 | 24,39 |
| $Al_2O_3$ | 8,87 | 9,04 | 9,57 |
| CaO | 4,55 | 5,22 | 8,56 |
| MgO | 2,07 | 1,95 | 4,20 |
| $SO_3$ | 1,38 | 1,14 | 1,13 |
| $P2O_5$ | 0,07 | 0,08 | 0,22 |
| $TiO_2$ | 0,17 | 0,16 | 0,22 |
| $Na_2O$ | 1,49 | 0,90 | 0,45 |
| $K_2O$ | 1,06 | 0,75 | 0,87 |

## 3. PRIKAZ REZULTATA

### 3.1. Tehnološki opis mogućih varijanti rešavanja problema

#### 3.1.1. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, na postojeći (konvencionalni) način, tj. na poljoprivrednom i drugom zemljištu postupcima i na način kojim se, bez prethodne pripreme terena

Ovakvo rešenje problema odlaganje pepela i šljake je trenutno u aktivnoj primeni u većini aktivnih postrojenja koje u svom tehnološkom postupku stvaraju značajne količine ovih nusproizvoda. Ono se u osnovi sastoji u odlaganju ovog industrijskog otpada na obradivo i drugo poljoprivreno zemljište bez (ili samo delimično) prethodne

pripreme terena namenjenog ovoj svrsi, uz maksimalno degradiranje površina terena, koji se potom privodi prvobitnoj nameni, sa više ili manje uspeha. Rešenje se u osnovi sastoji u iskopu i uklanjanju produktovnog površinskog sloja poljoprivrednog zemljišta, iskopu niže ležećih slojeva do određene dubine, nasipanja sloja gline (ili bez toga), izradi drenažnih bunara i kanala oko iskopane kasete, i odlaganje pepela i šljake u iskopani prostor do projektom određene visine. Sa ekonomskog stanovišta, stvarni troškovi primene ovakvog sistema odlaganja, troškovi ekonomske štete od primene ove tehnologije i efekti ekoloških oštećenja su obrađeni u narednoj analizi. Direktni troškovi[*] održavanja i eksploatacije postojećeg sistema za prikupljanje, pripremu, transport i odlaganje pepela i šljake TE "Nikola Tesla A" iznose 11,70 Eur/t, odloženog pepla i šljake [Dražović i sar., 2010.].

### 3.1.2. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu terena i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije

Rešenje problema odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na ovaj način podrazumeva kompleks mera i postupaka kojima bi se postojeći sistem odlaganja otpadnih materija tehnološki unapredio, tako da se uticaji na životnu sredinu svedu u prihvatljive okvire i da se postupak rekultivacije i remedijacije učini održivim. Predloženo rešenje u osnovi se sastoji od primene savremenih mera zaštite okolnog zemljišta, voda i vazduha od uticaja odloženih materija. Takođe, tehnološko rešenje predviđa primenu gustih hidromešavina u postupku transporta i ugradnje pepela i šljake na deponiji.

Sa ekološkog aspekta on je povoljnije rešenje jer se najveći broj uticaja na životnu sredinu svodi u propisane granice, a pojedini uticaji se u potpunosti eliminišu. Zbog gotovo «hermetičke izolacije» prostora deponije uticaj odloženih materija na okolno poljoprivredno zemljište se svodi na minimum. Takođe primena guste hidromešavine smanjuje količinu vode u deponiji i njen uticaj na podzemne i površinske vode, a solidifikacija deponije u dužem vremenskom periodu potpuno eliminiše nastajanje uvala i depresija u prostoru deponije. Ugradnja geotekstilnih pokrivača i biorazgradivih materijala sa ugrađenim biljnim kulturama poboljšava remedijaciju zauzetog prostora. Ojačavanje visokih kosina «zelenim terasmeš sistemom i biorogozama», uz prethodnu solidifikaciju i nanošenje humusnog pokrivača, dopunski osigurava prostor od uticaja eolske erozije i spiranja čestica odloženog materijala.

[*] *Ovaj podatak dobijen je iz «Studije opravdanosti i rekonstrukcije sistema za prikupljanje, pripremu, transport i odlaganje pepela i šljake TE"Nikola Tesla A" sa idejnim projektom i studijom o proceni uticaja na životnu sredinu», Rudarski institut d.o.o.- Energoprojekt – entel a.d, 2010.*

**Sl. 2.** *Izgled i konstruktivni elementi zelenog terasmeh sistema*

### 3.1.3. Tretman pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite.

Jedan deo nastalih količina šljake i pepela iz metalurških postrojenja i termoelektrana nalazi primenu, zbog svojih pucolanskih svojstava u industriji cementa i hemijskoj industriji. Nažalost, potrebe za ovim materijalima u pomenutim granama privrede kreću se od 10-30% u odnosu na ukupnu količinu ovih materija. [Dimovski, 2012.]

Na ovom mestu obrađena je, kao jedna od alternativa, tehnologija rešavanja ovog problema kroz njegovo vraćanje u utrobu zemlje, u stare otkopa.

