# POSTIZANJE RESURSNE UČINKOVITOSTI OBJEDINJAVANJEM SEKTORA ENERGETIKE, VODE I OTPADA

# ACHIEVING RESOURCE EFFICIENCY THROUGH THE INTEGRATION OF ENERGY, WATER AND WASTE SECTORS

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**Abstract:** *Current economic growth and the presently deployed technology result in high entropic cost for the planet. Resource efficiency considers using the Earth's limited resources in a sustainable manner while minimising impacts on the environment. Paper presents the concepts of entropy and circular economy, and elaborates on waste, energy/nutrients and water nexus. Integrating the energy, water and waste sectors is indispensable for achieving resource efficiency. The Republic of Croatia should endeavour to benefit from this strategy to conserve its ecosystems and natural capital. Moreover, resource efficiency achievement can generate substantial benefits which include reduced landfill and carbon emissions, higher rates of re-use and recycling of products and greater job creation.*
**Keywords:** *resource efficiency, energy-water-waste nexus, environmental protection, circular economy.*

**Sažetak:** *Sadašnji gospodarski razvitak i prevladavajuća tehnologija uzrokuju visok entropijski trošak za planet. Resursna učinkovitost podrazumijeva korištenje ograničenih resursa ovog planeta na održiv način kako bi se smanjio čovjekov utjecaj na okoliš. Rad daje prikaz pojma entropije i kružnog gospodarstva te obrađuje poveznicu između otpada, energije/hranjivih tvari i vode. Objedinjavanje sektora energije, vode i otpada je nužno za postizanje resursne učinkovitosti. Republika Hrvatska treba nastojati izvući korist iz opisane strategije kako bi sačuvala svoje ekosustave i prirodni kapital. Nadalje, postizanje resursne učinkovitosti može značajno pridonijeti smanjenju emisija, povećanom stupnju oporabe i recikliranja proizvoda kao i stvaranju novih radnih mjesta.*
**Ključne riječi:** *resursna učinkovitost, poveznica energija-voda-otpad, zaštita okoliša, kružno gospodarstvo.*

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## 1. INTRODUCTION

Present method of measuring progress and the currently deployed technology result in high entropic cost for the planet. Technical solutions and research are presently concentrated on high-tech hardware for processing large amounts of waste (Runko Luttenberger 2014). Biological materials from farming/collection and technical materials from mining and material manufacturing, including water that humans use for producing goods and services are depleted and degraded in a manner that will lead to scarcity or unbearable costs of extraction. The paper analyses entropic nature of economic processes, presents the concept of circular economy, and elaborates on waste, energy/nutrients and water nexus that is crucial for achieving resource efficiency.

## 2. ENTROPIC NATURE OF ECONOMIC PROCESSES

Nature provides the energy, materials and services needed to sustain life and expand economic output. Until recently, these resources and services were largely ignored in standard models of economic production although there exists a long and rich history of using thermodynamics and ecological principles to study economic systems (Cleveland 1999).

In 1965 Romanian economist Georgescu-Roegen wrote: „We tap low entropy by two essentially distinct procedures. We mine – or we shovel, as it were – the low entropy existing in the form of a stock in the Earth's crust. We also catch the low entropy which surrounds us in the form of a flow, the most vital of all being the flow of solar radiation. The first activity corresponds to mining, the second to husbandry. A third activity, manufacturing, merely transforms further the flow of low entropy fed by the first two sectors. Finally, consumption transforms the low entropy flow of consumer goods into high entropy. In this struggle, man has always striven to discover new sources of low entropy ...“ (Martinez-Alier 1997). The central role of the Second Law of Thermodynamics is that the entropy of the physical universe increases constantly because there is a continuous and irrevocable qualitative degradation of order into chaos. The entropic nature of the economic process, which degrades natural resources and pollutes the environment, constitutes the present danger.

The Earth is entropically winding down naturally, and economic advance is accelerating the process (Lozada 1995).

