EKSTERNI TROŠKOVI PROIZVODNJE ELEKTRIČNE ENERGIJE I POLITIKA ZAŠTITE OKOLIŠA

THE EXTERNAL COSTS OF THE PRODUCTION OF ELECTRICAL ENERGY AND THE ENVIRONMENTAL PROTECTION POLICY

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U radu su prikazane ekonomske osnove eksternih troškova i način njihove procjene. Opisana su dva osnovna načina za određivanje eksternih troškova: metoda slijeda utjecaja (ili metoda troškova štete) i metoda troškova kontrole. Pritom se definirao opseg analize, prioritetni utjecaji, pritisci na okoliš, prihvatna okolina, rasprostiranje polutanata u okolišu (procjena izloženosti), funkcijska veza izloženosti i učinaka, novčano vrednovanje i ocjena nesigurnosti. Zaključeno je da troškovi smanjenja emisija progresivno rastu sa stupnjem redukcije, iz čega slijedi da politika zaštite okoliša koja se temelji isključivo na propisivanju standarda nije idealno rješenje jer izaziva nepotrebno visoke troškove. Pokazalo se da bi relaksacija regulativnih prema tržišno orijentiranim mjerama mogla donijeti financijsku uštedu uz istu ekološku dobit.

In this article, the economic foundations for external costs and the manner of evaluating them are presented. Two basic methods for determining external costs are described: the impact pathway method (or the costs of damages method) and the costs of control method. The range of analysis, priority impacts, pressures on the environment, receiving environment, pollution distribution in the environment (assessment of exposure), the functional link between exposure and impact, monetary valuation and risk assessment are defined. It is concluded that the costs of reducing emission progressively increase with the level of reduction. Therefore, an environmental protection policy based exclusively on stipulated standards is not an ideal solution because it generates unnecessarily high expenditures. It has been demonstrated that easing the regulations toward market-oriented measures could yield financial savings of equal ecological benefit.

Ključne riječi: eksterni troškovi, emisije, metoda slijeda utjecaja, održivi razvoj, proizvodnja električne energije, termoelektrane, zaštita okoliša
Key words: emissions, environmental protection, external costs, impact pathway method, production of electrical energy, sustainable development, thermoelectric power plants

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1 UVOD

Energija je važan čimbenik bilo u kojem području društvene ili ekonomske aktivnosti. Za većinu zemalja u razvoju, ali i za razvijene zemlje, raspoloživost energije i kvaliteta energetskih usluga vitalni su za zadovoljavanje osnovnih ljudskih potreba i povećanje životnog standarda. Međutim, proizvodnja, konverzija i uporaba energije vodi k efektima degradacije okoliša. Ekonomski razvoj i strateške odluke bilo u kojoj zemlji u obzir moraju uzeti problematiku zaštite okoliša povezanu s energetikom. Zaštita okoliša mora biti održiva lokalno, regionalno i globalno da bi se postigao održivi razvoj.

U posljednje vrijeme jedan od glavnih smjerova istraživanja u okviru komparativne analize različitih tehnologija za proizvodnju električne energije je proučavanje utjecaja na okoliš i ljudsko zdravlje i tomu pridruženih eksternih troškova energijskih lanaca za proizvodnju električne energije. Stoga se kao jedna od komponenata pri odlučivanju o budućim energentima pojavljuju i eksterni troškovi proizvodnje električne energije. Princip uključenja eksternih u ukupne troškove pri planiranju resursa proizlazi iz činjenice da proizvodnja električne energije uzrokuje štete za okoliš i društvo koje nisu uključene u troškove proizvodnje.

Eksterni troškovi u elektroenergetici predstavljaju nekompenzirane štete koje se javljaju kao neželjene posljedice proizvodnje električne energije. Eksterni troškovi mogu se umanjiti izravnim mjerama zaštite okoliša, kao što su ekološki standardi i uređaji za smanjenje emisija, a kompenzirati pomoću ekonomskih instrumenata zaštite okoliša: uvođenjem emisijskih pristojbi i poreza te trgovanjem emisijskim dozvolama. Danas je u svijetu tendencija da se eksterni troškovi ne samo kompenziraju već i uključe u planiranje resursa. Eksterni trošak može se procijeniti na temelju troškova kontrole (tj. smanjenja emisija) ili troškova štete za okoliš, a uključiti u politiku zaštite okoliša primjenom težinskih faktora ili nekom vrstom "kažnjavanja", bilo same tehnologije, bilo emisija.

1 INTRODUCTION

Energy is an important factor in any area of social or economic activity. For the majority of developing countries, but also for more developed countries, the availability of energy and the quality of energy services are vital for meeting fundamental human needs and raising the standard of living. However, the production, conversion and use of energy lead to degradation of the environment. Economic development and strategic decisions in any country must take the problem of environmental protection in connection with energy production into account. Environmental protection must be sustainable locally, regionally and globally in order to achieve sustainable development.

In recent times, one of the main directions of investigation within the framework of the comparative analysis of various technologies for the production of electrical energy has been the study of the impact of the energy chain for the production of electrical energy upon the environment and human health, together with the associated external costs. Therefore, the components in deciding upon future power sources include the external costs of the production of electrical energy. The principle of the inclusion of externalities in the overall costs when planning resources is due to the fact that the production of electrical energy leads to damages to the environment and society that are not included in the production costs.

External costs in electrical power production represent the uncompensated damages that occur as the undesirable consequences of the production of electrical energy. External costs can be lowered through direct environmental protection measures, such as ecological standards and with equipment for reducing emissions, and can be compensated for using economic instruments for environmental protection through the introduction of emission fees and taxes, and through the trading of emission allowances. Today in the world, there is a tendency not only to compensate for the external costs but also to include them in resource planning. External costs can be assessed on the basis of cost controls (i.e. reduced emission) or the costs of damage to the environment, and also included in the environmental protection policy through the application of weighted factors or some form of "penalty," either on the technology itself or emissions.

2 EKSTERNI TROŠKOVI

Namjena je eksternih troškova, sasvim općenito, da potaknu promjene prema ekološki svjesnijem ponašanju. Eksterni troškovi mogu služiti za usporedbu različitih tehnologija za proizvodnju električne energije i različitih strategija razvoja elektroenergetskog sustava s obzirom na njihov utjecaj na okoliš. Pri planiranju sustava mogu se analizirati različiti scenariji razvoja s obzirom na njihov utjecaj na okoliš, i to tako da se osnovnim troškovima pojedinog scenarija pridodaju troškovi štete u okolišu. Eksterni se troškovi također mogu izravno uvrstiti u funkciju ukupnih troškova proizvodnje pri dispečiranju postojećih i optimiranju gradnje novih elektrana u sustavu.

2.1 Prioritetni utjecaji energijskih lanaca na ljude i okoliš

Detaljni prikaz utjecaja na okoliš svih tipova elektrana i ostalih elektroenergetskih postrojenja može se naći u [1].

Najvažnija opterećenja okoliša u lancu fosilnih goriva nastaju na lokaciji elektrane. To su:

- emisije onečišćujućih tvari u zrak: sumporni dioksid (SO_2), dušikovi oksidi (NO_x), krute čestice i teški metali,
- plinovi staklenika: ugljični dioksid (CO_2), metan (CH_4), klorofluorougljikovodici (CFC),
- kruti i tekući otpadi.

Prioritetni utjecaji na okoliš/zdravlje u energijskim lancima fosilnih goriva su: utjecaji onečišćenja atmosfere na ljudsko zdravlje, materijale, usjeve, šume i ekosustave; posljedice globalnog zagrijavanja; nesreće koje pogađaju pogonsko osoblje ili javnost. Detaljne studije pokazuju da su sekundarni utjecaji u lancu fosilnih goriva, kao što su emisije prilikom proizvodnje materijala, dva do tri reda veličine manji nego emisije iz elektrane (gledano po kWh) i da se mogu izostaviti iz razmatranja [2].

U nuklearnom energijskom lancu postoji mala vjerojatnost ozbiljnih nesreća, uz ostale štete od iskapanja i procesiranja goriva, a posebno odlaganja otpada. Prioritetni utjecaji su radiološki i neradiološki utjecaji na javno zdravlje kao posljedica normalnog pogona ili pak utjecaji na okoliš kao posljedica akcidenta. Najozbiljnijim utjecajem na okoliš smatra se ispuštanje štetnih tvari izazvano ozbiljnijim kvarom reaktora, što bi moglo uzrokovati gubitak obradivih površina i poljoprivrednih usjeva.

2 EXTERNAL COSTS

The purpose of external costs, generally speaking, is to prompt changes toward more ecologically conscious behavior. External costs can serve in comparing various technologies for the production of electrical energy and various strategies for the development of the electrical power system regarding their environmental impact. In the planning of a system, various development scenarios can be analyzed regarding their environmental impacts, in such a manner that the costs of the damage to the environment are added to the basic costs of an individual scenario. External costs can also be directly included in the function of the total costs of production in the dispatching of existing power plants and optimizing the construction of new power plants within a system.

2.1 Priority impacts of energy chains on people and the environment

A more detailed presentation of the environmental impacts of all types of electrical power plants and other electrical power facilities can be found in [1].

The most significant burdens to the environment in the fossil fuel chain occur at the sites of power plants. These are as follows:

- emissions of pollutants into the air: sulfur dioxide (SO_2), nitric oxides (NO_x), solid particles and heavy metals,
- greenhouse gasses: carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFC),
- solid and liquid wastes.

Priority impacts on the environment/health in the energy chains of fossil fuels are: impacts of atmospheric pollution on human health, materials, crops, forests and ecosystems; the consequences of global warming and accidents that affect plant employees or the public. Detailed studies have shown that the secondary impacts in the fossil fuel chain, such as emissions during the production of materials, are two to three orders of magnitude lower than emissions from power plants (in terms of kWh) and they can be excluded from consideration [2].

In the nuclear energy chain, there is a small probability of serious accidents, together with other damage from the excavation and processing of fuel, and especially the disposal of waste. Priority impacts are the radiological and non-radiological impacts on public health as the consequence of normal operations or environmental impact due to accident. The most serious environmental impact is considered to be the emission of harmful substances due to reactor breakdown, which could cause a loss of arable surfaces and agricultural crops.

Promatrajući cjelokupni energijski lanac, obnovljivi izvori energije također štetno utječu na okoliš. Prioritetni utjecaji u lancima obnovljivih izvora ovise o energentu (hidroenergija, vjetar, sunce, biomasa itd.) i drugim specifičnostima lanca. Tako se, primjerice, za energijski lanac vjetra navode nesreće koje pogađaju stanovništvo i pogonsko osoblje, narušavanje estetskog izgleda, buka te utjecaji zagađenja atmosfere zbog proizvodnje materijala i dijelova za vjetroturbinu.

U lancu solarne energije na okoliš štetno utječe proizvodnja materijala, a problem su i velike površine potencijalno obradivog zemljišta koje bi trebalo pokriti kolektorima ako se želi dobiti iole veća snaga solarne elektrane. Problem zauzeća zemljišta javlja se i kod vjetroelektrana (farme vjetrenjača).

Prioritetni utjecaji u lancu hidroenergije su poplavljivanje korisnog zemljišta za potrebe akumulacijskih bazena, erozija, narušavanje režima podzemnih voda i ugrožavanje usjeva, opasnost za staništa, opasnost za opskrbu vodom te estetsko neuklapanje u prirodnu sredinu u kojoj su izgrađene.

Osim negativnih, proizvodnja električne energije uzrokuje i pozitivne eksterne učinke, a to su poboljšanje kvalitete života, mogućnosti zaposlenja, porast produktivnosti i konkurentnosti na tržištu te doprinos državnoj sigurnosti.

2.2 Ekonomske osnove eksternih troškova

Eksterni učinak je sporedni proizvod neke djelatnosti koji nije uključen u tržišnu cijenu osnovnog proizvoda [3]. Pozitivni eksterni učinak nastaje kad ulaganje u neku aktivnost uzrokuje nekompenziranu dobit u nekoj drugoj aktivnosti. Nasuprot tomu, negativni eksterni učinak javlja se kad ulaganje u jednu aktivnost uzrokuje nekompenzirane negativne učinke na drugu aktivnost. Industrijske djelatnosti na razne načine, uglavnom negativno, djeluju na ljudsko zdravlje i prirodni okoliš, izazivajući određene troškove u društvu. Budući da oni ne ulaze u klasičnu ekonomsku bilancu poduzeća, tj. u proračun izravnih (tzv. privatnih) troškova, nazivaju se eksterni troškovi. Zbog postojanja eksternalija privatni troškovi manji su od društvenih (slika 1).

Considering the entire energy chain, renewable energy sources also have a detrimental effect upon the environment. The priority impacts in the chain of renewable sources depend upon the power source (hydroenergy, wind, sun, biomass etc.) and other specific aspects of the chain. Thus, for example, in the wind energy chain there are accidents that affect the population and plant employees, are detrimental to visual amenity, create noise and pollute the atmosphere due to the production of materials and wind turbine parts.

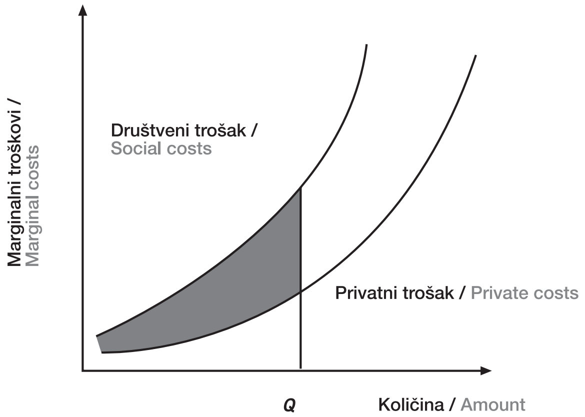
In the solar energy chain, there is harmful environmental impact from the production of materials, and problems also include the large surfaces of potentially arable land that must be covered with collectors if greater power from a solar energy plant is required. The problem of occupying land also occurs with wind-generated electricity (windmill farms).

Priority impacts in the chain of hydroenergy are the flooding of usable land to create a reservoir, erosion, destruction of the underground water regime, threats to crops, danger to the population, danger to the water supply, and detriment to the amenity in the natural milieus in which they are built.

In addition to negative impacts, the production of electrical energy also results in positive external effects, such as improving the quality of life, employment opportunities, increased productivity and competitiveness on the market, while also contributing to national security.

2.2 The economic foundations of external costs

The external impact is the byproduct of some activities that is not included in the market price of the basic product [3]. A positive external impact occurs when investment in some activity results in uncompensated profit in some other activity. Conversely, a negative external impact occurs when investment in an activity results in an uncompensated negative impact on another activity. Industrial operations in various ways generally negatively affect human health and the natural environment, resulting in various costs in the society. Since these are not included in a company’s classical financial statement, i.e. in the budget for direct (so-called private) costs, they are called external costs. Due to the existence of externalities, private costs are lower than social costs (Figure 1).



Slika 1
Odnos privatnih i društvenih troškova
Figure 1
The ratio of private and social costs

Na slici 1 su prikazane krivulje marginalnih privatnih i društvenih troškova. Marginalni ili granični trošak predstavlja trošak sljedeće jedinice proizvoda. Za bilo koju razinu proizvodnje ***Q***, ukupni trošak proizvodnje jednak je površini ispod krivulje marginalnih troškova. Osjenčana površina između krivulja privatnog i društvenog troška predstavlja eksterni trošak na razini proizvodnje ***Q***. Da bi se u ocjeni projekta uzeli u obzir i eksterni troškovi, trebalo bi umjesto s privatnim računati s društvenim troškovima. Međutim, u praksi to nije jednostavno jer stvarni društveni troškovi nisu poznati. Naime, nemoguće je ustanoviti i kvantificirati sve eksterne učinke, iako se nastoji doći do što bolje procjene.

U elektroenergetskom sustavu može se dogoditi da tržišne cijene električne energije ne odražavaju u potpunosti stvarne troškove i da su niže nego kad bi se u proizvodnu cijenu električne energije uključili eksterni troškovi. Niže cijene uzrokuju povećanu potrošnju električne energije, tj. nepravilnu raspodjelu resursa, a to vodi do smanjene ekonomske efikasnosti u društvu i negativnih utjecaja na društvo. Prema ekonomskoj teoriji društvenog blagostanja, onečišćenje okoliša uzrokovano proizvodnjom električne energije trebalo bi svesti na ekonomski efikasnu razinu i time ukloniti deformacije tržišta zbog eksternih učinaka. Ekonomski efikasna razina onečišćenja bila bi ona pri kojoj je proizvodna cijena električne energije jednaka marginalnom društvenom trošku proizvodnje električne energije, a taj uključuje i eksterne troškove proizvodnje električne energije.

Granična šteta je novčana vrijednost štete za okoliš ili ljudsko zdravlje koju uzrokuje dodatna jedinica onečišćenja. Krivulja granične štete prikazuje njezinu ovisnost o razini emisija; ona je horizontalna, ako svaka sljedeća tona polutanta izaziva jednaku štetu kao ona prethodna, tj. ako šteta ne ovisi o razini emisija. To je slučaj kad je ukupna šteta linearno proporcionalna emisijama.

In the figure 1 are shown the curves of the marginal private and social costs. The marginal cost represents the cost of the subsequent unit of production. For any level of production ***Q***, the total production cost is equal to the area below the curve of the marginal costs. The shaded area between the curve of the private and social costs represents the external cost on the level of production ***Q***. In order for external costs to be taken into account in the price, it would be necessary to include the social costs instead of the private costs in the calculation. However, in practice this is not simple because the actual social costs are unknown. It is not possible to establish and quantify all the external effects, although attempts are made to arrive at the best possible estimate.

In an electrical power system, it can happen that the market prices of electrical energy do not reflect the actual costs in their entirety, and are lower than they would be if the external costs were included in the production price of electrical energy. Lower prices result in an increased consumption of electrical energy, i.e. a lopsided distribution of resources, leading to lower economic effectiveness in the society with negative repercussions upon the society. According to the economic theory of social wellbeing, environmental pollution caused by the production of electrical energy should be reduced to an economically effective level, which would thereby eliminate the market deformation due to external impacts. An economically effective level of pollution would occur if the production costs of electrical energy were equal to the marginal social expenditures for the production of electrical energy, including the external costs of the production of electrical energy.