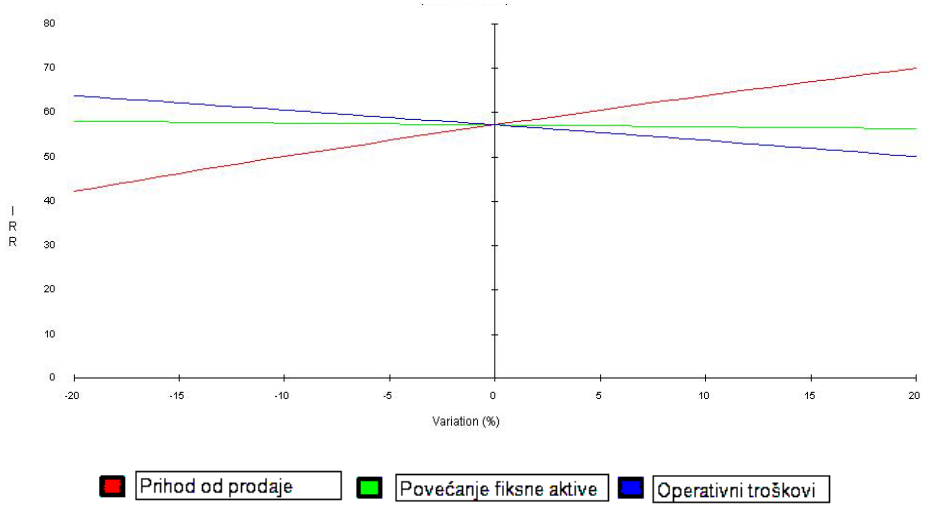
### 3.2. Ekonomska analiza predloženih rešenja

Za ekonomsko finansijsku ocenu primenjen je postupak ekonomske ocene projekata po UNIDO standardima i standardima svetske banke. [Hauarnek i sar., 2001.]. Primenjeni model kao konstantu u svakoj od razmatranih mogućih rešenja uzima procenjenu visinu štete nastale od neprimenjivanja intenzivne poljoprivredene proizvodnje određenih kultura na prostoriji namenjenoj za deponiju pepela i šljake, u period ekploatacije prostora deponije i ostale relevantne troškove izgradnje i eksploatacije deponija po opisanom tehnološkom postupku. Kao osnovni proizvod, za ekonomsku ocenu u ekonomskom modelu figurira proizvedena električna energija, i eventualno kao dopunski program cena pepela i šljake na komercijalnom tržištu, u slučaju termoelektrana, odnosno količine proizvedenih obojenih

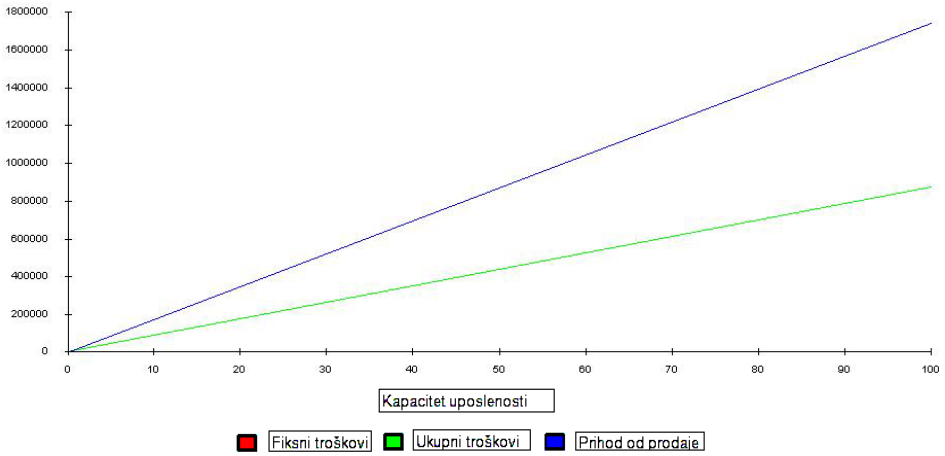
metala i ostalih proizvoda u slučaju rudnika u koje se odlažu ove materije. Rezultati modelovanja dati su u narednim tabelama i dijagramima.

### 3.2.1. Procena ekonomskih parametara primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu terena i uz upotrebu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije

Kako je već navedeno, površina poljoprivrednog zemljišta, koja će se u narednom periodu zauzeti, za potrebe izgradnje deponije pepela, a sve u cilju nastavka normalne proizvodne električne energije u TENT-A, procenjena je na oko 500 ha, u okviru ovog dela istraživanja razmotreni su neophodni dodatni troškovi za primenu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije zemljišta. Kako je već navedeno osnovni proizvod, za ekonomsku ocenu u ekonomskom modelu figurira proizvedena električna energija, i eventualno kao dopunski program cena pepela i šljake na komercijalnom tržištu. Kao vremenski horizont uzeto je vreme od danas pa za 40 godina za koje se vreme očekuje rad normalan elektrane sa postojećim kapacitetima i sa postojećom ili neznatno modernizovanom tehnologijom.