Marginal damage is the monetary value of damage to the environment or human health that causes additional units of pollution. The curve of marginal damage shows its dependence on the emission level: it is horizontal if each subsequent ton of

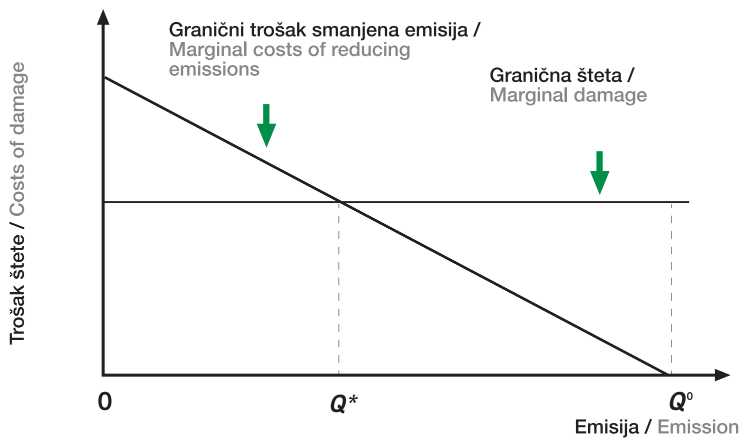
No, postoje učinci koji nisu linearni i kad su posljedice onečišćenja pri malim razinama emisija manje od onih pri većim razinama.

U analizi eksternih učinaka na okoliš najčešće se pretpostavlja da je granična šteta konstantna, bez obzira na razinu emisija. Naime, studije su pokazale da koncentracije polutanata u okolišu većinom linearno ovise o veličini emisija, a da su štete u receptorima u pravilu linearno ovisne o koncentracijama polutanata. To znači da su konačne štete za okoliš/zdravlje za većinu polutanata proporcionalne emisijama, tj. da su njihove granične štete konstantne. U tom su slučaju prosječne štete jednake graničnima i također konstantne (slika 2).

pollutant causes the same amount of damage as the previous one, i.e. if the damage does not depend upon the level of the emission. This is the case when the total damage is linearly proportional to the emissions. There are effects that are not linear, when the consequences of pollution with small levels of emissions are lower than those with higher levels.

In analyzing external environmental impact, it is most often assumed that marginal damage is constant, regardless of the level of emissions. Studies have shown that the concentrations of pollutants in the environment are generally linearly dependent on the amount of the emissions and the damages in the receptors are generally linear, depending upon the concentration of the pollutants. This means that the final damages to the environment/health for the majority of pollutants are proportional to the emissions, i.e. their marginal damages are constant. In this case, the average damages are equally marginal and also constant (Figure 2).

Slika 2 Šteta u okolišu i trošak njezinog smanjenja
Figure 2 Environmental damage and the cost of its reduction



Granični troškovi smanjenja emisija prikazuju troškove potrebne da se ukloni sljedeća jedinica onečišćenja. Opet, taj iznos ovisi o početnoj razini emisija. Na visokim razinama granični su troškovi redukcije manji jer su dostupne jeftinije mjere, ali kako se ukupna razina emisija smanjuje, potrebna su sve veća ulaganja za daljnje smanjenje emisija. Ekonomski optimalna razina emisija dobiva se izjednačenjem marginalne štete i marginalnih troškova za redukciju tih emisija. Pretpostavimo da Q^0 predstavlja nekontroliranu emisiju nekog polutanta (bez primjene redukcijskih mjera), dok je u ishodišnoj točki ta emisija jednaka nuli. Ako je razina emisija veća od Q^*, isplati se ulagati u njihovo smanjenje jer se tako ostvaruje dobit koja je veća od troškova potrebnih za njezino ostvarenje.

Naprotiv, ako je razina emisija ispod Q^*, mjere za smanjenje emisija se ne isplate jer će postignuta dobit biti manja od troškova. Prema

The marginal costs for reducing emissions show the costs required in order to eliminate the subsequent unit of pollution. Again, this amount depends on the initial level of emissions. At higher levels, the marginal costs of reduction are lower because less expensive measures are available, but since the total level of emissions decreases, increasingly large investments are required for the further reduction of emissions. The economically optimal level of emissions is obtained through equalizing the marginal damages and the marginal costs for the reduction of these emissions. Let us assume that Q^0 represents the uncontrolled emission of a pollutant (without the application of reduction measures), while at the origin point of emission the emission is equal to zero. If the level of emissions is greater than Q^*, it is economically justifiable to invest in reducing it because profit is thereby achieved that is greater than the expenditures necessary for achieving it.

tome, Q^* je ekonomski idealna razina emisija i ako se proizvođač nalazi upravo na toj razini, ne bi smio plaćati naknadu za preostalu emisiju Q^*. Ekonomski gledano, šteta zbog preostale emisije tada se ne bi trebala smatrati eksternim (nekompenziranim) troškom, već bi se moglo reći da je eksterni trošak uključen u troškove proizvodnje, a time i u tržišnu cijenu električne energije. No, treba naglasiti da određena šteta za okoliš uvijek postoji (emisije nikad nisu nula), čak i onda kad su svi eksterni učinci internalizirani.

2.3 Načini procjene eksternih troškova

Štete za okoliš i zdravlje zbog proizvodnje električne energije izazivaju eksterne troškove jer nisu kompenzirane cijenom električne energije. Preduvjet za uvođenje učinkovitog sustava zaštite okoliša je odrediti visinu eksternih troškova. Postoje dva osnovna načina za određivanje eksternih troškova: metodom troškova štete i metodom troškova kontrole.

2.3.1 Metoda troškova štete

Prema ovoj metodi, eksterni troškovi procjenjuju se na temelju stvarnih šteta u okolišu, što i jest najlogičnije rješenje. Znanstveno utemeljenim pristupom određuje se tzv. funkcija štete i odgovarajuća novčana vrijednost štete. Polazi se od uzroka štete (emisije polutanata) na nekoj lokaciji, prati njegova distribucija u okolišu, procjenjuje šteta izazvana u receptorima, kao i njezin eksterni trošak. Otuda naziv metoda funkcije štete ili metoda slijeda utjecaja. Treba naglasiti da ovakav postupak nije bio oduvijek moguć, njegov je intenzivni razvoj započeo tek sredinom 1990-tih godina zahvaljujući napretku znanosti i računalne tehnike.

Metoda funkcije štete ima svojih nedostataka – rezultati umnogome ovise o lokaciji, vrlo je složena, zahtijeva veliku količinu ulaznih podataka i detaljno poznavanje mehanizama u okolišu, pa se ne može primijeniti u procesima koje ne znamo (dovoljno dobro) modelirati. Najbolji primjer za to je proračun šteta globalnog zagrijavanja gdje se zbog velike nesigurnosti još uvijek uglavnom koristi jednostavniji pristup, tzv. metoda troškova kontrole. Pogotovo kontroverzan u metodi funkcije štete je zadnji korak, preračunavanje fizičkih i bioloških učinaka u novčane vrijednosti.

2.3.2 Metoda troškova kontrole

Eksterni troškovi po ovoj se metodi računaju na temelju ulaganja u mjere zaštite okoliša, potrebne za zadovoljenje postojećih ili budućih propisa. Općenito, princip je da se zada dopuštena

Conversely, if the level of emissions is below Q^*, the measures for reducing emissions are not economically justifiable because the profit that will be achieved is less than the amount of the expenditures. Accordingly, Q^* is the economically ideal level of emissions, and if a producer finds himself precisely at this level, he should not pay compensation for the remaining emission of Q^*. From the economic point of view, the damage due to the remaining emissions should then not be considered external (uncompensated) costs, but it could be said that the external costs are included in the production costs, and thereby in the market price of electrical energy. However, it should be emphasized that there is always a certain amount of damage to the environment (emissions are never at zero), even when all the external effects are internalized.

2.3 Methods of assessing external costs

Damages to the environment and health due to the production of electrical energy result in external costs because they are not compensated for by the price of electrical energy. A prerequisite for the introduction of an effective system of environmental protection is to determine the level of the external costs. There are two basic ways to determine external costs: the method of damage costs and the method of cost control.

2.3.1 The method of damage costs

According to this method, external costs are assessed on the basis of the actual damage to the environment, which is also the most logical solution. Through a scientifically based approach, the so-called damage function and the corresponding monetary value of the damages are determined. Starting from the cause of the damage (the emission of pollutants) at a particular location, its dispersion in the environment is monitored and damage in the receptors is assessed, as well as its external cost. This is the basis of the damage function method or the impact pathway method. It should be emphasized that such a procedure was not always possible but more intensive development began in the mid 1990s, owing to advances in scientific and computer techniques.

The damage function method has its shortcomings - the results greatly depend upon the location, it is highly complex, it requires a large quantity of input data and detailed acquaintance with the mechanisms in the environment, and it cannot be applied in processes that we do not know how to model (sufficiently well). The best example is the assessment of the damage from global warming, where a simpler approach is still used due to great uncertainty, the so-called method of control costs. The final step in the damage function method is especially controversial, the calculation of the physical and biological impacts in monetary terms.

ili ciljana razina onečišćenja i troškovi koji su potrebni da se taj cilj postigne. Eksterni trošak polutanta računa se kao omjer ulaganja u uređaj za pročišćavanje i smanjenja emisija koje se time postiže. Tako se npr. eksterni trošak sumpornog dioksida računa kao omjer troška za odsumporavanje i količine reduciranog sumpornog dioksida, a izražava se u novčanim jedinicama po toni polutanta. Pretpostavka ovog pristupa je da se stvarna šteta za okoliš ionako ne može točno izračunati. Zato se pribjegava pojednostavnjenom principu. Uz pretpostavku da se društvo nalazi na optimumu ekonomske efikasnosti, propisane granične vrijednosti emisije odražavale bi spremnost društva da investiranjem u kontrolne tehnologije izbjegne štetu. Međutim, kako u stvarnosti propisane razine emisija nisu ekonomski optimalne, već su rezultat političke odluke, troškove štete nije uputno poistovjećivati s troškovima kontrole. Ovaj princip koristi se u slučajevima gdje je proračun šteta složen ili mehanizam nastanka štete nije dovoljno istražen ili su velike nesigurnosti u procjeni štete, tj. kad metoda slijeda utjecaja nije primjenjiva. To je slučaj kod globalnog zagrijavanja gdje se razmjeri šteta i pripadni eksterni troškovi kreću u širokom rasponu jer su procjene posljedica vrlo nesigurne.

3 METODA SLIJEDA UTJECAJA ZA PROCJENU EKSTERNIH TROŠKOVA

Metoda je preuzeta iz studije ExternE, jedne od najvažnijih studija o eksternim troškovima lanaca za proizvodnju električne energije. Studija je nastala kao rezultat istoimenog projekta pod pokroviteljstvom Europske komisije. U toj je studiji primijenjena metoda slijeda utjecaja, što znači da se eksterni troškovi računaju na temelju stvarne štete u okolišu [4].

3.1 Definiranje opsega analize

Na početku analize treba definirati prostornu i vremensku granicu analize te raspon pritisaka na okoliš i učinaka koji će se obrađivati. Analiziraju se sljedeće kategorije pritisaka na okoliš: onečišćivači zraka (štetni plinovi i čestice koje se ispuštaju u atmosferu), kruti i tekući otpadi, nesreće, opasne tvari, buka, otpadna toplina i ostali pritisci. Pritisak na okoliš predstavlja svaku tvar koja izaziva ili bi mogla izazvati bilo kakav utjecaj na okoliš ili ljudsko zdravlje.

Najveću važnost u energijskom lancu za proizvodnju električne energije ima sama elektrana. Međutim, granice sustava treba odrediti tako da se

2.3.2 The method of control costs

According to this method, external costs are calculated on the basis of investment in the environmental protection measures that are necessitated by compliance with the existing or future regulations. Generally speaking, the principle is that the permitted or target levels of pollution and costs that are necessary in order to achieve this goal are assigned. The external cost of a pollutant is calculated as the ratio between investment in equipment for eliminating pollution and reducing emissions in order to achieve this. Thus, for example, the external cost of sulfur dioxide is calculated as the ratio of the cost for sulfur reduction and the quantity of the reduced sulfur dioxide, and is expressed in monetary units per ton of pollutant. The assumption regarding this approach is that the actual environmental damage cannot be calculated precisely. For this reason, a simplified approach is used. Assuming that the society is operating at optimum economic efficiency, the stipulated marginal values of emissions would reflect the readiness of the society to invest in control technology to avoid damage. However, since in reality the stipulated emission levels are not economically optimal but the result of political decisions, the damage costs should not be equated with the control costs. This principle is used in cases when the estimate of damages is complex, the mechanism for the origin of damage is not sufficiently specified or there is great uncertainty in the assessment of the damage, i.e. when the impact pathway method is not applicable. This is the case with global warming, where the dimensions of the damage and corresponding external costs range widely because the estimates of the consequences are highly uncertain.

3 THE IMPACT PATHWAY METHOD FOR THE ESTIMATE OF EXTERNAL COSTS

This method is taken from the study ExternE, one of the most significant studies on the external costs of the chain for the production of electrical energy. The study came about as the result of the project of the same name, under the sponsorship of the European Commission. In this study, the impact pathway method was used, which means that the external costs are calculated on the basis of the actual damages to the environment [4].

3.1 Definition of the range of analysis

At the beginning of analysis, it is necessary to define the spatial and temporal limits of the analysis, the range of environmental pressures and the effects that will be studied. The following categories of environmental pressures are analyzed: air pollutants uračunaju potencijalni učinci svih procesa vezanih uz proizvodnju električne energije. U općem slučaju, energijski lanac obuhvaća proizvodnju građevnog materijala, prijevoz građevnog materijala, izgradnju elektrane, istraživanje nalazišta i vađenje goriva, obradu goriva, prijevoz goriva, tretman dimnih plinova, proizvodnju otpadnog materijala, obradu otpada, dekomisiju elektrane i saniranje lokacije na kraju životnog vijeka elektrane. Prostorni opseg analize ima velik utjecaj, pogotovo na posljedice onečišćenja zraka. Razmatranje treba proširiti na nekoliko stotina kilometara od izvora jer mnogi polutanti imaju dalekosežne učinke (SO_2, No_x, sekundarne čestice, ozon) koji su se u nekim slučajevima pokazali veći od lokalnih jer zahvaćaju veći broj receptora. Ipak, na određenoj udaljenosti od izvora treba prekinuti analizu i pokušati ocijeniti omjer uračunatih i neuračunatih emisija.

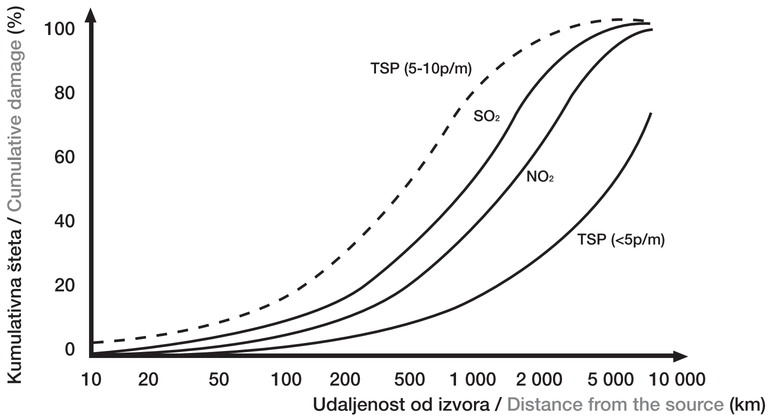
Da bi se dobio uvid u potreban opseg analize, u studiji ExternE proveden je jednostavan proračun disperzije SO_2, i letećih čestica (TSP< 5 μm i TSP 5-10 μm). Pretpostavljen je krajnje jednostavan model disperzije: homogeno trenutačno miješanje polutanata s okolišnim zrakom na visini sloja miješanja, ravnomjerna distribucija smjera vjetra tijekom godine, brzina vjetra jednaka prosječnoj godišnjoj brzini, zanemarene su kemijske reakcije polutanata u atmosferi, a kao način uklanjanja polutanata iz atmosfere računato je samo sa suhim taloženjem (mokro taloženje nije uzeto u obzir). Nadalje, pretpostavljene su linearne funkcije izloženost-učinak koje povezuju učinke na ljudsko zdravlje i navedene polutante te jednolika gustoća naseljenosti oko izvora. Uza sve te pretpostavke dobiva se da kumulativna šteta za zdravlje za sve polutante ima oblik funkcije $(1-e^x)$ gdje je $\boldsymbol{x}$ udaljenost od izvora (slika 3). Zaključak je da treba promatrati udaljenosti od tisuću i više kilometara da bi se uračunao najveći dio štete.

(harmful gasses and particles that are released into the atmosphere), solid and liquid wastes, accidents, hazardous substances, noise, waste heat and other pressures. An environmental pressure is each substance that provokes or could provoke any impact whatsoever upon the environment or human health.

The power plant is of the greatest importance in the energy chain for the production of electrical energy. However, the limits of the system should be determined in such a manner that the potential effects of all the processes in connection with the production of electrical energy are calculated. Generally, the energy chain includes the production of building material, the transport of building material, the construction of the power plant, site investigation, excavation of fuel, fuel processing, fuel transport, the treatment of flue gasses, the production of waste material, waste processing, taking the power plant out of commission and restoring the site at the end of the life of a large power plant. The spatial range of analysis has a great influence, especially on the consequences of air pollution. Observation should be extended for several hundred kilometers from the source because many pollutants have long-range effects (SO_2, NO_x, secondary particles, ozone), which in some cases have been shown to be greater than local effects because a larger number of receptors are affected by them. Nonetheless, at a certain distance from the source, analysis should stop and an attempt should be made to assess the ratio of the calculated and uncalculated emissions.

In order to obtain insight into the required range of analysis, in the study ExternE a simple estimate was performed of the dispersion of SO_2, NO_x and flying particles (TSP< 5 μm and TSP 5-10 μm). An extremely simple dispersion model is presented: homogeneous instantaneous mixing of pollutants with the environmental air at the level of the mixing layer. uniform distribution of the wind direction during the year, wind velocity equal to that of the average annual velocity, the chemical reactions of the pollutants in the atmosphere are ignored, and only dry sedimentation is calculated as a manner of removing the pollutants from the atmosphere (wet sedimentation is not taken into account). Furthermore, linear functions of exposure-effect are assumed that correlate the impact upon human health and the said pollutants, postulating uniform population density around the source. With all these assumptions, the cumulative detriment to health is obtained for all the pollutants, with the form of the function $(1-e^x)$, where $\boldsymbol{x}$ is the distance from the source (Figure 3). The conclusion is that it is necessary to study distances of a thousand and more kilometers in order to calculate the greatest part of the damage.