**Sl. 3.** *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u hiljadama evra)*



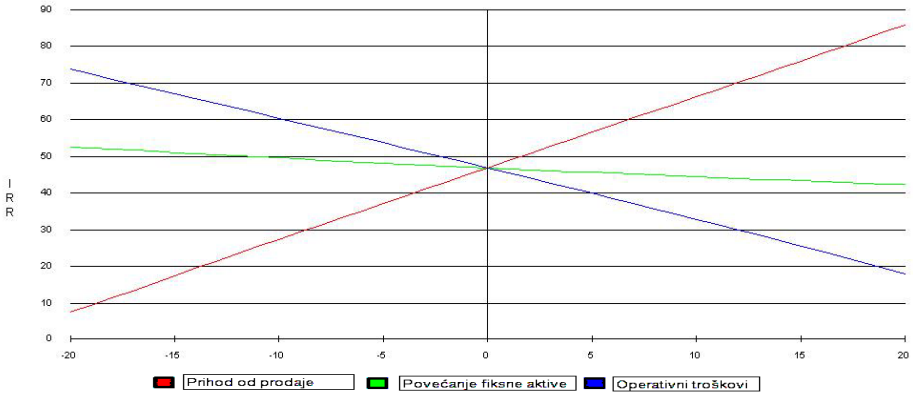

**Sl. 4.** *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u hiljadama evra)*

### 3.2.2. Procena ekonomskih parametara primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite

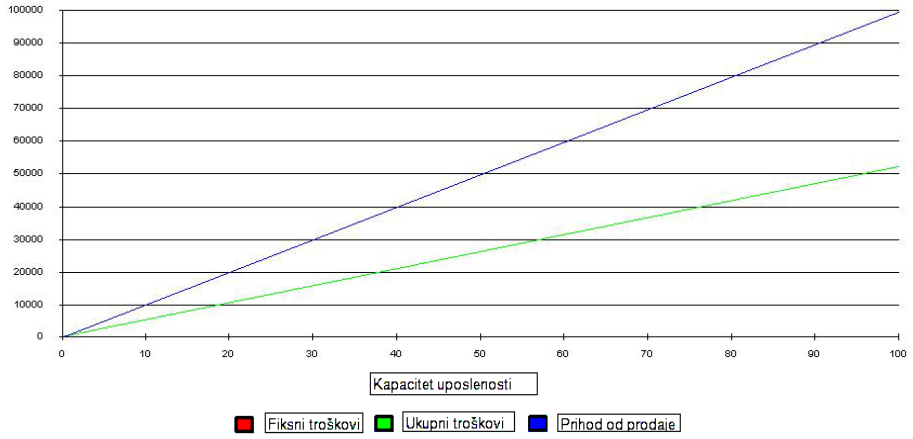
U cilju trajnog rešavanja problema odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, kao logična mogućnost sa stanovišta zaštite životne sredine, nameće se tehničko rešenje koje piodrazumeva vraćanje i odlaganje ovih materija na mesto nastanka, odnosno u otvorene prostore rudnika sa površinskom ili podzemnom eksploatacijom.

Ako se ima u vidu da su ovi prostori već degradirani samom tehnologijom otkopavanja, koja nema, na sadašnjem nivou tehnološkog razvoja, tehnoekonomski opravdanu alternativu, i da je za odlaganje ovih materija na površini terena potrebna degradacija značajne površine zemljišta, onda je sa stanovišta održivog razvoja ovo jedno od prihvatljivih rešenja, ukoliko se dokaže ekonomska opravdanost. Na ovom mestu razmotren je kompleksni tehnoekonomski model, tehnološkog rešenja vraćanja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja i raznih drugih otpadnih materija u različitim vrstama

mešavina u prazne prostore rudnika sa podzemnom eksploatacijom, na primeru podzemnog proizvodnog sistema u rudnom telu RT «Borska reka» u RTB Bor. [Dimovski, 1992.].




**Sl. 5.** *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u hiljadama evra)*




**Sl. 6.** *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u hiljadama evra)*

## 4. DISKUSIJA

Kako je navedeno u tački 3.1.1., posmatrano sa tehnološkog aspekta i interesa same termoelektrane (ova konstatacija se odnosi i na metalurška postrojenja i toplane) postojeći postupak odlaganja pepela i šljake je uhodan i za primenu najjednostavniji.

Sa ekološkog aspekta on je na osnovu iznetih analiza najnepovoljniji i predstavlja

trajno oštećivanje kompletnog ekosistema, posebno u delu promene pedološkog sasatav zemljišta, koji je njegovom primenom trajno oštećen i onesposobljen za osnovnu namenu.

Sa ekonomskog stanovišta, stvarni troškovi primene ovakvog sistema odlaganja, troškovi ekonomske štete od primene ove tehnologije i efekti ekoloških oštećenja su obrađeni u prethodnoj analizi. Direktna ekonomska šteta - **«poljoprivredna šteta»** od ne primenjivanja intenzivne poljoprivredne proizvodnje na prostoru koji je inače upotrebljen kao deponija, koja u do sadašnjem periodu slučajno ili namerno nije uzeta u razmatranje i analizirana na ovakav način, iznosi približno 73 miliona evra, u razmatranom periodu. Ova šteta je mnogo veća ako bi se razmotrili ostali aspekti privredne nadgradnje koji neminovno prate poljoprivrednu proizvodnju..

Ako se uzmu u obzir svi analizirani parametri može se zaključiti da je dalja primena ovakvog sistema, bez obzira na izvesna poboljšanja dugoročno neodrživa kako sa stanovišta zaštite životne sredine tako ni iz ugla dugoročne strategije održivog razvoja. Upornom primenom ovakve tehnologije državi se nanosi nenadoknadiva šteta.

Predloženo tehnološko rešenje opisano u tačkiu 3.1.2. posmatrano sa tehnološkog aspekta i interesa same termoelektrane (ova konstatacija se odnosi i na metalurška postrojenja i toplane) je nešto složenija, jer predpostavlja kompleksniji način pripreme terena za odlaganje, veće investiciono opterećenje, i veće troškove održavanja i primene predloženog sistema. Međutim i sa ovim investicionim i tehnološkim opterećenjima projekat proizvodnje električne energije nudi vrlo visoku stopu akumulativnosti projekta, što se vidi iz ekonomske analize, date u tački 3.1.4.1. ovog rada. Sa ekološkog aspekta on je na osnovu iznetih analiza povoljnije rešenje jer se najveći broj uticaja na životnu sredinu svodi u propisane granice, a pojedini uticaji se u potpunosti eliminišu. Zbog gotovo «hermetičke izolacije» prostora deponije uticaj odloženih materija na okolno poljoprivredno zemljište se svodi na minimum. Takođe primena guste hidromešavine smanjuje količinu vode u deponiji i njen uticaj na podzemne i površinske vode, a solidifikacija deponije u dužem vremenskom periodu potpuno eliminiše nastajanje uvala i depresija u prostoru deponije. Međutim, i pored svih pomenutih ekoloških benefita od primene predloženog rešenja ostaje navedena direktna ekonomska šteta - **«poljoprivredna šteta»** koja iznosi približno 73 miliona evra, sa svim analiziranim indirektnim efektima. Ukoliko bi primena ovakvih sistema zaštite bila ultimativna mera definisana određenim zakonskim propisima i pravilima (kakva važe u EU), i bila podržana od strane državnih organa i fondova Republike Srbije, onda bi efekti njihove primene došli do punog izražaja.Sa stanovišta rudnika primena ovog sistema zahteva investicije u površinski kompleks za prihvat i pripremu zasipne mešavine na površini terena, podzemnog kompleksa za zasipavanje i sistema za povratne vode. Benefiti rudnika su pored eliminisanja direktne rudarske štete od ne otkopane raspoložive korisne mineralne sirovine, i samim time viših stopa amortizacije tehnološke opreme, takođe i eliminisanje oštećenja površine terena i objekata na njoj. Investicioni trošak države odnosi se na investicije u železnički transportni sistem i železničku infrastrukturu. Troškovi ovih investicija pokrili bi se kroz eliminisanje direktne – poljoprivredne štete i kroz eliminisanje ili smanjivanje **rudarskih šteta**. Sa ekološkog aspekta on je na osnovu iznetih analiza najpovoljnije rešenje jer se najveći broj uticaja na životnu sredinu u potpunosti eliminiše. Kako je napred pomenuto, pošto se radi o značajnim investicionim ulaganjima, ukoliko bi primena ovakvih sistema zaštite bila ultimativna mera definisana određenim zakonskim propisima i pravilima (kakva važe u EU), i bila podržana od strane državnih organa i fondova Republike Srbije,

stvorili bi se uslovi da se prostor Republike Srbije u potpunosti oslobodi ovih materija. U čisto ekoonomskom smislu, ukoliko bi se posmatralo kumulativno, ukupni profit Republike Srbije iznosio bi oko **2 milijarde evra u periodu od oko 40 godina, odnosno oko 50 miliona evra godišnje**, ne računajući indirektne efekte od popravljanja stanja životne sredine, boljeg iskorišćenja raspoloživih resursa, novih radnih mesta, investicija u infrastrukturu itd.

## 5. ZAKLJUČAK

U radu je data kompleksna, uporedna tehno-ekonomska analiza primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja. Radi se o veoma dobro poznatom problemu kome se do sada iz raznih razloga nije pristupalo na celovit i sve obuhvatan način. Parcijalnim rešenjima popravljani su izdvojeni slučajevi, a pri razmatranju predloženih tehnoloških rešenja, nije uziman u obzir efekat industrijskih šteta u potrebnoj meri tako da su mnoga rešenja doneta bez prave argumantacije. Politika održivog tehnološkog razvoja Republike Srbije mora da integriše sve raspoložive resurse i mogućnosti i da zakonodavstvom i pratećim propisima obaveže glavne aktere na primenu tehnoloških rešenja koja minimalno oštećuju životnu sredinu i poboljšavaju održivo korišćenje raspoloživih prirodnih i privrednih resursa.

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# COMPARATIVE TECHNICAL-ECONOMIC ANALYSIS OF APPLICATION THE DUMPING PROCESS OF FLY ASH AND SLAG FROM THERMO POWER PLANTS, HEATING PLANTS AND METALLURGICAL PLANTS BY CONVENTIONAL PROCEDURES AND BACKFILLING TO THE « PLACE OF ORIGIN» I.E. IN THE ABANDONED MINED AREAS OF MINES WITH PREVIOUS PREPARATION AND APPLICATION OF MODERN DUMPING TECHNOLOGIES, RECLAMATION AND REMEDIATION AND MODERN METHODS OF PROTECTION

***Abstract***

*Previous experiences in production and processing of metals, nonmetals and coals, have shown the significance of problem of dumping the waste materials on the surface of e terrain, with all following consequences on the agricultural land and eco system as whole. Since, in this case is delaing with the material in annual amount of several millions $m^3$, which is almost certainly in some measure poisoned, and not rarely cancerous, the question of its dumping in nature (mostly on the agricultrural land ore in the close neighbourhood, closed to the facilities which produce it), and with it interruption of whole eco system must be treated with appropriate care. Therefore, the process of dumping such materials presents significant problem, which demands ecologically acceptable and economicly sustainable solutions.*

***Keywords:*** *ecology, economy, sustainable development, mining, industrial damages*

## 1. INTRODUCTION

Since in the modern world exists a great number of poison chemical compounds, it is possible to make detail exploration of them in purpose of their success full application (avoiding production, disintegration, application and destruction) and therefore in final to protect living environment. Simultaneously big group of highly toxic compounds (HTC), where dioxides and other are separated, which

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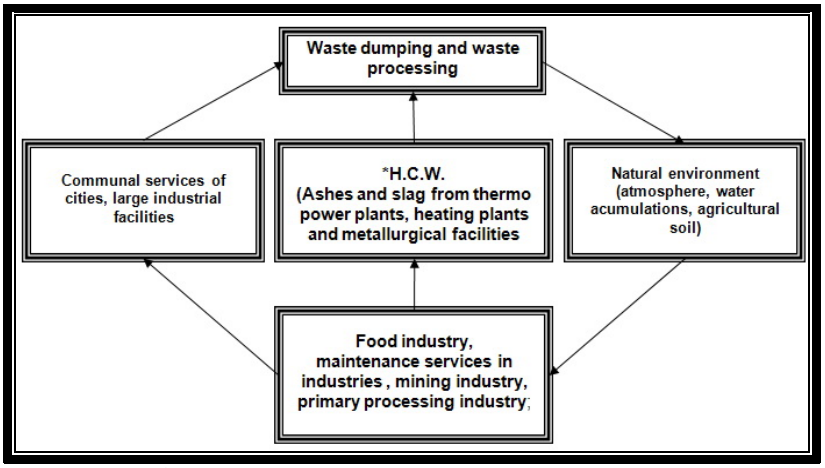
are relatively small explored till now, recently earn appropriate attention.