Slika 3 Očekivana kumulativna šteta ovisno o udaljenosti od izvora emisija
Figure 3 Anticipated cumulative damages at various distances from the emission source



Učinke bi trebalo računati kroz cijelo razdoblje manifestiranja. Tu se pojavljuje problem nesigurnosti dugoročnih učinaka, npr. globalnog zagrijavanja i odlaganja visokoradioaktivnog otpada. Da bi se u obzir uzeo raspon mogućih ishoda, kreiraju se razvojni scenariji u kojima su spomenute nepoznanice ulazni parametri. Vremenski opseg analize povezuje se i s pitanjem diskontiranja novčanih vrijednosti šteta. Općenito se smatra da bi ekološka diskontna stopa, tj. ona po kojoj bi se diskontirale novčane vrijednosti šteta za okoliš/zdravlje, trebala uzeti u obzir održivost razvoja društva i cijelog planeta.

3.2 Određivanje prioritetnih utjecaja

Analiza treba obuhvatiti one učinke koji prema današnjim spoznajama izazivaju najveće eksterne učinke. Često su lokalni učinci manje važni od regionalnih i globalnih jer pogađaju manji broj ljudi, i kad se normiraju na proizvedeni TWh, ispadaju zanemarivi. Međutim, u nekim su slučajevima lokalni eksterni troškovi ipak veći od regionalnih i globalnih, a to je uglavnom kad je riječ o nesrećama koje pogađaju radnike i stanovništvo te bolestima na radu. Budući da se ljudski život i zdravlje visoko cijene, pripadajući eksterni troškovi su visoki.

Izbor prioritetnih utjecaja ovisi i o tome želimo li odrediti štete ili samo eksterne učinke. Naime, postoje pritisci s velikim štetama za okoliš, ali vrlo malim eksternim troškovima jer je većina šteta kompenzirana. Na primjer, povećani rizici u nekim zanimanjima većinom se kompenziraju kroz plaće, dok se blizina industrijskog objekta, tj. vizualni utjecaj i buka, obično kompenziraju nižom cijenom stambenog prostora.

The effects should be calculated through the entire period of the manifestation. The problem of the uncertainty of the long-term impacts arises in, for example, global warming and the disposal of highly radioactive wastes. In order to take the range of potential results into account, developmental scenarios are created in which the cited unknowns are entry parameters. The temporal range of analysis is connected with the question of the discounting of the monetary values of the damages. It is generally considered that the ecological discount rate, i.e. according to which the monetary value of the damage to the environment/health would be discounted, should take into account the sustainability of the development of the society and the entire planet.

3.2 Determination of priority impacts

Analysis should cover those impacts that cause the greatest external impacts, according to current knowledge. The local impacts are often less important than the regional and global impacts because they affect a smaller number of people, and when they become negligible. However, in some cases the local external costs are nonetheless greater than the regional and global, generally when there are accidents that affect employees and the population, as well as occupational disorders. Since human life and health are of high value, the concomitant external costs are high.

The choice of priority impacts depends on whether we want to determine damages or only external impacts. There are pressures with great damages to the environment but very low external costs, because the majority of the damages are compensated for. As an example, increased risks in some occupations are for the most part compensated through salaries, while the vicinity to industrial objects, i.e. the loss of visual amenity and noise, are generally compensated for through lower housing prices.

3.3 Određivanje pritisaka na okoliš

Prvi korak analize relativno je jednostavan - treba izračunati emisije u zrak, vodu i tlo te ostale posljedice uzrokovane odabranom tehnologijom, npr. nesreće koje pogađaju radnike i stanovništvo. Emisije u zrak (CO_2, SO_2, NO_x, čestice, hlapljive tvari i sl.) mogu se odrediti s velikom točnošću na temelju poznatog sastava goriva i tehnologije izgaranja. Razmatraju se suvremene, ali već dokazane tehnologije za proizvodnju električne energije i uređaji za smanjenje emisija potrebni da se zadovolje emisijski standardi pojedine zemlje. Veći je problem utvrditi emisije elemenata u tragovima, npr. olova i žive, jer su zbog njihovih malih iznosa i mjerenja otežana. U energijskom lancu goriva najjednostavnije je ustanoviti emisije na lokaciji elektrane koje u lancima fosilnih goriva čine dominantni dio ukupnih emisija lanca.

3.4 Opis prihvatne okoline

Ako se procjenjuje utjecaj onečišćenja zraka na ljudsko zdravlje, treba poznavati meteorološke uvjete koji utječu na disperziju, transport i kemijske reakcije polutanata, dobnu strukturu i zdravstveno stanje stanovništva, stanje ekoloških resursa (kritična opterećenja ekosustava) te vrijednosne sustave pojedinaca. Za procjenu budućih šteta potrebne su neke pretpostavke o razvoju prihvatne okoline, npr. o broju stanovništva i mogućnostima liječenja u budućnosti.

3.5 Rasprostiranje polutanata u okolišu – procjena izloženosti

Promatraju se utjecaji na ljudsko zdravlje, materijale, usjeve, biljne i životinjske ekosustave, zatim posljedice globalnog zagrijavanja i ostali utjecaji. Za proračun svih učinaka vezanih uz emisije polutanata zajedničko je to što je potreban odgovarajući model atmosferske disperzije i poznavanje funkcija izloženost - učinak. Za modeliranje disperzije unutar 50-100 km od izvora koristi se Gaussov model disperzije koji zanemaruje kemijske transformacije polutanata u atmosferi, ali dobro opisuje vertikalnu i horizontalnu disperziju polutanata unutar sloja miješanja. Za modeliranje dalekosežne disperzije koriste se modeli trajektorija koji u obzir uzimaju kemijske reakcije u atmosferi te računaju ambijentalne koncentracije i taloženje primarnih i sekundarno stvorenih polutanata.

3.3 Determination of pressure on the environment

The first step in analysis is relatively simple. It is necessary to calculate the emissions into the air, water and soil, and other consequences caused by the selected technology, for example accidents that affect workers and the population. Emissions into the air (CO_2, SO_2, NO_x, particles, volatile substances etc.) can be determined with great precision on the basis of the known fuel composition and combustion technology. Modern but already confirmed technologies for the production of electrical energy and equipment for reducing emissions required to meet the emission standards of individual countries are being studied. It is a greater problem to determine the emission of trace elements, for example lead and mercury, because measurement is more difficult due to their small quantities. In the energy fuel chain, it is simplest to determine the emissions at the location of the power plant, of which the fossil fuel chain occupies the dominant portion of the total emission chain.

3.4 Description of the receiving environment

When the impact of air pollution on human health is assessed, it is necessary to be acquainted with the meteorological conditions that affect the dispersion, transport and chemical reactions of pollutants, seasonal structure, the state of health of the population, the status of the ecological resources (critical burden upon the ecosystem), and the value systems of individuals. In order to estimate future damages, some assumptions are necessary regarding the development of the receiving environment, for example the number of inhabitants and the possibilities for future medical treatment.

3.5 Distribution of pollutants in the environment – exposure estimate

Impact is studied on human health, materials, crops, flora and fauna ecosystems, the consequences of global warming and other influences. For an estimate of all the effects in connection with the emission of pollutants, a suitable model of atmospheric dispersion and knowledge of the function of exposure-effect are required. For the modeling of dispersion within 50-100 km from the source, the Gaussian dispersion model is used, which ignores the chemical transformation of pollutants in the atmosphere but provides a good description of the vertical and horizontal dispersion of pollutants within the mixing layer. For the modeling of far reaching dispersion, trajectory models are used that take into account the chemical reactions in the atmosphere and calculate the ambient concentrations and deposits of the primary and secondary pollutants created.

3.6 Funkcijska veza izloženosti i učinka

Za vrednovanje učinaka na okoliš i zdravlje koriste se funkcije izloženost-učinak. Određivanje funkcijske veze između izloženosti i učinka presudan je korak u metodi slijeda utjecaja.

Funkcija $Y=f_u(X)$ dovodi u vezu promjenu Y u receptoru, tj. učinak na receptor, s porastom koncentracije polutanta za vrijednost X, tj. s izloženošću. Te se funkcije nazivaju i doza-učinak jer doza predstavlja količinu tvari unesenu u organizam, npr. udisanjem, i ne mora biti jednaka izloženosti.

Da bi se odredila ovisnost učinka o dozi, odnosno izloženosti, treba u detalje razumjeti mehanizme širenja utjecaja jer je konačna manifestacija u receptoru rezultat više isprepletenih utjecaja. Primjenjivost rezultata u većem broju različitih uvjeta jedan je od pokazatelja postoji li između izloženosti i zabilježene posljedice zaista funkcijska veza i smiju li se rezultati poopćiti. Naime, rezultati mogu varirati zbog različite strukture stanovništva, različite smjese polutanata i drugih uvjeta, što je i primijećeno u epidemiološkim studijama. Stručnjaci smatraju da je bolje, ako ne raspolažemo vlastitom funkcijom izloženost-učinak, primijeniti "tuđu" funkciju (dobivenu u drukčijim uvjetima) nego promatrani učinak posve zanemariti jer ionako u oba slučaja postoji određena doza nesigurnosti.

Postoje različiti oblici funkcija izloženost-učinak, one mogu biti linearne i nelinearne, bez praga ili s pragom djelovanja (slika 4). Prag označava da postoji kritično opterećenje ekosustava za promatrani učinak. Funkcije koje opisuju učinke onečišćenja zraka na poljoprivredne usjeve iznimno su složene jer uključuju i pozitivne i negativne efekte (sulfati i nitrati djeluju i kao umjetno gnojivo i kao kiseli polutanti). Idealno se funkcije izloženost-učinak dobivaju iz epidemioloških analiza, u kojima se utvrđuju učinci polutanata na stvarne receptore: ljude, usjeve itd. Postavlja se pitanje je li opravdano učinke ekstrapolirati na doze niže od laboratorijskih, pogotovo ako se sumnja na postojanje praga. No, ipak se funkcije izloženost-učinak najčešće lineariziraju, a učinci zabilježeni na višim dozama ekstrapoliraju na niske doze, sve do nule, uz pretpostavku da ne postoji prag pojave učinka jer je iskustvo pokazalo da su te aproksimacije opravdane.

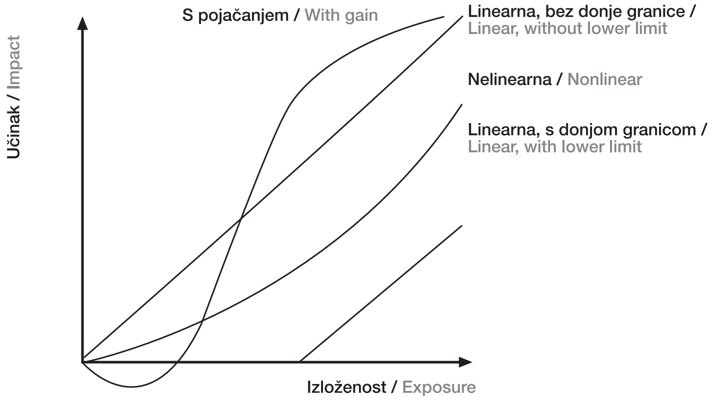
3.6 The functional connection between exposure and impact

Exposure-impact functions are used for the assessment of impact upon the environment and health. The determination of the functional connections between exposure and impact is a crucial step in the impact pathway method.

Function $Y=f_u(X)$ relates to a change of Y in the receptor, i.e. the impact on the receptor, with an increase in the concentration of pollutants by a value of X, i.e. with exposure. These functions are also called dose-impact because the dose represents the quantity of substances entering the organism, for example through inhalation, and does not have to be uniform to exposure.

In order to determine the dependency of the impact on the dose, that is to say exposure, it is necessary to understand the mechanisms for the dispersion of impact in detail, because the ultimate manifestation in the receptor is the result of many entwined impacts. The applicability of the results for a large number of varied impacts is one of the indicators of whether there is actually a functional connection between the exposure and the recorded consequences and whether the results may be published. Results can vary due to various population structures, various mixtures of pollutants and other conditions, as noted in epidemiological studies. Experts feel that it is better, if we do not have our own exposure-impact function, to apply a "foreign" function (obtained under other conditions) than to ignore a studied impact entirely, because in both cases there is a certain dose of uncertainty.

There are various forms of the exposure-impact function. They can be linear or nonlinear, with or without a threshold of activity (Figure 4). A threshold means that there is a critical burden on the ecosystem for the observed impact. The functions that describe the impacts of air pollution on agricultural crops are exceptionally complex because they include both positive and negative effects (sulfates and nitrates act both as artificial fertilizers and acid pollutants). Ideally, exposure-impact functions are obtained from epidemiological analyses, in which the impacts are determined on actual receptors: humans, crops etc. The question is posed whether it is justified to extrapolate impacts on doses lower than laboratory doses, especially if the existence of a threshold is suspected. Nonetheless, exposure-impact functions are most often linearized, and the impacts are recorded for high doses extrapolated to lower doses, all the way to zero, with the assumption that there is no threshold for the occurrence of impact because experience has shown that such approximations are justified.



Slika 4
Vrste funkcija izloženost-učinak
Figure 4
Types of the exposure-impact function

3.7 Novčano vrednovanje

Cilj je novčanog vrednovanja dobara ustanoviti koliko je pojedinac spreman platiti da izbjegne određenu štetu za zdravlje i/ili okoliš. Pitanja o kojima treba voditi računa pri vrednovanju šteta i o kojima se još uvijek vode rasprave jesu opravdanost prenošenja rezultata iz jednog u drugi kontekst, tj. primjena rezultata na gospodarske, političke i zemljopisne uvjete različite od izvornih, zatim postojanje razlike između svojevoljnog i nametnutog rizika, izbor diskontne stope, nesigurnost procjene itd.

3.8 Ocjena nesigurnosti

Faktori koji utječu na procjenu eksternih troškova metodom slijeda utjecaja su vrste i svojstva receptora, prostorne granice analize, svojstva elektrane, vrste analiziranih putova utjecaja, modeli atmosferske disperzije, funkcije izloženost-učinak, novčane vrijednosti šteta i način diskontiranja bazne godine. Nesigurnost procjene eksternih troškova prilično je velika jer se oni dobivaju množenjem niza parametara čije su vrijednosti također nesigurne. Najbrojniji izvori nesigurnosti, koji se ubrajaju u kategoriju statističke nesigurnosti, vezani su uz nesigurnost tehničkih i znanstvenih podataka. Oni uključuju nesigurnost ulaznih podataka, nedovoljno poznavanje emisija u dijelovima energijskog lanca prije i poslije elektrane, aproksimacije u modelima disperzije polutanata, nepoznanice u određivanju funkcija izloženost-učinak i način novčanog vrednovanja štete. Većina tih parametara može se procijeniti s točnošću unutar jednog reda veličine. Statistička nesigurnost može se izračunati primjenom statističkih metoda koje daju interval pouzdanosti oko srednje vrijednosti. Na temelju detaljne usporedbe najvažnijih studija eksternih troškova do sada, koje su promatrale učinke onečišćenja zraka na ljudsko zdravlje [5], zaključeno je da u postupku određivanja funkcije štete najveće nesigurnosti uzrokuje modeliranje atmosferske

3.7 Monetary valuation

The goal of the monetary valuation of goods is to establish how much an individual is prepared to pay in order to avoid specific damage to health and/or the environment. The questions that should be taken into account when evaluating damage, which are still being debated, are the justifiability of transferring results from one context to another, i.e. the application of results for economic, political and geographical conditions that are different from the original ones, the existence of differences between voluntarily undertaken and imposed risks, the choice of a discount rate, the uncertainty of estimation etc.

3.8 Assessment of uncertainty

The factors that affect the assessment of external costs using the impact pathway method are the types and properties of the receptors, the spatial limits of analysis, the properties of the power plant, the types of analyzed impact pathways, models of atmospheric dispersion, exposure-impact functions, the monetary value of damages and the manner of discounting the base year. The uncertainty of the assessment of external costs is fairly great because they are obtained through the multiplication of a series of parameters whose values are also uncertain. The most numerous sources of uncertainty, which are included in the category of statistical uncertainty, are connected with the uncertainty of the technical and scientific data. They include the uncertainty of the entry data, insufficient knowledge of the emissions in parts of the energy chain before and after the power plant, approximations in the pollutant dispersion models, unknowns in the determination of the exposure-impact function and the manner of the monetary evaluation of damages. The majority of these parameters can be assessed with precision within one order of magnitude. Statistical uncertainty can be calculated using statistical methods that yield an interval of reliability of approximately average values. On the basis of more detailed comparisons of the most important studies of external costs up to the disperzije. Mogući razlozi za neslaganje rezultata su meteorološki parametri, razlika u pozadinskim koncentracijama amonijaka i načinu modeliranja kemijskih reakcija u atmosferi. Svi ostali koraci metode slijeda utjecaja kompatibilni su među studijama.

Ostali izvori nesigurnosti su:

- nesigurnost modela,
- nesigurnost uzrokovana etičkim i društveno-političkim pitanjima,
- nesigurnost u definiranju scenarija budućeg razvoja.

To je nestatistička nesigurnost koja se ne može odrediti statističkim metodama već analizom osjetljivosti koja daje ovisnost rješenja o izboru ulaznih parametara. Unatoč nesigurnosti, metoda slijeda utjecaja preporuča se za proračun eksternih troškova jer omogućuje transparentnost i interdisciplinarnost analize te usporedbu različitih kategorija utjecaja u istom, novčanom mjerilu koje, osim toga, u velikoj mjeri odražava preferencije javnosti.

4 UKLJUČENJE EKSTERNIH TROŠKOVA U POLITIKU ZAŠTITE OKOLIŠA

Mjere zaštite okoliša mogu biti regulativne, kojima se propisuju različiti standardi, ili pak ekonomske, koje se u ostvarenju ekološkog cilja oslanjaju na tržišne mehanizme. U regulativne mjere ubrajaju se standardi kvalitete okoliša, standardi kvalitete proizvoda, emisijski standardi, tehničko-tehnološki standardi, sigurnosni propisi itd. U ekonomske mjere ubrajaju se politika cijena, subvencije, ekološki porezi, emisijske pristojbe i kazne, i fleksibilni mehanizmi kao što su propisivanje emisijskih kvota i trgovanje emisijskim dozvolama. U eri procvata tržišne ekonomije sve popularnije postaju tržišne mjere. Njihova je osnovna prednost što isti ekološki cilj postižu uz manje ukupne troškove.

4.1 Regulativne mjere

Konvencionalne mjere zaštite okoliša sastoje se od sljedećeg: donošenje propisa (standarda) - nadzor provedbe - nametanje sankcija za nepoštivanje. U proizvodnji električne energije najčešće se propisuju maksimalno dopuštene emisije štetnih tvari iz stacionarnih izvora. Za elektrane na fosilna goriva propisane su granične vrijednosti emisije za krute čestice, sumporni dioksid, dušične okside, hlapljive organske tvari

present, which study the impacts of air pollution on human health [5], it has been concluded that in the procedure for the determination of the function of damages, the greatest uncertainties are caused by the modeling of atmospheric dispersion. Possible reasons for the disparity of the results are the meteorological parameters, variations in the background concentrations of ammonia and the manner of modeling chemical reactions in the atmosphere. All the other steps of the impact pathway method are compatible among the studies.