Figure 1 gives a condition scheme of natural cycle as the reflection of real happenings in present time. As it is espied, the emission of poisonous substances participate in thic chain by its infiltration in environment, and then on process of manufacturing, food, vegetables and fruits, various products of animal orgin (milk, meat, eggs, etc.), and in one or oth-erwise is returning in human organism with adequate joint conseqences.

Naturally, the most rational approach to this problem was not eliminated with the acceptance and accumation of (HTC), but with the aspiration to eliminate obtained toxic materials. Also, it is quite natural, avoiding the production of (HTC), i.e. cutting the recirculating cycles, which is schematicly shown in fig.1. [Dimovski, 2003, Grechko, Denisov, 2001.], and the solutions for this is in processing of waste by application the methods which simultaneously eliminate dioxides (HTC).




➢ *H.C.W.- Hard comunal waste*

**Fig. 1.** *Scheme of existing cycle of toxic materials in nature*

Special problem reperesents so-called «unauthorized» dumping which are the most frequent case. There is waste dumping of materials with high temperature in the moment of dumping (600-900°C), which at the same time still burn and make the emission of toxic dioxide gases direct into atmosphere, which is app. 25 - 30 % of greatest polluters. Analyses of adequate information of scientific and technologic explorations enable defining main conditions which make possible solving mentioned problems during the treatment of some materials (waste). These are:

- ❖ Extrimely high temperature of process (t > 1250°C);
- ❖ Oxidizing atmosphere (oxidizing factor of combustion a > 1.05);
- ❖ Final time of processing the products in such conditions (D>2 sec.);
- ❖ Thermal instantaneous of process (TIP) [****]

From the mentioned analyse a conclusion can be made that solving of waste dumping the waste materials in nature represents a complex and demanding task. In solving such type of problems exists different approaches.For the experimental testings and techno-economic modeling

[****] *Thermal instantaneity of process*

aimed to solve this problem in the paper, the following processes are chosen:

1. Dumping fly ash and slag from thermo power plants, heating plants and metallyrgic facilities by conventional procedures on arable and the other agricultural land by using the procedures and in manner which make, without previous preparation, maximal degradation of surface of the terrain, and then reclamation to the previous purpose, with more or less success.
2. Dumping fly ash and slag from thermo power plants, heating plants and metallyrgic facilities by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration.
3. Treatment of fly ash and slag from thermo power plants, heating plants and metallyrgic facilities with backfilling it «at the place of origin» i.e. In the abandoned mined out areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection methods

Such approach is choosen from the reason because it is necessary to enlite to the single detail real state in this area, taking into consideration demands of sustainable development and economic dimension of solving any problem, with purpose to, by comparation ecological-economical analyse, reach the most acceptable solution of the problem.

## 2. EXPERIMENTAL PART

As the objects of experimental testings are choosen waste dump of thermo power plant Nikola Tesla in Obrenovac, so-called «TENT»A, and the mined out areas of open pit mines of mining basin «Kolubara», mined areas of the open pit mines of RTB Bor and mined out caves in the underground copper mine «Jama» of Bor copper mine. To find out what is the degree of influence of dumped waste materials (fly ash and slag from thermo power plants, heating plants and metallyrgic facilities), without previous preparation on arable and other agricultural land i.e. in nature at all, the certain results of explorations are present in this paper, from which is enable to establish influence of waste materials on the pedologic content of soil after the process of waste dumping. Raw lignite from the coal basin «Kolubara», what burning in the thermo power plant «TENT» A, has very variable quality. [Dželetović et al., 2001]. Content of mineral meterials which follows coal substance vary, so the content of fly ashes in raw lignite from mining basin «Kolubara», it is from 22 to 40%, and in the cleaned lignite it is from 9.5 to 20%. Clean lignite has different chemical content of ash, in comparation with raw lignite. Chemical elements contained in coals has dual origin. Most of the chemical elements content into the coals come from the remains of plants and other living organisms, from which became coal seams. Some of micro elements which exists in coals, could be brought, into the coal seams from the surrounding, from the surrounding rocks, or by circulating underground waters, which is bringing several dissoluted mineral substances. Ashes made by combustion of lignite of mining basin «Kolubara» have, in comparation with physical characteristics natural soils, small specific mass, extremely low density, either in intact coal massive, or in disinegrated mass, which explain their high erosion disposal (Table 1).

***Table 1.*** *Physical characteristics of fly ashfrom «TENT»A*

| | | | | |
|---|---|---|---|---|
| Specific mass ($g/cm^3$) | 1.93 | 1.93 | 1.86-2.06 | 2.5-2.6 |
| Specific area ($cm^2/g$) | 4020 | 4020 | | |
| Remains on screen from 0,0063mm (%) | 27.6 | 36.1 | | |
| Volume mass in disintegrated state ($kg/m^3$) | 600 | 550 | 462-539 | 1000 |
| Volume mass in compacted state ($kg/m^3$) | 760 | 760 | - | 1700 |

Content of some heavy metals in ash (Table 2) are raised for the some plant sorts and they could have toxic concentrations. Relatively are high concentrations of: Va, V, Cd and Al; and they could have influence not only to the grow of plants, but also on the quality of seeds.