Other sources of uncertainty are as follows:

- uncertainty of the model,
- uncertainty caused by ethical and sociopolitical questions,
- uncertainty in the definition of scenarios of future development.

This is nonstatistical uncertainty that cannot be determined through statistical methods but through analysis of sensitivities, that yields in the selection of entry parameters. Despite uncertainties, the impact pathway method is recommended for the calculation of external costs because it facilitates transparency and interdisciplinary analysis, and the comparison of various categories of impact in the same monetary measure, which moreover to a great extent is reflected in public preferences.

4 INCLUSION OF EXTERNAL COSTS IN THE ENVIRONMENTAL PROTECTION POLICY

Environmental protection measures can be regulatory, according to which various standards are stipulated, or economic, which rely on market mechanisms in order to achieve an ecological goal. Regulatory measures include environmental quality standards, product quality standards, emission standards, technical-technological standards, safety regulations etc. Economic measures include price policy, subsidies, ecological taxes, emission fees and penalties, and flexible mechanisms such as the stipulation of emission quotas and the issue of emission permits. In an era of the blossoming of the market economy, market measures are becoming increasingly popular. Their basic advantage is that the same ecological goal is achieved with lower total expenditures.

4.1 Regulatory measures

Conventional measures for environmental protection consist of the following: the adoption of regulations (standards), the supervision of implementation and imposing penalties for noncompliance. In the itd. Propisane vrijednosti mogu se zadovoljiti odabirom "čistijeg" goriva, povećanjem efikasnosti izgaranja, modifikacijama uvjeta izgaranja i, što je najdjelotvornije, pročišćavanjem dimnih plinova nakon izgaranja. Ovo posljednje zahtijeva posebne uređaje - filtre i katalizatore - koji imaju veliku sposobnost uklanjanja štetnih tvari iz dimnih plinova, ali bitno povećavaju troškove proizvodnje električne energije. Iako mjere regulative strogo kontroliraju razine emisija, njihov je nedostatak što nisu ekonomski efikasne i ne minimiziraju troškove zaštite okoliša. Naime, proizvođač nije motiviran smanjiti svoje emisije više nego što je minimalno potrebno jer mu to ne bi donijelo nikakvu ekonomsku prednost. U sustavu koji se bazira na mjerama regulative nema ekonomskog poticaja za tehnološka unapređenja i inovacije. Zato na važnosti dobivaju tržišne mjere zaštite okoliša, iako su mjere regulative i dalje zadržale svoje mjesto.

4.2 Ekonomske mjere

Zaštita okoliša sve se više oslanja na ekonomske mjere, što je u skladu s prevagom tržišnog gospodarstva u svijetu. Dobro osmišljene tržišne mjere mogu osigurati da se željeni ekološki cilj postigne uz najmanji mogući trošak, zajedničkim djelovanjem više aktera. Osnovni tipovi ekonomskih mjera su emisijske pristojbe i porezi te trgovanje emisijskim dozvolama. Emisijske pristojbe terete proizvođača proporcionalno onečišćenju koje uzrokuje, a definiraju se po jedinici ispuštenog polutanta. U pravilu, svaki će izvor reducirati svoje emisije na razinu pri kojoj su marginalni troškovi redukcijskih mjera jednaki pristojbi na emisije. Takav pristup potiče proizvođače da minimiziraju troškove redukcijskih mjera, pa se ekološke pristojbe smatraju ekonomski efikasnijom mjerom zaštite okoliša od propisivanja standarda. Na idealnom tržištu pristojba bi trebala biti jednaka graničnoj dobiti smanjenja emisija, odnosno visini izbjegnute granične štete. Iz tog proizlazi da je u odabiru visine pristojbe poželjno poznavati stvarnu štetu u okolišu, a ona se može procijeniti metodom slijeda utjecaja.

Budući da u praksi tržište nije idealno, ne zna se kakav će biti odgovor proizvođača električne energije na uvođenje pristojbi i koliko će se smanjenje emisija time zaista postići. Zato se kao bolji mehanizam navodi trgovanje emisijskim dozvolama [6]. Preduvjet za uspostavu tržišta dozvolama je definiranje ukupne kvote emisija i raspodjela emisijskih dozvola među sudionicima na tržištu. Proizvođači koji emitiraju manje od svoje kvote mogu višak dozvola prodati onima kojima nedostaje. Na idealnom tržištu uspostavlja se cijena emisijske dozvole jednaka graničnom

production of electrical energy, most often the maximum permitted emissions of harmful substances from a stationary source are stipulated. For power plants using fossil fuel, the limit values are stipulated for emissions of solid particles, sulfur dioxide, nitric oxide, volatile organic substances etc. The stipulated values can be met by choosing "cleaner" fuel, increasing combustion efficiency, modifications of the combustion conditions and, which is most effective, cleaning the flue gasses after combustion. This last measure requires special equipment - filters and catalyzers - that have a great ability to remove harmful substances from flue gasses but significantly increase the costs of the production of electrical energy. Although the regulatory measures strictly control the emission levels, they are not economically efficient and do not minimize the costs of environmental protection. A producer is not motivated to reduce emissions by more than the minimum requirement because it would not bring him any economic advantage whatsoever. In a system that is based upon regulatory measures, there is no economic incentive for technological advancement and innovations. Therefore, market measures for environmental protection acquire greater importance, although the regulatory measures continue to retain their place.

4.2 Economic measures

Environmental protection increasingly relies upon economic measures, which is in accordance with the prevailing market economy in the world. Well thought out commercial measures can assure that the desired ecological goal is achieved with the minimum possible expense, through the joint efforts of several participants. The basic types of economic measures are emission fees, taxes and the trading of emission allowances. Emission fees are charged to a producer in proportion to the pollution caused, and are defined according to units of released pollutant. As a rule, each source will reduce its emissions to the level at which the marginal costs of the reduction measures are equal to the emission fees. Such an approach provides an incentive for producers to minimize the costs of reduction measures, so that ecological fees are considered more economically efficient measures for environmental protection than the stipulation of standards. On an ideal market, the fee should be equal to the marginal profits of reduced emissions, i.e. the amount of marginal damages avoided. From this it ensues that in the determination of the amount of fees, it is desirable to be acquainted with the actual damage to the environment, which can be assessed by the impact pathway method.

Since in practice the market is not ideal, it is not known what will be the response of the producers of electrical energy to the introduction of fees and how much of a reduction in emissions will actually be trošku smanjenja emisija. Proizvođači koji mogu smanjiti emisije uz manji trošak po toni polutanta preuzet će na sebe proporcionalno veći udio u ukupnoj obvezi smanjenja emisija, ali će od toga i profitirati, npr. prodajom svojih emisijskih dozvola. Ukupni troškovi postizanja zadane emisijske kvote bit će minimalni, a granični troškovi smanjenja emisija u idealnom slučaju bit će jednaki za sve proizvođače. Osim što minimiziraju ukupne troškove, tržišne mjere potiču inovacije, tj. razvoj jeftinijih i boljih tehničkih rješenja za smanjenje onečišćenja.

Fleksibilni mehanizmi za smanjenje emisija postali su posebno zanimljivi nakon potpisivanja Protokola u Kyotu o smanjenju emisija ugljičnog dioksida u razvijenim i tranzicijskim zemljama. Oni omogućuju da se smanjenje emisija ostvari zajedničkom akcijom dviju ili više zemalja, čime se zadani cilj ostvaruje uz najmanji mogući trošak. U fleksibilne mehanizme ubraja se trgovanje emisijskim dozvolama i projekti u kojima razvijena zemlja ulaže kapital u smanjenje emisija izvan vlastitih granica, u zemlji u tranziciji ili u razvoju, jer je to jeftinije nego smanjenje vlastitih emisija. Najčešće su to ulaganja u niskougljične tehnologije za proizvodnju električne energije, npr. povećanje efikasnosti potrošnje i obnovljivi izvori energije.

4.2.1 Emisijske pristojbe i porezi

Pristojbe i porezi na emisiju mogu potaknuti efikasniju uporabu resursa, primjenu čistijih goriva i tehnologija te stimulirati održivi razvoj. Ekološki porezi ne bi smjeli povećati ukupno porezno opterećenje stanovništva, već bi na račun njih trebalo smanjiti neke druge poreze, po mogućnosti porez na dohodak i štetne subvencije (npr. na potrošnju fosilnih goriva). Porezi i pristojbe na emisiju CO_2 ili njihovi ekvivalenti (npr. porez na sadržaj ugljika u gorivu) posebno su osjetljivo pitanje jer mogu uzrokovati opći porast cijena i, ako se primjenjuju izolirano, smanjiti konkurentnost na međunarodnom tržištu. Zato bi se porezi takvog tipa trebali uvesti istodobno i u istom iznosu u svim zemljama.

Danas najveći globalni ekološki problem predstavlja globalno zagrijavanje, tj. emisije ugljičnog dioksida. Budući da su tehnička rješenja za uklanjanje ugljičnog dioksida iz dimnih plinova još uvijek ograničena i ekonomski neprihvatljiva, najizgledniji način za smanjenje emisija su posredne mjere koje se mogu stimulirati ekonomskim instrumentima. Istina, emisijske pristojbe i porezi ne mogu bitnije smanjiti potrošnju fosilnih goriva u primjenama gdje nema zamjenskog energenta ili je taj nepovoljniji. Takav

achieved thereby. Therefore, the trading of emission allowances is a better mechanism [6]. A prerequisite for the establishment of a allowances market is the definition of the total quota of emissions and the distribution of emission allowances among the participants on the market. Producers who emit less than their quota may sell their excess allowances to those who lack them. On an ideal market, the price of the emission of allowances is established as equal to the marginal cost of reduced emissions. Producers who can reduce emissions with lower expenditures per ton of pollutant will take upon themselves a proportionally larger share in the overall obligation to reduce emissions, but they will also profit from this, for example through the sale of their emission allowances. The total expenditures for achieving the assigned emission quotas will be minimal and the marginal costs of reduced emissions in the ideal case will be uniform for all the producers. Besides minimizing overall expenditures, market measures promote innovations, i.e. the development of less expensive and better technical solutions for reducing pollution.

Flexible mechanisms for the reduction of emissions have become particularly interesting after the signing of the Kyoto Protocol on the reduction of the emission of carbon dioxide in developed and transition countries. They make it possible to achieve a reduction in emissions through the joint activity of two or more countries, according to which the given goal is achieved with the minimum possible expenditure. Flexible mechanisms include trade in emission allowances and projects in which developed countries invest capital in the reduction of emissions outside their own borders in countries in transition or development, because this is less expensive than reducing their own emissions. Most frequently, these are investments in low carbon technologies for the production of electrical energy, for example by increasing the efficiency of consumption and the renewable of energy sources.

4.2.1 Emission fees and taxes

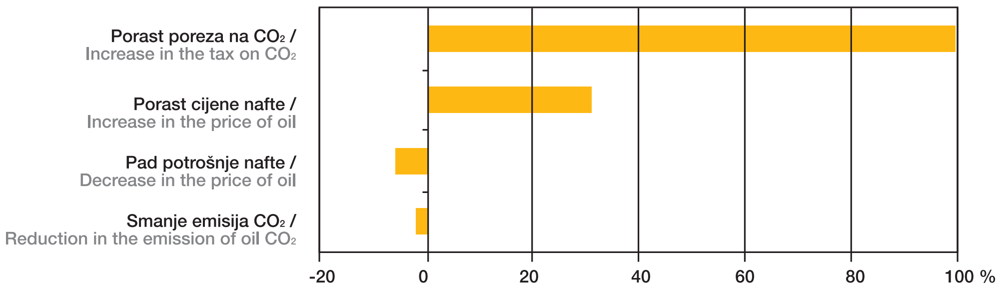
Fees and taxes on emissions can promote a more effective use of resources, the use of cleaner fuels and technologies, and stimulate sustainable development. Ecological taxes should not be permitted to increase the total tax burden on the population but on their account some other taxes should be lowered, if possible income tax and detrimental subsidies (e.g., for the consumption of fossil fuels). Taxes and fees on the emission of CO_2 or its equivalents (e.g., tax on the carbon content in fuel) are particularly sensitive questions because they can lead to a general rise in prices and, if applied in an isolated manner, reduce competitiveness on the international market. Therefore, such taxes should be introduced at the same time and in the same amount in all countries.

primjer je potrošnja tekućih goriva za potrebe prijevoza i petrokemijske industrije koja je gotovo neelastična na promjenu cijene goriva. Primjer takvog ekološki neefikasnog poreza daje slika 5. Simulirano je udvostručenje poreza na emisiju ugljičnog dioksida u Švedskoj [7]. To bi rezultiralo porastom cijena nafte od oko 30 %, zbog čega bi potrošnja nafte pala za samo 6 %, a emisije CO_2 zanemarivih 1 %.

Međutim, pristojba na emisiju CO_2 mogla bi utjecati na izbor energenata za nove elektrane, dakle u situaciji gdje fosilna goriva imaju alternativu. Zbog pristojbe bi se povećali proizvodni troškovi jedinica s velikim emisijama CO_2 po proizvedenom kWh, čime bi se smanjila njihova ekonomska prednost. To bi utjecalo na optimalni sastav proizvodnih kapaciteta u sustavu.

The greatest global ecological problem today is global warming, i.e. the emission of carbon dioxide. Since the technical solutions for the reduction of carbon dioxide from flue gasses are still limited and economically unacceptable, the most promising methods for reducing emissions are indirect methods that can provide incentives with economic instruments. It is true that emission fees and taxes cannot significantly reduce the consumption of fossil fuels in applications where there are no alternative energy sources or unsuitable energy sources. Such an example is the consumption of liquid fuels for the needs of transportation and the petrochemical industry, which is nearly inelastic regarding changes in the price of fuel. An example of such an ecologically ineffective tax is presented in Figure 5. The double taxation on carbon dioxide emissions in Sweden is simulated [7]. This would result in an increase in the price of oil by approximately 30 %, due to which oil consumption would decline only 6 % and CO_2 emissions would decline by a negligible 1 %.

However, a fee on the emission of CO_2 could affect the choice of energy sources for new power plants, in a situation where there is an alternative to fossil fuel. A fee would increase the production costs of units with high CO_2 emissions per kWh, thereby reducing their economic advantage. This would affect the optimal system of production capacities in the system.

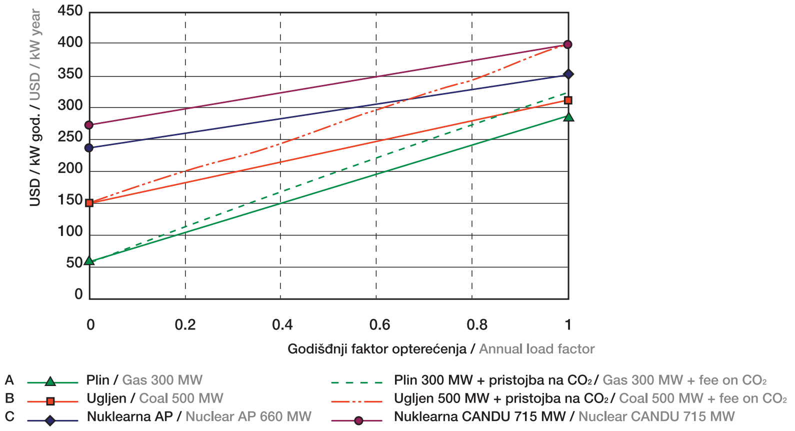


Slika 5
Simulacija: utjecaj poreza na smanjenje emisija CO_2
Figure 5
Simulation: the impact of taxes on the reduction of CO_2

Slika 6 prikazuje kako bi pristojba na emisiju CO_2 utjecala na godišnje troškove elektrana kandidata za buduću gradnju u Hrvatskoj: plinskih jedinica snage 300 MW i jedinica loženih ugljenom snage 500 MW (karakteristike elektrana kandidata uzete su prema [8]). Računato je s pristojbom od 10 USD/t jer se ta ili slična vrijednost u literaturi navodi kao trošak štete za okoliš zbog prekomjerne emisije CO_2. Godišnji troškovi elektrana kandidata uključuju anuitet investicije, troškove goriva i održavanja. Primjećuje se da pristojba na emisiju CO_2 ne bi bitnije povećala troškove plinskih jedinica, ali bi troškovi jedinica na ugljen porasli za 15 % - 20 %, čime bi se smanjila njihova prednost pred skupljim nuklearnim elektranama.

Figure 6 shows how fees on CO_2 emission would affect the annual costs of a candidate power plant for future construction in Croatia: 300 MW gas units and 500 MW coal units (characteristics of the candidate power plant are according to [8]). A fee is calculated of 10 USD per ton, because this or a similar value is cited in the literature as the damage cost of excessive CO_2 emission to the environment. The annual costs of a candidate power plant include annuity investments, fuel costs and maintenance. It is noted that the fee on the emission of CO_2 would not significantly increase the costs of gas units, but the costs of coal units would increase 15 % -20 %, thereby reducing their advantage over more expensive nuclear power plants.

Slika 6
Utjecaj pristojbe na emisiju CO_2 na proizvodne troškove elektrana
Figure 6
The impact of fees on CO_2 emission on the production costs of power plants



Pretpostavimo da je raspoloživost plina za proizvodnju električne energije ograničena te da se ostatak potražnje može pokriti kombinacijom hidroenergije, ugljena i nuklearne energije (to je jedan od razvojnih scenarija do 2030. godine u [8]). Bez pristojbe bi optimalni sastav energenata u 2030. godini uključivao 40 % ugljena i 25 % nuklearne energije, dok bi s pristojbom od 10 USD/t CO_2 optimalni sastav uključivao samo 10 % ugljena i čak 50 % nuklearne energije. Zbog promijenjenog sastava energenata, relativne emisije CO_2 se u opciji s pristojbom smanje na 40 % prvobitnih vrijednosti (tablica 1).

Let us assume that the availability of gas for the production of electrical energy is limited, and that the remainder of the demand can be covered by a combination of hydroenergy, coal and nuclear energy (this is one of the developmental scenarios up to the year 2030 in [8]). Without fees, the optimal energy source system in the year 2030 would include 40 % coal and 25 % nuclear energy, while with a fee of 10 USD per ton of CO_2 the optimal system would include only 10 % coal and 50 % nuclear energy. Due to the change in the system of energy sources, the relative emissions of CO_2 in the option with a fee are reduced by 40 % of their original values (Table 1).