***Table 2.*** *Chemical analysis of ash made in combustion of lignite from the Mining Basin «Kolubara» in thermo power plants*

| | **TENT - A** | **TENT - B** | **TEK - A** |
|---|---|---|---|
| **Content** | | **(%)** | |
| $SiO_2$ | 55.40 | 56.20 | 50.35 |
| $Fe_2O_3$ | 24.87 | 24.47 | 24.39 |
| $Al_2O_3$ | 8.87 | 9.04 | 9.57 |
| CaO | 4.55 | 5.22 | 8.56 |
| MgO | 2.07 | 1.95 | 4.20 |
| $SO_3$ | 1.38 | 1.14 | 1.13 |
| $P2O_5$ | 0.07 | 0.08 | 0.22 |
| $TiO_2$ | 0.17 | 0.16 | 0.22 |
| $Na_2O$ | 1.49 | 0.90 | 0.45 |
| $K_2O$ | 1.06 | 0.75 | 0.87 |

## 3. PRESENTATION OF THE RESULTS

### 3.1. Technological description of possible variants of solving the problems

#### 3.1.1. Dumping fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures on arable and the other agricultural land by using the procedures and in manner which make, without previous preparation

Such solution of problem of waste dumping the fly ashes and slag is in the moment in active application im most of the electric power plants which in their technological procedure produce significant amount of waste products. It is basicly consists of waste dumping of this industrial waste on arable and the other agricultural

land without (or partly) previous preparation of terrain aimed for such purpose, with maximal degradation surface of the terrain, and then reclamation to the previous purpose, with more or less success. Solution is basicly consists of digging and removal productive surface seam of agricultural land, digging lower seams to some depth, dam the seam of clay (or without it), making vertical drains and channels around the dug cassette, waste dumping the fly ashes and slag into the cave to the project defined height. From the economy viewpoint, the real costs of this system application of waste dumping, costs of economic damage from application of this technology and the effects of ecological damges are presented in following analysis. Direct costs* of maintenance and exploitation of existing system for collecting, preparation, transport and dumping fly ashes and slag in TENT A is 11,70 Eur/t, measured on dumped fly ashes and slag [Dražović i sar., 2010.].

### 3.1.2. Dumping fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration

Solution of problem of waste dumping the fly ashes and slag from thermo power plants, heating plants and metallyrgic facilities in this way means complex of measures and procedures by which, existing system of dumping of waste materials, is going to be improved, so the influences on living environment will be reduced into the acceptable frames, and the procedure of reclamation and restoration make sustainable. Proposed solution basicly consists of application of modern measures of protection the surrounding land, water and atmosphere from influence of dumped materials. Also, technological solutions foresee application of dense hydro mixtures in procedure of transport and building in fly ashes and slag into the slag dump. From the ecological aspect, it is more favorable solution, because the most of influences on living environment is reduced into the acceptable level, and some of them are completely eliminated. Because of almost «hermetic isolation» of the slag dump area influence of dumped materials on the surrounding agricultural land is reduced on minimum. Also, the application of dense hydro mixtures reduce amount of free water in dump and their influence on underground and surface water, and solidification of dump in longer period completely eliminate appearance of caves and depressions in the area of dump. Building in geotextiles covers and biodissintegrated materials with integrated plant cultures improve restoration of occupied area. Reinforce of high slopes by «green terasmesh system and biocattail», with previous solidification and humus covering, additionaly protect the area from influences of eolian erosion and flood the particles of dumped materials.

* *This fact is obtained from the source «Feasibility Study and Reconstruction the System for Collection, Preparation, Transport and Dumping of Ash and Slag from the TPP"Nikola Tesla A" with Conceptual Design and Study on Impact Assesment on Environment», Mining Institute Ltd.- Energoprojekt – entel a.d, 2010.*

**Fig. 2.** *View and constructive elements of green terasmesh system*

### 3.1.3. Treatment of fly ash and slag from thermo power plants, heating plants and metallurgical plant with backfilling on the « place of origin» i.e. in the abandoned mined areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection methods

The part of amount of slag and fly ash from metallurgical plantsand thermo power plants, have the application, because of its puzzuolanic characteristics, in cement and chemical industry. Unfortunately, demands for these materials in mentioned branches of economy vary from 10-30 % in comparation with total amount of these materials. [Dimovski, 2012.] In this place is treated, as one alternative, technology of solving of theses problems by its backfilling into the underground mined out caves.

### 3.2. Economic analyses of proposed solutions

For the economic and financial evaluation, a procedure of economical estimate of investment projects is applied in accordance to the UNIDO standards and standards of WORLDBANK. [Hauarnek et al., 2001.] Applied models as a constant in any of considerd possible solutions take estimated amount of damage appeared from non application intensive agricultural production of some plants on the area aimed for the waste dump, in period of exploitation of the area of the dump and the other relevant costs of building and the exploitation of dump in accordance to described technological procedure. As a basic product, for the economical appraisal in economical model is produced electric energy, and eventally as additional program price of fly ashes and slag on commercial market, in case of thermo

power plants, i.e. amount of produced non-ferrous metals and other products in case of mines in which are dumping these materials. The results of modeling are shown in fthe ollowing tables and diagrams.

### 3.2.1. Estimate of economical parameters of application the procedure of waste dumping of fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration

As it is already mentioned, surface of agricultural land, which is going to becaptured in future period, in purpose of building the waste dump, with final aim of continuity the normal production of electric energy in TENT A, is estimated on 500 ha, in this part of explorations is considered necessary additional costs for the application modern technologies of waste dumping, and reclamation and restoration of captured land. Since, as it is mentioned, that the basic product, for the economical appraisal in economic model exists produced electric energy, and eventally as additional program price of fly ashes and slag on commercial market. As a time horizon is taken period from today and next 40 years for which is expected normal work of thermo power plant with existing capacities, and with existing or insignificantly improved technology.

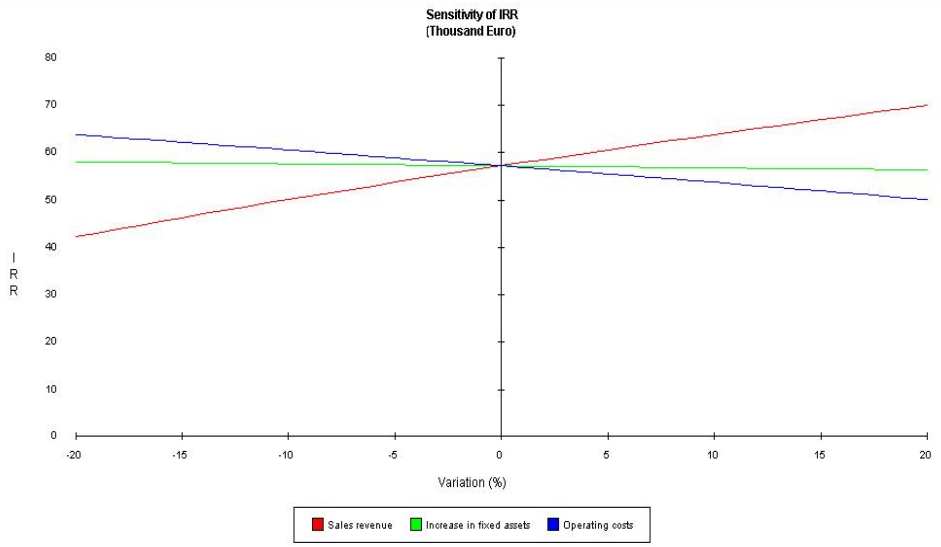



**Fig. 3.** *Diagram of sensitivity of internal rate of return (in thousand euro)*

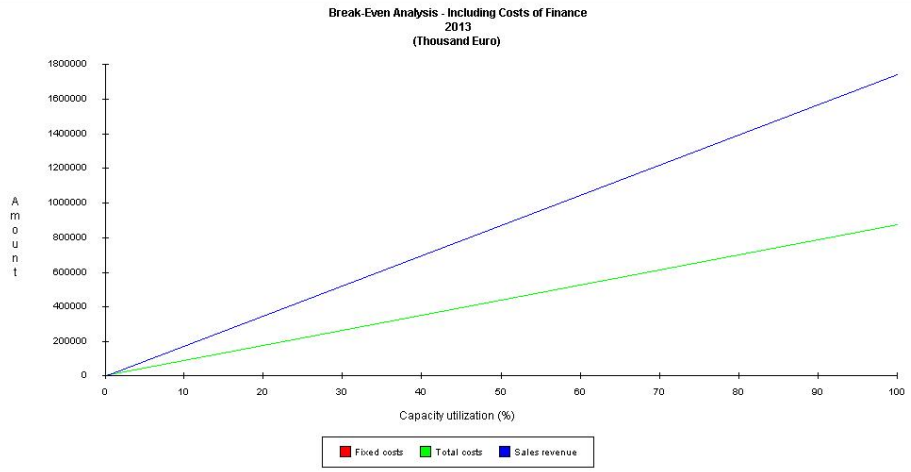



**Fig. 4.** *Analysis of critical point of the project including costs of finance in 2013 (in thousand euro)*

### 3.2.2. Estimate of economical parameters of application the procedure of waste dumping of fly ash and slag from thermo power plants, heating plants and metallurgical plants with backfilling to the « place of origin» i.e. in the abandoned mined out areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection method

In purpose of permanent solving the problem of dumping the fly ash and slag from thermo power plants, heating plants and metallyrgic facilities, as a logical possibility from viewpoint of environ-mental protection, is imposing technical solution which undertake backfilling and dumping this materials at the place of origin i.e. in the abandoned mined out areas of mines with open pit or underground exploitation. Having on mind, that these areas are already degradated with the minig technology itself, which has not, at the present level of technological development, techno-economically feasible alternative, and the dumping these materials demand degradation of significant area, then from viewpoint of sustainable development, such solution is one of most acceptable, if could be justified economical feasibility. At this place a complex techno-economic model is considered of technological solution of returning of fly ash and slag from thermo power plants, heating plants and metallyrgic facilities and several other waste materials in different compounds in opened caves of mines with underground exploitation, as an example of underground minig system in ore body «Borska reka» in RTB Bor. [Dimovski, 1992].