Tablica 1 - Proizvodnja po energentima i pripadajuće emisije CO_2 u 2030. godini
Table 1 - Production according to energy sources and the corresponding CO_2 emissions in the year 2030

	Optimalni udjeli u proizvodnji el. energije 2030. godine / Optimal percentage in the production of electrical energy in the year 2030				Relativne emisije / Relative emissions
	Ugljen / Coal (%)	Plin / Gas* (%)	Nuklearna / Nuclear (%)	Hidro / Hydro (%)	CO_2
Bez pristojbe / Without a fee	40	10	25	25	1**
Pristojba / Fee 10 USD/t	10	15	50	25	0,4

* raspoloživost prirodnog plina je ograničena na 700 MW u plinskim elektranama /
* the availability of natural gas is limited to 700 MW in gas power plants
** apsolutni iznos = 15 Mt/god. / absolute amount = 15 Mt/year

Smanjenje emisija CO_2 može se postići i ako se emisijska pristojba primijeni na postojeća postrojenja u sustavu. Tada bi se promijenio poredak proizvodnih jedinica u ekonomskom dispečingu, tj. u redoslijedu pokrivanja dnevnog dijagrama opterećenja. Jedinice s velikim emisijama CO_2, koje su dotad zahvaljujući najmanjim proizvodnim troškovima pokrivale bazno opterećenje, preselile bi se u središnji ili čak vršni dio dijagrama opterećenja i manje proizvodile. Zbog toga bi se smanjile i emisije CO_2 u elektroenergetskom sustavu.

Reduction in CO_2 emissions can also be achieved if emission fees are applied to existing plants within a system. This changes the order of the production units in terms of economical dispatching, i.e. in order to cover the daily load diagram. Units with high CO_2 emissions, which heretofore had covered the base load due to the lowest production costs, would be shifted to the central position or even the top part of the load diagram and produce less. Consequently, CO_2 emissions in the electrical energy system would be reduced.

4.2.2 Fleksibilni mehanizmi

Ugljični dioksid je tzv. globalni polutant, tj. njegov učinak na okoliš ne ovisi toliko o prostornoj raspodjeli emisija koliko o ukupnoj svjetskoj emisiji. Zato je dovoljno ograničiti ukupnu emisiju CO_2 u određenom razdoblju i proporcionalno njoj izdati ukupan broj raspoloživih emisijskih dozvola. Svaka zemlja s obvezom ograničenja emisija dobit će onoliko emisijskih dozvola koliko smije kumulativno emitirati do neke godine, a svaki proizvođač mora imati dozvolu za svaku emitiranu jedinicu. Jedna emisijska dozvola odgovarat će određenoj masi CO_2, npr. jednoj toni. Tržišna cijena emisijske dozvole trebala bi biti jednaka graničnom trošku smanjenja emisija u zemljama sudionicama.

Pojedina zemlja može propisanu granicu zadovoljiti djelomično smanjenjem vlastitih emisija, a djelomično kupnjom emisijskih dozvola i ulaganjem u smanjenje emisija negdje drugdje u svijetu gdje je to jeftinije. Na tržištu savršene konkurencije proizvođač bi smanjio svoje emisije do razine gdje granični trošak smanjenja emisija postaje veći od emisijske pristojbe ili od ravnotežne cijene emisijske dozvole. Ako proizvođač ocijeni da je tržišna vrijednost emisijske dozvole veća od ulaganja u niskougljične tehnologije, dobivenu dozvolu neće iskoristiti nego će je sačuvati za poslije ili prodati najboljem ponuđaču.

4.3 Proračun troškova smanjenja emisija

U kreiranju mjera zaštite okoliša, pogotovo pri određivanju visine emisijskih pristojbi i ukupnih razina emisija, jedan od ključnih podataka je optimalna razina emisija. Teorija eksternih troškova kaže da se ekonomski optimalna razina emisija dobiva izjednačenjem graničnih troškova smanjenja emisija s graničnim troškovima štete u okolišu. Troškovi štete mogu se izračunati metodom slijeda utjecaja, što je i učinjeno u početnom dijelu ovog rada. To znači da još moramo odrediti troškove smanjenja emisija. Oni će ovisiti o tipu mjera zaštite okoliša - jesu li one regulativne ili tržišne, tj. jesu li propisani emisijski standardi ili postoji neka vrsta fleksibilnih mehanizama.

4.3.1 Sustav s regulativnim mjerama

U sustavu s regulativnim mjerama granična vrijednost emisije određuje se ovisno o gorivu i toplinskoj snazi ložišta. Sva ložišta koja pripadaju istoj kategoriji morat će zadovoljiti isti standard bez obzira na njihove ostale karakteristike. U tom su slučaju troškovi smanjenja emisija zapravo troškovi uređaja za pročišćavanje dimnih plinova.

4.2.2 Flexible mechanisms

Carbon dioxide is a so-called global pollutant, i.e. its impact on the environment does not depend so much upon the spatial distribution of emission as it does upon the overall global emission. Therefore, it is sufficient to limit the total CO_2 emission within a particular period and proportionally issue a total number of available emission allowances. Each country with the obligation of limiting emissions will obtain as many emission allowances as necessary to cover its permitted cumulative emissions for a given year, and every producer must have a allowance for each emitted unit. One emission allowance corresponds to a specific quantity of CO_2, for example one ton. The market cost of emission allowances should be equal to the marginal cost of reduced emissions in the participating countries.

An individual country may comply with the stipulated limit partially by reducing its own emissions and partially by purchasing emission allowances and investing in the reduction of emissions somewhere else in the world, where it is less expensive. On a market with perfect competition, a producer would reduce its own emissions to the level where the marginal cost of reducing emissions becomes greater than the emission fees or in balance with the price of emission allowances. If a producer assesses that the market value of an emission allowance is greater than investment in low carbon technology, he will not use the allowance but will keep it for later or sell it to the highest bidder.

4.3 Estimated costs of reducing emissions

In the creation of environmental protection measures, particularly in determining the amount of the emission fees and the total emission levels, the optimal emission level is among the crucial factors. The theory of external costs states that the economically optimal level of emissions is obtained when the marginal costs of reducing emissions are equal to the damage costs to the environment. Damage costs can be calculated by the impact pathway method, as performed in the introductory section of this article. This means that we must still determine the costs of reducing emissions. They will depend upon the types of environmental protection measures - whether they are regulative or market, i.e. whether there are stipulated emission standards or whether there are some types of more flexible mechanisms.

4.3.1 A system with regulative measures

In a system with regulative measures, the marginal value of emissions is determined according to the fuel and thermal power of the combustion source. All combustion sources that belong to the same category must meet the same standard, regardless

U nastavku su izračunati troškovi smanjenja emisija za elektranu na ugljen snage 350 MW, stupnja djelovanja 37 %. Pretpostavljeno je da elektrana loži ugljen sadržaja sumpora 1 % te da je opremljena elektrostatskim filtrom (ESP) za otprašivanje dimnih plinova koji uklanja 99,95 % čestica iz dimnih plinova. Početne emisije onečišćujućih tvari, u slučaju da nije primijenjeno odsumporavanje i odušičivanje dimnih plinova, i odgovarajući standard za nova postrojenja daje tablica 2. Elektrana radi na nazivnoj snazi 6 570 sati na godinu.

of their other characteristics. In this case, the costs of reducing emissions are actually the costs of the equipment for processing flue gasses.

The costs are calculated for reducing emissions for a coal-fired 350 MW power plant, with an efficiency of 37 %. It was assumed that the coal used in the power plant contains 1 % sulfur by weight, and that it is equipped with an electrostatic filter (ESP) that removes 99,95 % of the particles from the flue gasses. The initial emissions of the pollutants in the event that the reduction of sulfur and nitrate from the flue gasses is not performed and the corresponding standard for a new plant are presented in Table 2. The power plant operates 6 570 hours per year at the nominal power rating.

Tablica 2 - Početne vrijednosti emisije i standard / Table 2 - Initial emission values and the standard

	Emisija / Emission (mg/m³)	Granična vrijednost emisije / Marginal value of emissions (mg/m³)
SO_2	2 225	400
NO_x	1 200	650 (200)*
Čestice (nakon ESP) / Particles (after ESP)	<50	50

* očekivano postroženje standarda jer je u sklopu konvencije LRTAP potpisan Protokol o daljnjem smanjenju emisija / A stricter standard is anticipated because Protocol 1 on further reduction in NOx emission has been signed within the Long-Range Transboundary Air Pollution Convention.

Analizira se nekoliko tehnoloških rješenja za smanjenje emisija NO_x i SO_2 koja se međusobno razlikuju po stupnju redukcije i cijeni, a koja bi se po svojim karakteristikama mogla primijeniti u ovoj elektrani (tablica 3). Za odušičivanje su na raspolaganju tzv. primarne mjere (u engleskoj literaturi LowNO_x mjere) kojima se na smanjenje emisije utječe još u ložištu, modifikacijom izgaranja. To je najjeftinije rješenje, ali i s najmanjom djelotvornošću uklanjanja, 25 %. Tehnike pomoću kojih se emisija NO_x smanjuje nakon izgaranja, iz dimnih plinova, su selektivna nekatalitička redukcija (SNCR), s efikasnošću 50 %, te još napredniji, ali i skuplji postupak selektivne katalitičke redukcije (SCR), čija je efikasnost 85 %.

Za odsumporavanje se može primijeniti suho ubrizgavanje lužine u kanal dimnih plinova (DSI, dry sorbent injection), suhi proces odsumporavanja (SDA, spray dryer absorption) i mokro odsumporavanje (WS, wet scrubber). Njima se može postići smanjenje emisije SO_2 do 50 %, 85 % i 92,5 %, redom. Tablica daje investicijske troškove i troškove pogona i održavanja za svaku od spomenutih tehnika.

Several technological solutions have been analyzed for reducing emissions of NO_x and SO_2, which differ from each other in terms of degree of reduction and cost, and which according to their characteristics could be used in this power plant (Table 3). For nitrogen reduction, primary LowNO_x measures are available which reduce the emissions, through modified combustion. This is the most inexpensive solution but it is also the least effective for reduction, 25 %. Techniques which help to reduce NO_x emissions from flue gasses after combustion are selective noncatalytic reduction (SNCR), with an efficiency of 50 %, and the more advanced but more expensive procedure of selective catalytic reduction (SCR), with 85 % efficiency.

For sulfur reduction, it is possible to use dry sorbent injection (DSI) in channel flue gasses, spray dryer adsorption (SDA), and a wet scrubber (WS). With them, it is possible to achieve reductions in SO_2 emissions of up to 50 %, 85 % and 92,5 %, respectively. Table 3 presents the investment costs, plant costs and maintenance costs for each of these cited techniques.

Tablica 3 - Mjere za smanjenje emisija SO_2 i NO_x u elektrani na ugljen
Table 3 - Measures for reducing SO_2 and NO_x emissions in coal-fired power plants

	Stupanj uklanjanja / Degree of reduction	Trošak kapitala / Capital cost	Stalni troškovi pogona i održavanja / Permanent plant and maintenance expenses	Promjenjivi troškovi pogona i održavanja / Variable plant and maintenance costs
	(%)	(USD/kW)	(USD/kW)	(USD/mWh)
Smanjenje emisija SO_2 / Reduction of SO_2 emissions				
mokro odsumporavanje (WS) / wet scrubber (WS)	92,5	165	11,4	1
–suho odsumporavanje (SDA) / spray dryer absorption (SDA)	85	130	8,5	1,7
–ubrizgavanje lužine (DSI) / dry sorbent injection (DSI)	50	100	6,0	2,6
Smanjenje emisija NO_x / Reduction of NO_x emissions				
–katalitička redukcija (SCR) / catalytic reduction (SCR)	85	70	0,5	2
–nekatalitička redukcija (SNCR) / noncatalytic reduction (SNCR)	50	10	0,2	0,7
–modifikacija ložišta (LowNO_x) / furnace modification (LowNO_x)	25	15	0	0

izvori: Environmental Manual v1.1, Oeko Institut, Darmstadt, 1998; Pollution Prevention and Abatement Handbook, World Bank, 1998; Argonne National Laboratory, USA & US EPA, 1998. /
Sources: Environmental Manual vo1.1, Oeko Institut, Darmstadt, 1998; Pollution Prevention and Abatement Handbook, World Bank, 1998; Argonne National Laboratory, USA & US EPA, 1998

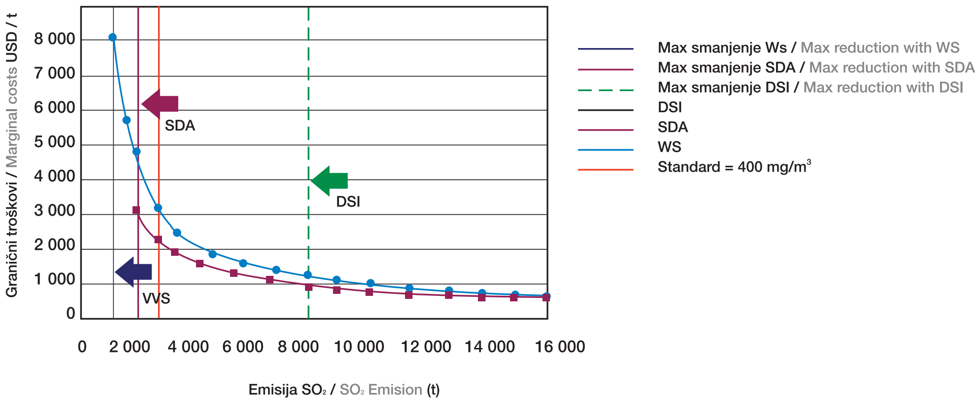
Izračunajmo sad trošak smanjenja emisija SO_2 pomoću spomenutih uređaja za odsumporavanje.

Godišnji trošak odsumporavanja uključuje investiciju i troškove pogona i održavanja. Ako se zna da investicija za DSI postupak iznosi 100 USD/kW, stalni troškovi pogona i održavanja 6 USD/kW na godinu, a promjenjivi 2,6 USD/MWh, dobiva se da aktualizirani godišnji trošak ove mjere, ako elektrana radi 6 570 h na godinu na nazivnoj snazi, u iznosi 11,2 milijuna USD. Pretpostavka je da se investicija otplaćuje kroz 30 godina uz diskontnu stopu od 8 %. Ako ukupni trošak odsumporavanja izrazimo po toni SO_2, dobit ćemo krivulju graničnih troškova kao što prikazuje slika 7. Granični trošak se povećava sa smanjenjem razine emisija. Tablica 4 sadrži stalnu i promjenjivu komponentu graničnih troškova, na temelju kojih su konstruirane krivulje graničnih troškova odsumporavanja.

Let us now calculate the cost of reducing SO_2 emissions using the cited equipment for sulfur reduction.

The annual cost of sulfur reduction includes investment in the costs of the plant and maintenance. If it is known that investment for the DSI procedure amounts to 100 USD/kW, the permanent costs of the plant and maintenance are 6 USD/kW annually, and with variable costs of 2,6 USD/MWh. Thus, the actual annual cost of this measure is obtained. If the power plant operates for 6 570 hours annually at rated power, it amounts to 11,2 million dollars. It is assumed that the investment is paid off over 30 years with a discount rate of 8 %. If we express the overall cost of sulfur reduction per ton of SO_2, we shall obtain the curve of marginal costs that is shown in Figure 7. Marginal costs increase with a reduction in the level of emissions. Table 4 contains the permanent and variable components of marginal costs, on the basis of which the curves of marginal costs of sulfur reduction are constructed.

Slika 7
Granični troškovi i djelotvornost uobičajenih tehnika odsumporavanja
Figure 7
The marginal costs and effectiveness of the customary techniques of sulfur reduction



Ako želimo emisije smanjiti ispod 50 % početnih, treba primijeniti SDA uređaj, čiji su granični troškovi veći od troškova DSI. Kako se vidi iz slike, u ovom bi slučaju SDA uređaj bio dovoljan jer je minimalna razina emisija koja se može postići suhim odsumporavanjem nešto ispod dopuštene vrijednosti (GVE) koju propisuje standard. Ta vrijednost za promatranu elektranu iznosi 400 mg/m^3, što odgovara emisiji od 3 000 tona na godinu. Napokon, ako je potreban još veći stupanj odsumporavanja, treba instalirati mokri filtar, WS. On može reducirati SO_2 na oko 1 300 t/god.

If we want to reduce emissions below 50 % of their initial value, it is necessary to use SDA equipment and the marginal costs are greater than the costs of DSI. As seen from the figure, in this case the SDA equipment would be sufficient because the minimum level of emissions that can be accomplished with dry sorbent injection is somewhat below the permitted values (GVE) stipulated by the standard. This value for the power plant under consideration amounts to 400 mg/m^3, which corresponds to emissions of 3 000 tons annually. Finally, if an even greater degree of sulfur reduction is required, it is necessary to install a wet scrubber, WS. It can reduce SO_2 to approximately 1 300 tons per year.

Tablica 4 -Troškovi smanjenja emisija SO_2 i NO_x
Table 4 - Costs for the reduction of emissions of SO_2 and NO_x

	Stalni troškovi / Permanent costs*	Promjenjivi troškovi / Variable costs	Ukupni godišnji trošak / Total annual costs	Prosječni trošak / Average cost **	Granični trošak / Marginal cost **
	(10^6 USD/ god/year)	(USD/t)	(10^6 USD /god/year)	(USD/t)	(USD/t)
DSI	5,2	365	11,2		
SDA	7,0	240	10,9	800	2200
WS	9,1	140	11,4	775	3.160
LowNO$_x$	0,47	0	0,5		
SNCR	0,38	100	2,0	445	185
SCR	2,38	280	7,0	915	1.850

* trošak kapitala + stalni troškovi pogona i održavanja (pretp.: povrat investicije 30 godina, diskontna stopa 8 %) /
capital expenditure + permanent plant and maintenance expenditures (assumption: return of investment in 30 years, discount rate 8 %);
** iznos potreban za zadovoljenje standarda, tj. za smanjenje emisija ispod propisanih vrijednosti /
amount necessary to meet the standards, i.e. to reduce emissions below the stipulated values

Na emisijama iznad 8 000 t/god. rezultantni granični trošak slijedi DSI krivulju, a zatim na manjim vrijednostima skače na SDA, odnosno WS krivulju. U sustavu s propisanim standardima, za razliku od tržišnog, granični trošak smanjenja emisija je jednoznačan jer je propisana maksimalno dopuštena razina emisija, pa je i izbor uređaja za smanjenje emisija ograničen. U ovom slučaju odabiremo SDA postupak tako da granični trošak odsumporavanja iznosi oko 2 200 USD/t SO_2 (slika 7, sjecište krivulje SDA i pravca GVE). Prosječni trošak odsumporavanja bio bi 800 USD/t, izraženo po količini reduciranog SO_2. Tu vrijednost dobijemo dijeljenjem godišnjeg troška za SDA u iznosu od 10,9 milijuna USD s količinom reduciranog SO_2 koja iznosi 13 600 tona.

Slična analiza provedena je za tehnike odušičivanja. Početna emisija NO_x iznosi oko 9 000 tona na godinu ili 1 200 mg/m^3 (ali ta vrijednost umnogome ovisi o konstrukciji ložišta i temperaturi izgaranja, pa može biti i manja). Primarnim mjerama početna se emisija može smanjiti za 25 %, tj. na 7 000 t/god. Trenutačno je u Hrvatskoj na snazi standard za NO_x koji za ovaj tip elektrane propisuje 650 mg/m^3 (GVE1), ali očekuje se postroženje standarda s obzirom na to da je Hrvatska potkraj 1999. godine potpisala Protokol o suzbijanju zakiseljavanja, eutrofikacije i prizemnog ozona uz Konvenciju o dalekosežnom prekograničnom onečišćenju zraka. Prema Protokolu, emisija za ovaj tip elektrana ograničit će se na 200 mg/m^3 (GVE2). Ako je GVE 650 mg/m^3, primarne mjere nisu dovoljne, već je potreban SNCR uređaj. Uza još stroži standard, bio bi potreban SCR uređaj. Krivulje graničnih troškova prikazuje slika 8.

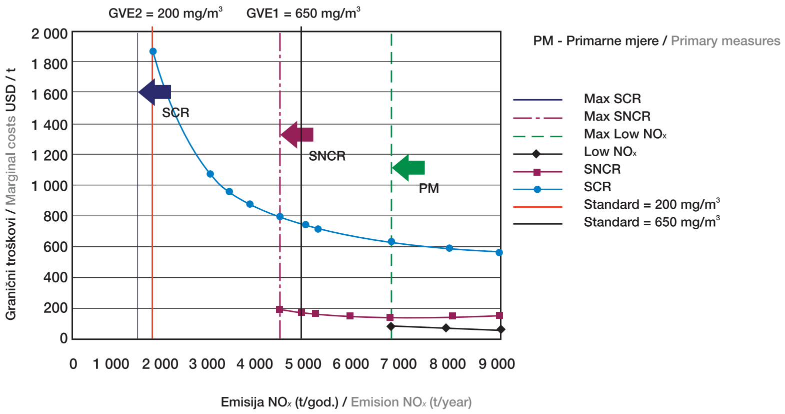
Ako je emisija manja od 7 000 t/god., granični trošak kretat će se po krivulji LowNO_x, zatim krivuljom SNCR do 4 500 t/god. i konačno krivuljom SCR do 1 500 t/god. Da bi se zadovoljio danas vrijedeći standard od 650 mg/m^3, granični trošak smanjenja NO_x iznosi oko 185 USD/t (sjecište krivulje marginalnog troška za SNCR i standarda 650 mg/m^3). Ako se uzme da je standard 200 mg/m^3, granični bi trošak iznosio 1 850 USD/t. Prosječni trošak odušičivanja iznosi 445 USD/t za SNCR uređaj (jer on smanji emisije za 50 % uz godišnji trošak od 2 milijuna USD), odnosno 915 USD/t za SCR uređaj, izraženo po toni reduciranog NO_x. Prosječni troškovi SNCR i SCR uređaja razlikuju se za faktor 2, a granični za faktor 10. To znači da je od presudne važnosti na kojoj se razini obavlja redukcija emisija.

For emissions of over 8 000 tons per year, the results of the marginal costs follow the DSI curve, and then at lower values jump to the SDA, respectively the WS curve. In a system with stipulated standards, unlike market-oriented measures, the marginal cost for reducing emissions is unambiguous because the maximum permitted level of emissions is stipulated, so that the choice of equipment for reducing emissions is limited. In this case, we chose the SDA procedure, so that the marginal cost of sulfur reduction amounts to approximately 2 200 USD per ton of SO_2 (Figure 7, the intersection of the SDA curve and the GVE line). The average cost of sulfur reduction would be 800 USD/t, expressed according to the quantity of reduced SO_2. We obtain this value by dividing the annual expenditure for SDA in the amount of 10,9 million USD by the quantity of reduced SO_2 that amounts to 13 600 tons.

A similar analysis is performed with the technique of nitrogen reduction. The initial emission of NO_x amounts to approximately 9 000 tons annually or 1 200 mg/m^3 (but this value is highly dependent on the construction of the furnace and the temperature of combustion, which can also be lower). Through the application of measures, the initial emission can be reduced by 25 %, i.e. to 7 000 tons per year. Currently in Croatia a NO_x standard is in force which stipulates 650 mg/m^3 (GVE1) for this type of power plant, but stricter standards are anticipated since Croatia has signed the Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone to the Convention on Long-Range Transboundary Air Pollution in late 1999. According to the Protocol, the emission for this type of power plant will be limited to 200 mg/m^3 (GVE2). If the GVE is 650 mg/m^3, primary measures are not sufficient and SNCR equipment is necessary. With the even stricter standard, SCR equipment will also be necessary. The curve of marginal costs is shown in Figure 8.

If emissions are lower than 7 000 tons per year, the marginal cost will follow the LowNO_x curve, then the SNCR curve up to 4 500 tons per year and finally the SCR curve up to 1 500 tons per year. In order to meet the current prevailing standard of 650 mg/m^3, the marginal cost of reducing NO_x amounts to approximately 185 USD per ton (the intersection of curve of the marginal cost for SNCR and the standard 650 mg/m^3). If the standard is taken of 200 mg/m^3, the marginal cost would amount to 1 850 USD per ton. The average cost of nitrogen reduction would amount to 445 USD per ton for SNCR equipment (because it reduces emissions by 50 % at an annual cost of 2 million USD), i.e. 915 USD per ton for SCR equipment, expressed per ton of reduced NO_x. The average costs of SNCR and SCR equipment differ by a factor of 2, and marginally by a factor of 10. This means that the level at which the reduction of emissions is conducted it is of crucial importance.

Slika 8
Granični troškovi i djelotvornost uobičajenih tehnika odušičivanja
Figure 8
Marginal costs and the effectiveness of the customary techniques for nitrogen reduction



Nakon što su određeni granični troškovi smanjenja emisija i zadovoljenja standarda, cilj je odrediti optimalnu razinu emisija u skladu s ekonomskom teorijom eksternih troškova. Podsjetimo se, ekonomski optimalna razina emisija dobiva se izjednačavanjem graničnih troškova štete u okolišu s graničnim troškovima smanjenja emisija. Granični troškovi štete u okolišu bit će u ovom slučaju troškovi štete za zdravlje. Granična šteta ne ovisi o razini emisija - to je jedna od osnovnih postavki metode slijeda utjecaja. Promatrat će se, kao i dosad, tri razine eksternih troškova - lokalna, regionalna za Hrvatsku i regionalna za Europu. Za ovaj proračun potrebni su troškovi štete izraženi po toni polutanta.

Već je na prvi pogled jasno da je regionalna šteta za Europu višestruko veća od graničnih troškova odsumporavanja, odnosno odušičivanja i da, ako želimo izjednačiti štetu za zdravlje i trošak uređaja za smanjenje emisija, optimalna razina emisija teži nuli. Drugim riječima, i najmanja emisija rezultira velikim štetama za zdravlje jer je izložen velik broj ljudi. Opet se potvrđuje da su strogi emisijski standardi za SO_2 i NO_x opravdani upravo zbog njihovih dalekosežnih učinaka kojima je izložen veliki broj ljudi.

Ostaje promatrati lokalne učinke i regionalne učinke za Hrvatsku. Od lokalnih polutanata zanima nas jedino SO_2 jer pretpostavljamo da su krute čestice već reducirane na najmanju moguću mjeru uporabom visokoučinkovitog elektrostatskog filtra. Šteta za zdravlje za lokaciju Zagreb iznosi 110 eura/t SO_2, tj. 137,5 USD/t. Ta je vrijednost manja od troška najjeftinijeg uređaja za odsumporavanje, što znači da optimalna razina emisija teži u beskonačnost. To znači da je šteta dovoljno niska da ne utječe na izbor metode odsumporavanja.

Na kraju promatramo u kakvom su odnosu regionalna šteta za Hrvatsku i granični troškovi

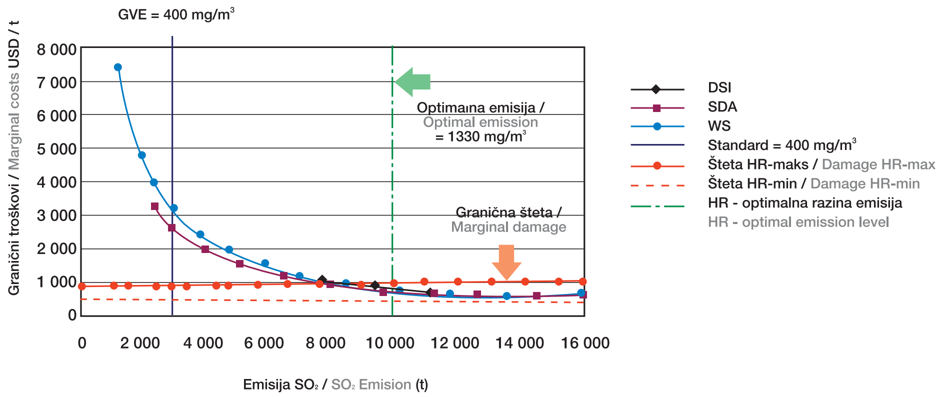
After the marginal costs for the reduction of emissions are determined and the standards met, the goal is to determine the optimal level of emissions pursuant to the economic theory of external costs. Let us recall that the economically optimal level of emissions is obtained when the marginal costs of environmental damage are equal to the marginal costs of reducing emissions. Marginal costs of environmental damage will in this case be damage to health. Marginal damages are not dependent on the level of emission - this is one of the fundamental assumptions of the impact pathway method. As up to now, three levels of external costs will be monitored - local, regional for Croatia and regional for Europe. For this estimate, it is necessary to express damage costs per tons of pollutant.

At first glance, it is already clear that the regional damage for Europe is many times greater than the marginal costs of sulfur reduction or nitrogen reduction and that, if we wish to equate the damage to health and the cost of equipment for reducing emissions, the optimal level of emissions would aim for zero. In other words, even the least emission results in great damages to health because a large number of people are exposed. It is again determined that strict emission standards for SO_2 and NO_x are justified due to their far ranging impacts, to which a large number of people are exposed.

The local impacts and regional impacts for Croatia remain to be studied. Of the local pollutants, we are only interested in SO_2 because we assume that solid particles have already been reduced to the lowest possible level through the use of highly effective electrostatic filters. Damage to health for the location of Zagreb amounts to 110 euro per ton of SO_2, i.e. 137,5 USD per ton. This value is less than the cost of the least expensive equipment for sulfur reduction, which means that the optimal level of emissions tends toward infinity. This means that the damage is sufficiently low that it does not affect the selection of the method of sulfur reduction.

smanjenja emisija. Šteta za zdravlje kreće se od 488 do 950 USD/t SO_2, raspon se odnosi na različite lokacije elektrane unutar Hrvatske (gornja vrijednost odnosi se na slučaj kad je elektrana smještena u Zagrebu). Te su vrijednosti ucrtane kao horizontalni pravci, slika 9, horizontalni zato što je granična šteta konstantna.

Finally, we consider the ratio between the regional damage for Croatia and the marginal costs for reducing emissions. Damage to health ranges from 488 to 950 USD per ton of SO_2. The range refers to various locations of power plants within Croatia (the upper value refers to the case of the power plant located in Zagreb). These values are entered as horizontal lines, Figure 9, and are horizontal because the marginal damage is constant.



Slika 9
Određivanje optimalne razine emisija SO_2
Figure 9
Determination of the optimal level of SO_2 emissions

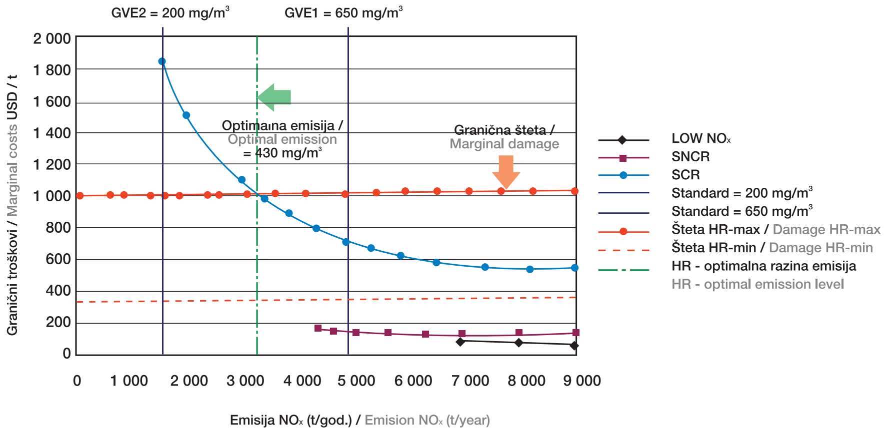
Donja vrijednost štete (šteta HR - min.) ne siječe se ni s jednom krivuljom troškova smanjenja emisija, što znači da nije mjerodavna za kreiranje emisijskog standarda. Gornja vrijednost štete, 950 USD/t SO_2, siječe se sa sve tri krivulje, i to na emisiji od oko 9 000 t/god. s DSI krivuljom, na 10 000 t/god. s SDA krivuljom i na 11 000 t/god. s WS krivuljom. Optimalna razina emisija bila bi oko 10 000 tona SO_2 na godinu, što bi odgovaralo sadržaju od oko 1 330 mg/m³ SO_2 u dimnim plinovima.

Slična analiza - utvrđivanje optimalne razine emisije - napravljena je i za NO_x (slika 10). Regionalna granična šteta za Hrvatsku zbog učinaka dušičnih oksida na zdravlje kreće se od 320 do 1 000 USD po toni. Obje su vrijednosti ucrtane kao horizontalni pravci na dijagramu s graničnim troškovima odušičivanja. Viša vrijednost eksternog troška, označena kao šteta HR-maks. (1 000 USD/t) siječe se s SCR krivuljom pri emisiji od 3 250 t NO_x /god., što odgovara koncentraciji od oko 430 mg/m³ u dimnim plinovima. Ta vrijednost, koja se nalazi točno u sredini između vrijedećeg standarda (650 mg/m³) i budućeg strožeg standarda (GVE2 = 200 mg/m³), predstavlja optimalnu razinu emisija s aspekta utjecaja na zdravlje stanovništva u Hrvatskoj.

The lower value of damage (damage HR - min.) does not intersect with any of the emission reduction cost curves, which means that it is not relevant for the creation of an emission standard. The upper value of damages of 950 USD per ton of SO_2 intersects with all three curves, and this at emissions of approximately 9 000 tons per year with the DSI curve, 10 000 tons per year with the SDA curve and 11 000 tons per year with the WS curve. The optimal emission level would be approximately 10 000 tons of SO_2 annually, which would correspond to a content of approximately 1 330 mg/m³ SO_2 in flue gasses.

A similar analysis - the determination of the optimal emission level, was also performed for NO_x (Figure 10). The regional marginal damage for Croatia due to the effect of nitric oxide upon health ranges from 320 to 1 000 USD per ton of NO_x. Both values are entered as horizontal lines on the diagram with the marginal costs of nitrogen reduction. The higher value of external costs, marked as damage HR-max. (1 000 USD per ton) intersects with the SCR curve at an emission of 3 250 tons of NO_x per year, which corresponds to a concentration of approximately 430 mg/m³ of NO_x in flue gasses. This value, which is located precisely midpoint between the prevailing standard (650 mg/m³) and the future stricter standard (GVE2 = 200 mg/m³), represents the optimal emission level from the aspect of the health impact upon the population in Croatia.

Slika 10
Određivanje optimalne razine emisija NO_x
Figure 10
Determination of the optimal NO_x emission level

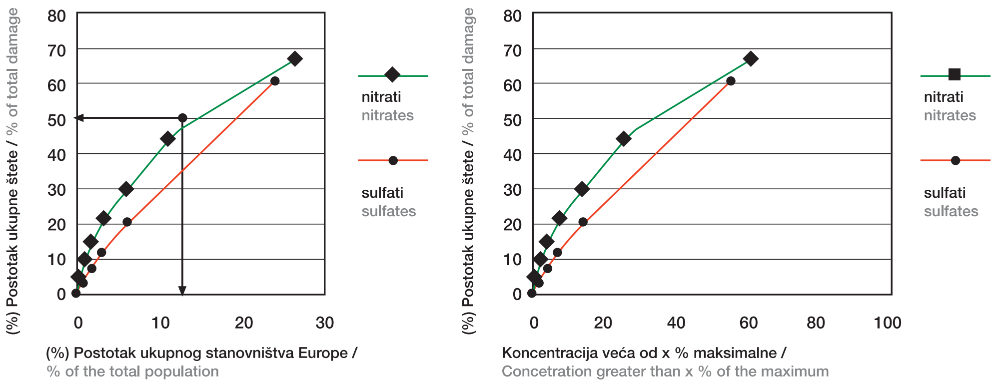


Treba naglasiti da se eksterni trošak, na temelju kojeg je donesen ovaj zaključak, odnosi samo na receptore u Hrvatskoj, iako se zdravstvene posljedice manifestiraju na većim područjima, izvan hrvatskih granica. Zato ovakav način određivanja optimalne razine emisije nije najprikladniji. Promatranje bi trebalo proširiti na razuman opseg izvan državnih granica, na primjer do udaljenosti na kojoj eksterni trošak (šteta za zdravlje), koji je proporcionalan sumi koncentracija (s) × broj stanovnika na nekom području podijeljenom na kvadrante indeksa "*i*", dostigne zadani postotak ukupne štete, npr. 50 % ukupne štete u Europi. Naime, u slučaju dugotrajnih relativno niskih ambijentalnih koncentracija polutanata, koje se javljaju pri razmatranju regionalnih učinaka na zdravlje, nije toliko presudna maksimalna koncentracija već ukupna šteta koja ovisi o veličini izloženog stanovništva. Zato se za opseg promatranja ne postavlja uobičajeni uvjet da koncentracija padne na 10 % ili 20 % maksimalne vrijednosti, već da bude uračunat određeni postotak ukupne štete.