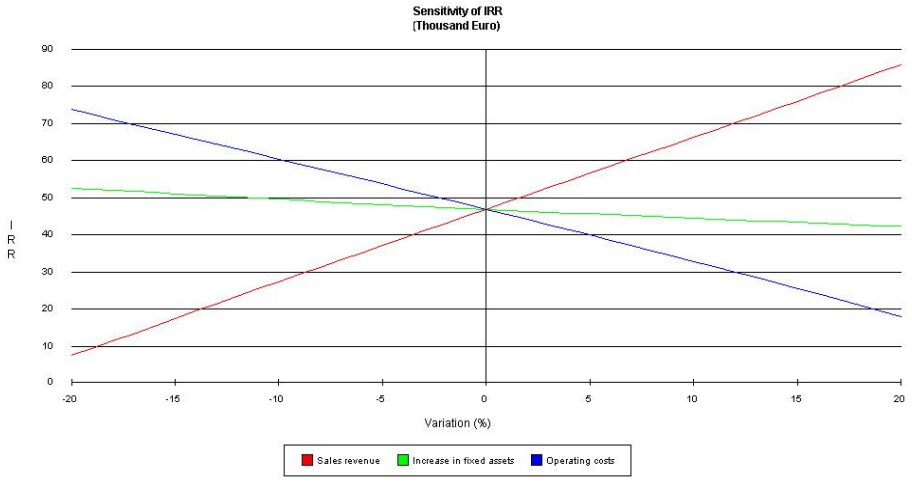



**Fig. 5.** *Diagram of sensitivity of internal rate of return (in thousand euro)*

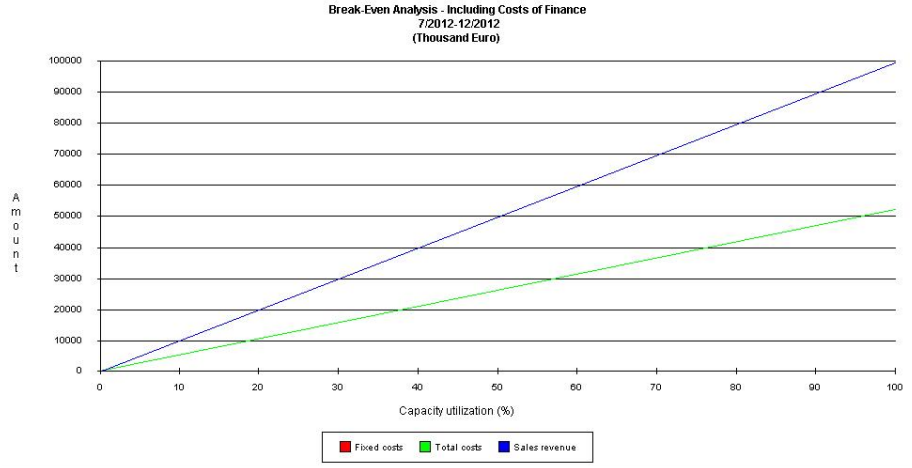



**Fig. 6.** *Analysis of critical point of project including costs of finance in 2013.(in thousand euro)*

## 4. DISCUSSION

As it is mentioned in chapter 3.1.1., from technological aspect and interest of thermo power plant itself (this statement is relate also for metallyrgic facilities and heating plants) existing procedure of dumping the fly ash and slag is operating smoothly and most simpliest in application. From ecological aspect, it is based on presented analyses most unpleasant and represents permanent damaging of comlete eco system, especially in part of change the pedological content of soil, which is whit it application permanently damaged and incapacitated for it basic purpose. From economic viewpoint, real costs of application of such system of dumping, costs of economic damage from application of this technology and the ef-

fects of ecological damage are treated in following analyse. Direct economic damage - **«agricultural damage»** from non application of intensive agricultural production at the place which is otherwise used as waste dump, which accidentally or with some purpose was not took into consideration and analysed in such manner, is app. 73 milion euro, in considered period. This damage is much bigger if are considered other aspects of agricultural industrial superstructure which inevitably follows agricultural production. Taking into consideration all analysed parameters, it could be concluded that further application of that system, beside to certain improvement long term unsustainable neither from the aspect of environmental protection, nor from vievpoint of long term strategy of sustainable development. Stubborn application of such technology making irreparable damage to the state. Technological solution described in chapter 3.1.2. considered from technological aspect and the interest of the thermo power plant itself (this statement is relate also for metallyrgic facilities and heating plants) have bigger complexity, because it presents more complex way of preparation the captured terrain, bigger investments, and bigger costs of maintenance and application proposed system. Meanwhile, with this investment and technological burden also, project of production of electrical energy offers very high rate of accumulation of project, which could be seen from economical analyse, shown in chapter 3.2.2. of this paper. From ecological aspect, it is based on presented analyses, more suitable solution because the most of influences on environment is reduced to acceptable frame, and some of them is completely eliminated. Because of almost «hermetic isolation» of the slag dump area influence of dumped materials on the surrounding agricultural land is reduced on minimum. Also the application of dense hydro mixtures reduce amount of free water in dump and their influence on underground and surface water, and solidification of dump in longer period completely eliminate appearance of caves and depressions in the area of dump. Meanwhile, beside all mentioned ecological benefits of application of prposed solution remains mentioned direct economic damage - **«agricultural damage»**, which is app. 73 milion euro, with all considered indirect effects. If the application of such systems of environmental protection would be ultimate measure defined with certain legal regulations and rules (as they are in EU), and if they will be supported from the state and funds of Republic of Serbia, then the effects of their application will have full expression. From viewpoint of mines application of this system demands investments in surface facilities for collecting, preparation of backfilling mixture at the surface of the terrain, underground complex for bacfilling and the sytem for reversible water. Benefits for mines are, beside the elimination of direct economic damage - «**mining damages»** from unexploitated available mineral resources, and with this higher rate of amortization of technological equipment, also elimination of damages the surface of the terrain and the objects built on it. Investments costs of the state relates on investments in rail transporting system and rail infrastructure. Costs of such investment would be covered through the elimination of direct economic damage - **«agricultural damage»** and through the elimination or reduction of «**mining damages».** From ecological aspect it is based on presented analyse most suitable solution because, usage of this solution most of influences on environment is completely eliminated. As it is mentioned above, since it is dealing with significant investments, if the application of such systems of environmental protection would be ultimate measure defined with certain legal regulations and rules (as they are in EU),

and if they will be supported from the state and funds of the Republic of Serbia, then will be created conditions for the whole territory of the Republic of Serbia, to be released of this materials. In pure economical manner, if the whole problem is observed cumulatively, total profit for Republic of Serbia would be app. **2 billion euro in period of 40 years, i.e. app. 50 milion euro per year**, without taking into account the indirect effects from improvement the living environment, better usage of available mineral resources, new workih places, investments in infrastructure etc.

## 5. CONCLUSION

This paper presents a complex comparative techno-economic analysis of applied procedures of waste dumping ashes and slag from thermo power plants, heating plants and metallurgical facilities. In the matter is considered well known problem which was not appropriately treated as whole from different reasons. By partial solutions was only repared singular cases, and in considerations of proposed solutions were not taken effect of industrial damages at appropriate level, and therefore the technical solutions where adopted without real argumentation. Policy of sustainable technological development of Republic of Serbia must integrate any reliable resources and possibilities, and by legislation and following legal regulations and standards, and to obligate main actors on application the technological solutions which minimally damaging living environment and improve sustainable using of reliable natural and economy resources.

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