Slika 11 prikazuje ovisnost eksternog troška (troška štete) izazvanog nitratima, odnosno sulfatima o veličini obuhvaćenog stanovništva u Europi te o visini koncentracija dotičnih polutanata. Vidi se da oko 13 % stanovništva u Europi snosi 50 % ukupne štete zbog nitrata (lijevi dijagram) te da je izloženo koncentracijama nitrata većim od 20 % maksimalne koncentracije (desni dijagram). Za sulfate je slično – oko 18 % europskog stanovništva podnosi pola ukupne štete zbog sulfata, pri čemu su izloženi koncentracijama iznad 15 % maksimalne.

It should be emphasized that the external cost on the basis of which this conclusion was drawn refers only to receptors in Croatia, although the consequences to health are manifested over larger areas, outside the Croatian borders. Therefore, this manner of determining the optimal emission level is not the most suitable. The investigation should be extended to cover a reasonable range outside the national borders, for example up to the distance at which the external cost (damage to health), which is proportional to the sum of concentration(s) × the number of inhabitants in a region, divided by the quadrant index "*i*", reaches the given percentage of total damages, for example 50 % of the total damages in Europe. In the case of long-term relatively low ambient concentrations of pollutants, that occur in the investigation of regional impacts on health, the maximum concentration is not as crucial as the total damages, which depend on the size of the exposed population. Therefore, for the range of observation, the customary prerequisite is not established for the concentration to fall to 10 % or 20 % of the maximum value, but a certain percentage of the total damages is calculated.

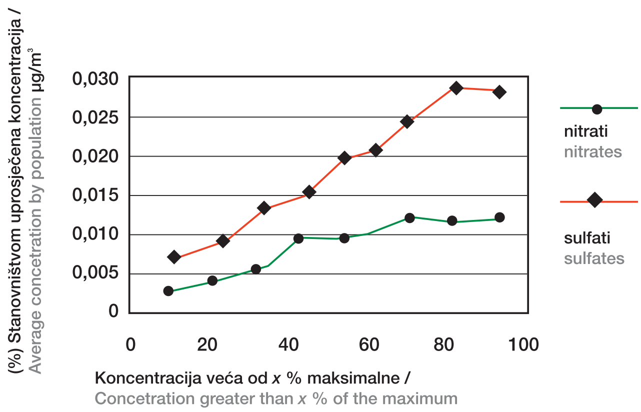
Figure 11 shows the dependence of the external cost (damage cost) caused by nitrates or sulfates on the size of the affected population in Europe, and on the level of the concentrations of these pollutants. It is seen that approximately 13 % of the population in Europe bears 50 % of the total damages caused by nitrates (left diagram), and is exposed to concentrations of nitrates that are greater than 20% of the maximum concentration (right diagram). For sulfates it is similar - approximately 18 % of the European population bears half the total damages due to sulfates, and is exposed to concentrations over 15 % of the maximum.



Slika 11
Ovisnost eksternog troška sulfata i nitrata o opsegu analize
Figure 11
Dependence of the external costs of sulfates and nitrates in the range of analysis

Može se zadati i uvjet da prosječni eksterni trošak po stanovniku ne prekorači određeni iznos. Eksterni trošak po stanovniku ovisi o položaju receptora s obzirom na izvor te o veličini obuhvaćenog stanovništva. Stanovništvom uprosječena koncentracija polutanta, koja je mjerodavna za određivanje eksternog troška, dobiva se zbrajanjem umnožaka koncentracije i broja stanovnika po kvadrantima i dijeljenjem dobivenog iznosa s ukupnim brojem stanovnika u obuhvaćenim kvadrantima. Ta vrijednost, koja se izražava u μg/m³, ukazuje na veličinu fizičkih učinaka na zdravlje, ali i na veličinu eksternog troška po stanovniku jer ako se pomnoži s faktorom izloženost-učinak i novčanom vrijednosti štete, daje iznos eksternog troška. Stanovništvom uprosječena koncentracija mijenja se s udaljenošću od izvora, kako prikazuje slika 12.

It is possible to stipulate the condition that the average external cost per inhabitant should not exceed a certain amount. The external cost per inhabitant depends on the position of the receptors in relation to the source, and on the size of the affected population. Average concentration of pollutant by population, suitable for the determination of external cost, is obtained by adding the multiplied concentration and the number of inhabitants per quadrant and dividing this figure by the total number of inhabitants in the quadrants affected. This value, that is expressed in μg/m³, denotes the magnitude of the physical impact upon health but also the amount of the external cost per inhabitant, because it yields the amount of external cost if it is multiplied by the exposure-impact factor and the monetary value of the damage. Average concentration by population changes with the distance from the source, as shown in Figure 12.



Slika 12
Pokazatelj eksternog troška po stanovniku, ovisno o opsegu analize
Figure 12
Index of external cost per inhabitant, depending on the range of analysis

U blizini izvora, što u regionalnoj podjeli znači u istom ili susjednom kvadrantu kao elektrana, taj će iznos biti veći, a na većim udaljenostima će padati. To jednostavno znači da je stanovništvo na većim udaljenostima manje pogođeno učincima polutanata. U ovom slučaju, relativna šteta po stanovniku uzrokovana nitratima smanji se proširenjem granica analize s 0,028 na 0,006,

In the vicinity of the source, which in the regional division means in the same or neighboring quadrant as the power plant, this amount will be greater and will decline at greater distances. This simply means that the population at greater distances is less affected by the impact of the pollutants. In this case, the relative damages per inhabitant caused by nitrates decline with an extended boundary dakle gotovo pet puta. Šteta zbog djelovanja sulfata na zdravlje smanji se šest puta, s 0,012 na 0,002. Prema tome, u kvadrantima u kojima koncentracija nitrata i sulfata iznosi manje od 10 % svoje maksimalne vrijednosti, šteta po stanovniku bit će 5-6 puta niža nego u najizloženijim kvadrantima.

4.3.2 Sustav s tržišnim mjerama

Za kreiranje tržišnih mjera zaštite okoliša mjerodavni su troškovi smanjenja emisija na razini cijelog gospodarstva, a ne samo za pojedini sektor ili elektranu, jer se smanjenje emisija postiže zajedničkim djelovanjem svih aktera na tržištu. U takvom sustavu mjere zaštite okoliša imaju zadatak potaknuti restrukturiranje gospodarstva i promjenu ponašanja proizvođača, djelovati na uzrok onečišćenja, a ne samo na posljedicu. Zato pri određivanju troškova smanjenja emisija treba promatrati ne samo potrebna ulaganja u uređaje za smanjenje nego i obilježja tvrtke (veličinu, udio državnog vlasništva u tvrtki), ekološku svijest tvrtke, npr. broj zaposlenika na poslovima zaštite okoliša i politiku zaštite okoliša, poštivanje propisanih standarda, visinu emisijskih pristojbi koje tvrtka plaća (ako takav sustav postoji) te sadašnje i buduće mjere smanjenja emisija u tvrtki. Drugim riječima, nastoji se nagovijestiti ponašanje proizvođača spram mjera zaštite okoliša i na osnovi toga procijeniti troškove.

Hartman je 1994. g. izračunao prosječne troškove smanjenja emisija SO_2 i NO_x za cijelo gospodarstvo SAD-a, i to analizom velikog broja industrijskih postrojenja, prateći razine emisija i statistiku ulaganja u uređaje za smanjenje emisija [9]. Slična analiza za Litvu u istom radu pokazuje da su u tranzicijskim zemljama granični troškovi smanjenja emisija manji nego u razvijenim zemljama. To može biti pokazatelj za kreiranje učinkovitih mjera zaštite okoliša u zemljama u tranziciji u kojima nema razgranate mreže za mjerenje emisija, a podaci o troškovima smanjenja emisija u pravilu ne postoje [10]. Podaci dobiveni u studijama za zapadne zemlje mogu se uzeti kao gornja granica troškova za tranzicijske zemlje.

Sljedeći primjer pokazat će kako se određuje krivulja graničnih troškova smanjenja emisija i kreira emisijska pristojba. Analizom industrijskih postrojenja određeni su prosječni troškovi smanjenja emisija po sektorima za tipične polutante (SO_2, NO_x, čestice, olovo, toksične tvari), kao i količina reduciranih emisija po sektorima. Sektori se poredaju po prosječnim troškovima smanjenja emisija, od najmanjih prema najvećima (tablica 5). Znajući prosječni trošak po sektoru i količinu emisija koja bi se mogla smanjiti po toj cijeni,

analysis from 0,028 to 0,006, which is nearly five times. The damages due to the impact of sulfates on health are reduced by six times, from 0,012 to 0,002. Accordingly, in quadrants where the concentrations of nitrates and sulfates are less than 10 % of their maximum values, the damage per inhabitant will be 5-6 times lower than in the most exposed quadrants.

4.3.2 System with market measures

For the creation of market measures of environmental protection, the costs of reduced emissions on the level of the entire economy are relevant, not only for an individual sector or power plant. Emission reduction is achieved through the joint activities of all the participants on the market. In such a system, the environmental protection measures have the task of prompting the restructuring of the economy and changing the behavior of producers, acting on the sources of pollution and not only on its consequences. Therefore, in the determination of the cost of reducing emissions, it is necessary to consider not only the required investment in equipment for reduction but also the characteristics of the company (size, share of public ownership in the company), the company's ecological awareness, for example the number of employees engaged in environmental protection and environmental protection policy, compliance with the stipulated standards, the amount of emission fees that the company pays (if such a system exists), and the present and future measures for reducing emissions in the company. In other words, it is attempted to predict producers' compliance with environmental protection measures and assess costs on this basis.

In 1994, Hartman calculated the average costs for reducing SO_2 and NO_x emissions for the entire economy of the USA, through analysis of a large number of industrial plants, monitoring the emission levels and the statistics for investment in reduction equipment [9]. A similar analysis performed for Lithuania in the same study showed that in transition countries the marginal costs of emission reduction are less than in developed countries. This could be an indicator for the creation of more effective measures of environmental protection in transition countries where there are no fixed networks for measuring emissions and data on the costs of reducing emissions as a rule do not exist [10]. Data obtained in studies for western countries can be taken as the upper limits for costs for transition countries.

The next example will show how the curve of the marginal costs of reduced emissions is determined and emission fees are created. Through analysis of industrial equipment, average costs are determined možemo konstruirati krivulju graničnih troškova za sve sektore ili za prioritetnu grupu sektora. Poanta je da se promatra više sektora zajedno i nađe optimalna politika smanjenja emisija.

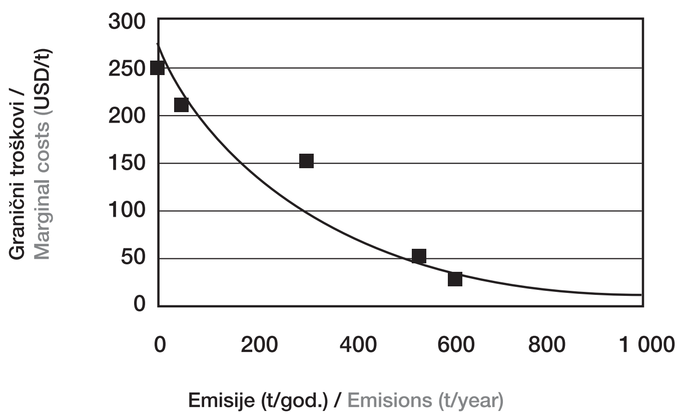
for emission reduction according to the sector for typical pollutants (SO_2, NO_x, particles, lead, toxic substances), as well as the quantity of reduced emissions according to sector. The sectors are listed according to the average costs for emission reduction, from the lowest to the highest (Table 5). If we know the average cost per sector and the quantity of emissions that could be reduced at that price, we can construct a curve of marginal costs for all the sectors or for a priority group of sectors. The point is that several sectors are considered together and an optimal policy for emission reduction is found.

Tablica 5 - Prosječni troškovi smanjenja emisija čestica za pet industrijskih grana u SAD-u
Table 5 - Average costs for emission reduction of particles for five branches of industry in the USA

Sektor / Sector	Masa reduciranog polutanta / Weight of reduced pollutant (t)	Kumulativna emisija / Cumulative emission (%)	Prosječni troškovi smanjenja emisija / Average costs for reducing emissions (1996) (USD /t)
Industrija nemetala / Nonmetal industry	400	40	23
Celuloza i papir / Cellulose and paper	100	50	50
Poljoprivredne kemikalije / Agricultural chemicals	250	75	148
Željezo, čelik / Iron, steel	200	95	211
Ostale kemikalije / Other chemicals	50	100	246

Iz tablice se vidi da se najviše isplati smanjiti emisije u industriji nemetala gdje se 400 tona polutanta može smanjiti uz prosječni trošak od 23 USD/t, zatim slijedi industrija celuloze i papira gdje se daljnjih 100 tona može smanjiti po cijeni od 50 USD/t. Možemo reći da granični trošak smanjenja emisija za promatranu grupu sektora kod 50 % redukcije iznosi 50 USD/t. Za daljnje smanjenje emisija granični se trošak povećava, kako prikazuje slika 13.

From the table, it is evident that it is the most economical to reduce emissions in the nonmetal industry, where 400 tons of pollutants can be reduced at an average cost of 23 USD per ton, followed by the cellulose and paper industry, where another 100 tons can be reduced at a cost of 50 USD per ton. We can say that the marginal cost of 50 % emission reduction for the group of sectors considered is 50 USD per ton. For further reduction of emissions, the marginal cost increases, as shown in Figure 13.



Slika 13 Granični troškovi smanjenja emisija za grupu sektora
Figure 13 Marginal costs of reduced emissions for the group of sectors

Na primjer, ako umjesto 40 % želimo eliminirati 95 % emisija, granični troškovi porast će čak devet puta. Ova saznanja mogu nam pomoći da postavimo razumna ograničenja na ukupne emisije, takva koja će ujedno biti i ekonomski prihvatljiva.

Istu logiku možemo obrnuti te podatak o graničnim troškovima iskoristiti u kreiranju emisijskih pristojbi. Podaci u tablici kazuju nam da bi se uz emisijsku pristojbu od oko 30 USD/t postiglo smanjenje emisija od oko 40 % jer će takva pristojba utjecati na industriju nemetala - tvrtkama će se više isplatiti smanjiti emisije nego plaćati pristojbu. Udvostručenjem pristojbe (oko 60 USD/t) emisije će se smanjiti za sljedećih 10 %. Ako želimo postići 95 %-tno smanjenje emisija, visina pristojbe morat će narasti na najmanje 200 USD/t.

Još jedan zaključak nameće se iz ovog primjera. Naslućujemo da bi prosječni trošak smanjenja emisija u sustavu s tržišnim mjerama, uz sudjelovanje većeg broja industrijskih sektora, bio višestruko manji nego trošak uređaja za smanjenje emisija za pojedinačnu elektranu (koji je izračunat u prethodnom primjeru za elektranu na ugljen). To znači da su stvarni troškovi smanjenja emisija niži, gledano za cjelokupnu industriju, ali pod uvjetom da se iskoriste prednosti tržišta, tj. omoguće fleksibilne mjere kao npr. trgovanje emisijskim dozvolama. Međutim, tu treba biti oprezan. Pri uspostavi tržišta emisijskim dozvolama treba imati na umu da je većina polutanata lokalnog ili regionalnog karaktera te da njihov učinak na okoliš i zdravlje ovisi o lokaciji izvora. Zato se tržište dozvolama za polutante koji nisu globalni mora ograničiti na određenu regiju, da ne bi došlo do suprotnog učinka-prekomjernog opterećenja nekih područja i još većeg utjecaja na okoliš.

Činjenica je da troškovi smanjenja emisija progresivno rastu sa stupnjem redukcije, iz čega slijedi da politika zaštite okoliša koja se temelji isključivo na propisivanju standarda nije idealno rješenje jer izaziva nepotrebno visoke troškove. Relaksacija regulativnih prema tržišno orijentiranim mjerama mogla bi donijeti financijsku uštedu uz istu ekološku dobit. Ako se već propisuju standardi, preporuka je [11] da se najprije odrede željeni standardi kvalitete zraka, tj. maksimalno dopuštene ambijentalne koncentracije polutanata, a tek onda emisijski standardi. Propisivanje standarda koji zahtijevaju vrlo skupe mjere smanjenja emisija opravdano je jedino ako se time postižu ekološke i društvene dobiti veće od troškova tih mjera. Te se dobiti mogu promatrati kao ušteda na troškovima štete u okolišu.

For example, if instead of 40 % we want to eliminate 95 % of the emissions, the marginal costs will increase by nine times. This knowledge can help us to establish reasonable limitations on total emissions that will also be economically acceptable.

Using the same logic, the data on marginal costs can be used in the creation of emission fees. The data in the table tell us that with an emission fee of approximately 30 USD per ton, an emission reduction of approximately 40 % would be achieved, because such a fee would affect the nonmetal industry - the companies will find it more economical to reduce emissions than to pay the fee. By doubling the fee (to approximately 60 USD per ton), emissions will be reduced by a further 10 %. If we want to achieve a 95 % reduction in emissions, the amount of the fee must increase to a minimum of 200 USD per ton.

One other conclusion arises from this example. We conjecture that the average cost of emission reduction in a system with market measures, with the participation of a large number of industrial sectors, would be several times less than the cost of equipment for reducing emissions for an individual power plant (which is calculated in the previous example for a coal-fired power plant). This means that the actual costs of emission reduction are lower when industry is viewed as a whole, provided that the market advantages are utilized, i.e. flexible measures are made possible such as, for example, the trading of emission allowances. However, it is necessary to be cautious here. Before the establishment of an emission allowance market, it is necessary to bear in mind that the majority of pollutants are of a local or regional character and that their impact on the environment and health depends upon the source locations. Therefore, markets for pollution allowances that are not global must be limited to a specific region, in order not to achieve the opposite effect - an excessive burden upon some areas and even greater environmental impact.

It is a fact that the costs of reducing emissions increase progressively with the level of reduction, from which it follows that an environmental protection policy based exclusively upon stipulated standards is not an ideal solution because it requires unnecessarily high expenditures. Relaxation of regulations toward market oriented measures could yield financial savings with the same ecological profit. When standards are being stipulated, it is recommended [11] that the desired standards for air quality should be determined first, i.e. the maximum permitted ambient concentration of pollutants, and then emission standards. Stipulated standards that require very expensive measures for reducing emissions are only justified if they achieve ecological and social profits greater than the costs of these measures. These profits can be considered as savings on the damage costs in the environment.

U prethodnom poglavlju izračunata je optimalna razina emisija SO_2 i NO_x, izjednačavanjem granične štete za zdravlje i graničnog troška uređaja za odsumporavanje, odnosno odušičivanje (slika 9 i slika 10). Te vrijednosti mogu poslužiti kao smjernica u odabiru emisijskih pristojbi u sustavu s tržišnim mjerama zaštite okoliša. Uz pristojbu od oko 1 000 USD po toni SO_2 proizvođač bi bio motiviran emisije SO_2 smanjiti na oko 60 % početnog iznosa. Tek bi pristojba od 3 000 USD/t osigurala primjenu mokrog odsumporavanja, tj. smanjenje emisija na 400 mg/m³, što je u skladu s današnjim standardom. Slično se dobiva za NO_x : pristojba od 200 USD po toni NO_x navela bi proizvođača da smanji emisiju na oko 55 % nekontrolirane vrijednosti (primjenom SNCR uređaja). Iole veće smanjenje emisija zahtijevalo bi pristojbu od bar 800 USD/t jer bi se tada isplatio SCR uređaj. Uz 1 000 USD po toni emisije bi se svele na ekonomski optimalnu razinu (oko 430 mg/m³), a za postizanje vrlo niskih razina emisija, kakve zahtijeva standard od 200 mg/m³, bilo bi nužno uvesti pristojbu od oko 1 900 USD/t NO_x .

Ove vrijednosti predstavljaju približne troškove smanjenja emisija za tipičnu elektranu na ugljen. U sustavu s tržišnim mjerama zaštite okoliša ta bi elektrana mogla djelovati u kombinaciji s još nekim industrijskim postrojenjima u smanjenju ukupnih emisija na nekom području. Ukupni troškovi takvog zahvata vjerojatno bi bili manji nego zbroj troškova pojedinačnih izvora.

4.4 Primjer: Analiza isplativosti uvođenja strožeg standarda za emisiju NO_x

Želimo izračunati koliko se smanje troškovi štete za zdravlje ako se uvede stroži standard za emisiju NO_x iz elektrana na ugljen i s današnjih 650 snizi na 200 mg/m³. Naime, takav će propis vrlo vjerojatno biti uskoro donesen jer je Hrvatska potpisala tzv. Drugi protokol o smanjenju emisija NO_x u sklopu LRTAP konvencije. Prema tom propisu, emisija NO_x iz ložišta toplinske snage veće od 300 MWt bit će ograničena na 200 mg/m³, za razliku od 650 mg/m³ koliko je sad na snazi.

Promatrajmo referentnu elektranu na ugljen, 350 MW, za koju je u prethodnim poglavljima proveden proračun eksternih troškova. Cilj je odrediti kolike bi bile društvene koristi propisivanja strožeg standarda za NO_x i usporediti ih s troškovima te mjere. Društvene koristi izračunat ćemo kao uštedu u trošku štete za zdravlje, a troškovi će biti jednaki dodatnom ulaganju potrebnom za efikasniji uređaj za odušičivanje. Promatrat ćemo tri razine s obzirom na prostorni opseg analize:

In the previous chapter, the optimal emission levels of SO_2 and NO_x were calculated through equalizing the marginal damages to health and the marginal costs of equipment for reducing sulfur or nitrogen (Figure 9 i Figure 10). These values can serve as guidelines in the determination of emission fees in a system with market measures of environmental protection. With a fee of approximately 1 000 USD per ton of SO_2, a producer would be motivated to reduce SO_2 emissions by approximately 60 % of the initial amount. A fee of 3 000 USD per ton would secure the application of a wet scrubber, i.e. reduce emissions to 400 mg/m³, which is in accordance with the current standard. Similar results are obtained for NO_x. A fee of 200 USD per ton of NO_x would induce producers to reduce emissions to approximately 55 % of the uncontrolled values (with the application of SNCR equipment). A slightly greater reduction in emissions would require a fee of at least 800 USD per ton, because in such a case SCR equipment would be profitable. With 1 000 USD per ton, emissions would be reduced to the economically optimal level (approximately 430 mg/m³). In order to achieve a very low emission level, as required by a standard of 200 mg/m³, it would be necessary to introduce a fee of approximately 1 900 USD per ton of NO_x.

These values represent the approximate costs of reducing emissions for a typical coal-burning power plant. In a system with market measures of environmental protection, this power plant could operate in combination with several other industrial plants in reducing the total emissions in a region. The total costs of such an undertaking would probably be less than the sum of the costs of individual sources.

4.4 Example: Analysis of the economic justification for the introduction of a stricter standard for NO_x emission

We want to calculate how much damage costs to health will be reduced if a stricter standard for the emission of NO_x is introduced for a power plant fueled by coal, from the current 650 mg/m³ to 200 mg/m³. Such a regulation will most likely be adopted soon because Croatia has signed the Second Protocol on reducing NO_x emission as part of the Long-Range Transboundary Air Pollution Convention. According to this regulation, the emission of NO_x from a combustion source with thermal power greater than 300 MWt will be limited to 200 mg/m³, rather than the 650 mg/m³ currently in force.

Let us consider the reference coal-burning power plant, 350 MW, for which an estimate of the external costs was performed in the previous chapters. The goal is to determine the social benefits that would be achieved by the stipulated stricter standard for NO_x and compare them with the costs of this measure. We lokalnu za Zagreb, regionalnu za Hrvatsku i regionalnu za cijelu Europu.

Dobit

Uz emisiju NO_x = 200 mg/m³ eksterni će trošak biti proporcionalno manji nego pri emisiji 650 mg/m³. Ako prosječna šteta uz emisiju NO_x = 650 mg/m³ iznosi 0,534 eura/stan za Hrvatsku, tad će prosječna šteta uz emisiju 200 mg/m³ iznositi 0,164 eura/stan, tj. razlika je 0,37 eura/stan. To pomnoženo s populacijom od 4,8 milijuna ljudi daje 1,77 milijuna eura, tj. 2,2 milijuna USD (tablica 6).

shall calculate the social benefits as savings of the damage costs to health, and the costs will be equal to the additional investment necessary for the more effective equipment for nitrogen reduction. We shall consider three levels in terms of the spatial range of analysis: local for Zagreb, regional for Croatia and regional for all of Europe.

Benefit

With an emission of NO_x = 200 mg/m³, the external cost will be proportionally lower than at an emission of 650 mg/m³. If the average damage with the emission of NO_x = 650 mg/m³ equals 0,534 euro/capita for Croatia, then the average damage with the emission of 200 mg/m³ will equal 0,164 euro/capita, i.e. a difference of 0,37 euro/capita. This multiplied by a population of 4,8 million persons yields 1,77 million euro, i.e. 2,2 million USD (Table 6).

Tablica 6 - Usporedba eksternog troška za blaži i stroži propis za emisiju
Table 6 - Comparison of the external costs for more lenient and stricter regulations for NOx emissions

Opseg analize / Range of analysis	Prosječna šteta (eura/stan) / Average damage (euro/capita)		Eksterni trošak (milijuna eura/god.) / External cost (Million euro/year)		Razlika u eksternom trošku (milijuna eura/god.) / Difference in external cost (Million euro/year)
	NO_x= 650	NO_x= 200	NO_x= 650	NO_x = 200	
Lokalna - Zagreb / Local - Zagreb	0	0	0	0	0
Regionalna - Hrvatska / Regional - Croatia	0,534	0,164	2,55	0,78	1,77
Regionalna - Europa / Regional - Europa	0,091	0,028	49,0	15,1	33,9

Analogno se može izračunati za slučaj kad analiza obuhvaća cijelu Europu. Tada razlika u eksternom trošku zbog smanjenog utjecaja na zdravlje stanovništva iznosi 33,9 milijuna eura ili 42,4 milijuna USD na godinu. Naime, promatra se populacija od 538 milijuna stanovnika, a razlika u prosječnoj šteti po stanovniku iznosi 0,063 euro/stan.

Trošak

Koliki je dodatni trošak uređaja za odušičivanje koji će emisiju NO_x smanjiti sa 650 na 200 mg/m³? Ako je početna, nekontrolirana emisija NO_x manja od 850 do 900 mg/m³, primarne mjere (LowNO_x) su dovoljne da emisiju NO_x drže ispod 650 mg/m³. Ako se standard postroži na 200 mg/m³, potreban je uređaj za selektivnu katalitičku redukciju, SCR (tablica 3). Ukupni godišnji trošak SCR uređaja iznosi 7 milijuna USD, dok trošak primarnih mjera iznosi 0,5 milijuna USD. Razlika, koja predstavlja dodatni trošak zbog ugradnje SCR uređaja, iznosi 6,5 milijuna USD/god. Taj iznos treba usporediti s dobiti zbog smanjenog utjecaja na zdravlje.

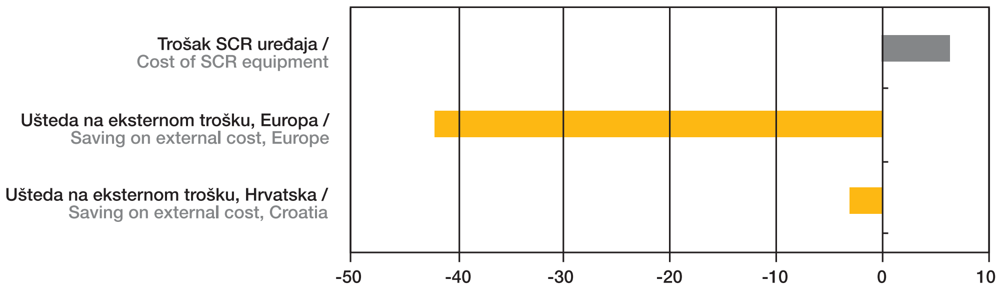
Analogously, it is possible to calculate for a case when analysis includes all of Europe. Then the difference in the external cost due to the reduced impact on the health of the population amounts to 33,9 million euro or 42,4 million dollars annually. This involves a population of 538 million inhabitants, and the difference in the average per capita damage is 0,063 euro/capita.

Cost

How much is the additional cost for treatment equipment that will reduce the emission of NO_x from 650 to 200 mg/m³? If the initial, uncontrolled emission of NO_x is less than 850-900 mg/m³, primary measures (LowNO_x) are sufficient to hold the NO_x emission below 650 mg/m³. If the standard is tightened to 200 mg/m³, equipment for selective catalytic reduction, SCR, will be necessary (Table 3). The total annual cost of SCR equipment amounts to 7 million USD, while the cost of primary measures amounts to 0,5 million USD. The difference represented by the additional cost due to the installation of SCR equipment amounts to 6,5 million USD/year. This amount should be compared with the profits from reducing the impact upon health.

Na lokalnoj razini dobit zbog smanjenog utjecaja na zdravlje jednaka je nuli jer, kako se pretpostavlja, NO_x na lokalnoj razini ne utječe na zdravlje. Prema tome, SCR uređaj ne bi se isplatio. Ako se promatra cijela Hrvatska, tj. 4,8 milijuna ljudi, ušteda na eksternom trošku bila bi 1,77 milijuna eura na godinu, tj. 2,2 milijuna USD ako se pretpostavi tečaj 1:1,25 (1999. godine). Dakle, SCR uređaj još uvijek ne bi bio isplativ. Konačno, ako opseg promatranja proširimo na cijelu Europu, s oko 540 milijuna stanovnika, dobit bi iznosila 33,9 milijuna eura ili 42,4 milijuna USD, što višestruko nadmašuje troškove SCR uređaja (slika 14). Prema tome, ispada da bi se SCR uređaj isplatio tek ako se promatra cijela Europa. Vjerojatno su dalekosežne dobiti jedan od glavnih razloga za postroženje standarda i donošenje protokola o daljnjem smanjenju emisija NO_x u okviru LRTAP konvencije.

At the local level, the benefit due to the reduced impact on health would equal zero, because it is assumed that on the local level NO_x does not have an impact upon health. Accordingly, the SCR equipment would not be economically justified. If all of Croatia is considered, i.e. 4,8 million people, the savings on external costs would be 1,77 million euro annually, i.e. 2,2 million dollars, assuming a rate of exchange of 1:1,.25 (1999). Thus, SCR equipment would still not be economically justified. Finally, if we extend the range of observation to include all of Europe, approximately 540 million inhabitants, the benefit would amount to 33,9 million euro or 42,4 million USD, which many times exceeds the cost of the SCR equipment (Figure 14). Accordingly, it follows that SCR equipment would only be economically justified when all of Europe is considered. It is likely that the long-range benefits are among the main reasons for tightening the standard and adopting the protocol on the further reduction of NO_x emissions within the framework of the Long-Range Transboundary Air Pollution (LRTAP) Convention.



Slika 14
Analiza troškova i dobiti SCR uređaja
Figure 14
Analysis of the costs and benefits of SCR equipment

Za potpunu analizu troškova i dobiti ugradnje SCR uređaja trebalo bi još analizirati koliko se zbog njegovog rada smanjuje stupanj djelovanja elektrane, tj. povećavaju emisije te koliki je eksterni trošak samog procesa katalitičke redukcije. Naime, jedan od reagenata u procesu redukcije je amonijak, štetni plin koji tijekom reakcije djelomično pobjegne u okoliš. Osim toga, produkt procesa redukcije je N_2 iz kojeg na visokim temperaturama nastaje staklenički plin N_2O. No, to su ionako eksterni učinci koji idu na stranu troškova uređaja, pa je omjer troškova i dobiti još nepovoljniji.

For a complete analysis of the costs and benefits of the installation of SCR equipment, it would also be necessary to analyze the extent that its operation would reduce the degree of operations of the power plant, i.e. increase emissions, and how much the external cost of the process of catalytic reduction would be. One of the reagents in the process of reduction is ammonia, a harmful gas that partially escapes into the environment during the reduction process. Moreover, a product of the reduction process is N_2, from which the greenhouse gas N_2O occurs at high temperatures. However, these are external impacts that are included in the equipment costs, so that the cost-benefit ratio becomes even less favorable.

5 ZAKLJUČAK

U članku je elaborirano nekoliko mogućih primjena eksternih troškova. Spoznaje dobivene prikazanom analizom mogu nam pomoći da postavimo razumna ograničenja na ukupne emisije, takva koja će ujedno biti i ekološki i ekonomski prihvatljiva.

Činjenica je da troškovi smanjenja emisija progresivno rastu sa stupnjem redukcije, iz čega slijedi da politika zaštite okoliša, koja se temelji isključivo na propisivanju standarda, nije idealno rješenje jer izaziva nepotrebno visoke troškove. Relaksacija regulativnih prema tržišno orijentiranim mjerama mogla bi donijeti financijsku uštedu uz istu ekološku dobit. Ako se već propisuju standardi, preporuka je da se najprije odrede željeni standardi kvalitete zraka, tj. maksimalno dopuštene ambijentalne koncentracije polutanata, a tek onda emisijski standardi. Propisivanje standarda koji zahtijevaju vrlo skupe mjere smanjenja emisija opravdano je jedino ako se time postižu ekološke i društvene dobiti veće od troškova tih mjera.

Eksterni troškovi mogu poslužiti za izbor optimalnog skupa mjera zaštite okoliša, takvih da se uz ograničena sredstva koja su dodijeljena za zaštitu okoliša postigne najveće smanjenje rizika na ljude i okoliš. Svaki projekt je karakteriziran veličinom pritiska na okoliš, a učinkovitost neke mjere zaštite okoliša može se definirati kao smanjenje učinka na okoliš po jedinici uloženih financijskih sredstava. Tek kad se učinci izraze u jedinstvenom mjerilu, kao što je eksterni trošak, moguća je usporedba učinkovitosti različitih strategija zaštite okoliša. I konačno, ali ne i najmanje važno, eksterni troškovi mogu biti jedan od pokazatelja održivog razvoja jer omogućuju da se raznorodni učinci prikažu u istom mjerilu.

5 CONCLUSION

In this article, several potential applications of external costs are elaborated. The insight obtained trough the analysis presented can help us to set reasonable limits on total emissions, which will be both ecologically and economically acceptable.

It is a fact that the costs of reducing emissions increase progressively with the degree of reduction, for which it follows that an environmental protection policy based exclusively on the stipulation of standards is not an ideal solution because it results in unnecessarily high costs. Relaxation of regulations in favor of market oriented measures could yield financial savings with the same ecological benefit. If standards are already being stipulated, it is recommended to determine the desired air quality standards first, i.e. the maximum permitted ambient concentration of pollutants, and then set the emission standards. The stipulation of standards that require very expensive measures for reducing emissions is only justified if they achieve ecological and social benefits that are greater than the costs of these measures.

External costs can be used in choosing an optimal group of environmental protection measures, so that the greatest reduction in risk to humans and the environment is achieved with the limited funding allocated for environmental protection. Each project is characterized by the amount of pressure on the environment, and the effectiveness of a measure of environmental protection can be defined as the reduction of environmental impact per unit of invested funding. Only when the impacts are expressed in the same unit of measurement, such as external costs, is it possible to compare the effectiveness of various environmental protection strategies. Finally, but no less importantly, the external costs can be one of the indicators of sustainable development because they make it possible to present various impacts using the same unit of measurement.

LITERATURA / REFERENCES

[1] The Swiss Study Infras/Prognos 1994.
[2] LEE, KRUPNICK, BURTRAW, et al., Estimating Externalities of Electric Fuel Cycles: Analytical Methods and Issues, McGraw–Hill/Utility Data Institute, Washington DC, 1995.
[3] Electricity Generation and Environmental Externalities (Case Studies), EIA - Energy Information Administration, Washington DC, 1995.
[4] European Commission, DGXII: ExternE Project, Methodology Report, 2nd Edition, Brussels, 1998.
[5] KRUPNICK, BURTRAW: The Social Costs of Electricity: Do the Numbers Add Up?, Resources for the Future, Washington DC, 1996.
[6] STAVINS, WHITEHEAD, The Next Generation of Market–Based Environmental Policies, Resources for the Future, Washington DC, 1996.
[7] BRÄNNLUND, Green Tax Reforms: Some Experiences from Sweden, Green Budget Reform in Europe, Springer Verlag, Berlin–Heidelberg, 1999.
[8] FERETIĆ, D., TOMŠIĆ, Ž., KOVAČEVIĆ, T., The role of nuclear power in sustainable development of the Croatian power system, 2nd Intl. Conf. on Nuclear option in countries with small and medium electricity grids, Dubrovnik, June 1998.
[9] HARTMAN, WHEELER, SINGH, The Cost of Air Pollution Abatement, Applied Economics, 29, pp. 759–774, 1997.
[10] SCOTT, CONVERY, Cohesion Countries: Experience in Countries on the European Periphery, Green Budget Reform in Europe, Spinger Verlag, 1999.
[11] Okoliš, broj 96, Državna uprava za zaštitu prirode i okoliša, Zagreb, siječanj 2000.

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