In 1972 the biophysicist Donella Meadows and her colleagues at the Club of Rome published The Limits to Growth, explaining how declining resources would eventually limit economic growth. The following year, economist Robert Solow delivered a lecture to the American Economic Association in response. Solow claimed that capital could be substituted for resources and that if this were true, then the world can, in effect, get along without natural resources according to the following formula:

$$\text{output} = \text{capital} \times \text{labour} \times \text{resources}$$

However, in any mechanical process energy is depleted and degraded. We cannot burn the same barrel of oil twice. Common sense tells us that a pile of boards and sawdust is not a tree, even if it represents the same amount of material. Although we can recycle materials, every transformation degrades matter and burns energy. Money, therefore, is not a substitute for energy, trees, fresh water or any other resource, and material constraints do indeed limit economic growth The promoters of endless growth mock this as pessimism, but when one looks around at degraded Earth – acidic seas, drained aquifers, growing deserts, extinct species – what can be witnessed is the entropic cost of human economic growth (Wyler 2010).

Therefore, a living being can evade the entropic degradation of its own structure only. It cannot prevent the increase of the entropy of the whole system, consisting of its structure and its environment. On the contrary, from all we can tell now, the presence of life causes the entropy of a system to increase faster than it otherwise would (Georgescu-Roegen 1971).

## 3. CIRCULAR ECONOMY

Cycles mean renewal and regeneration for Earth as for organisms and ecosystems whose rhythms are tied to those of the Earth. Most, if not all environmental problems come from disrupting natural cycles by using up resources or generating wastes faster than the material cycles can accommodate. Top of the list is burning fossil fuels and generating $CO_2$ faster than the photosynthetic organisms can absorb, resulting in the increase of $CO_2$ in the atmosphere and global warming. Practically all biological activities are in cycles: those yielding energy being directly coupled to those requiring energy, and the giving and taking can be reversed as necessity arises. The activities occur over the entire range of space times, so no essential activity is left without energy at any one time (Ho 2012).

The closed loop model is a biomimetic (life-imitating) approach, a school of thought that takes nature as an example and considers that our systems should work like organisms, processing nutrients that can be fed back into the cycle – hence the "closed loop" or "regenerative" terms usually associated with it (Ellen MacArthur Foundation 2014).

Its application as an economic model was presented in 1966 by Kenneth E. Boulding in „The Economics of the Coming Spaceship Earth“ (Boulding 1966). The increasing scarcity of raw materials aroused economic interest in waste as a material resource, and countries began to invest in the re-use and recycling of waste which has been around for centuries. When done right, it delivers significant environmental benefits by reducing demand for raw materials, energy and water (Gunther, 2014).

The generic concept has been refined and developed by the following schools of thought (Ellen MacArthur Foundation 2014): Regenerative design (John T. Lyle); Performance economy (Walter Stahel); Cradle to Cradle (Michael Braungart and Bill McDonough); Industrial ecology (see also - Runko Luttenberger 2000); Biomimicry (Janine Benuys) and Blue Economy (Gunter Pauli).

Cradle to Cradle (C2C) design for instance perceives the safe and productive processes of nature's 'biological metabolism' as a model for developing a 'technical metabolism' flow of industrial materials. Product components can be designed for continuous recovery and reutilisation as biological and technical nutrients within these metabolisms. The Cradle to Cradle framework addresses energy and water inputs. It eliminates the concept of waste, advocates the use of current solar income and management of water use to maximise quality, promotes health ecosystems and respects local needs (Ellen MacArthur Foundation 2014). Cradle to Cradle pursues eco-effectiveness or doing the right things (eco-efficiency implies doing things right) (Drucker 2002).

The sustainable handling of natural resources is not simply a question of technology, ecology and waste management but also includes economic, social, political, cultural and technical aspects; therefore the optimization of entire processes and systems rather than single components becomes increasingly important. This 'systems thinking' is at the core of the concept of circular economy (Circular Economy 2014). Donella Meadows, one of the authors of 1972 Limits to Growth whose forecasts still remain unchallenged (The Guardian 2014a) brought the very concept of systems thinking to wider audience (Meadows 2008).

The circular economy is based on a few simple principles: design out waste, build resilience through diversity, work towards using energy from renewable sources, think in 'systems', and prices must tell the truth. It draws a sharp distinction between the consumption and use of materials advocating the need for a 'functional service' model in which manufacturers or retailers increasingly retain the ownership of their products and, where possible, act as service providers – selling the use of products, not their one-way consumption. This shift has direct implications for the development of efficient and effective take-back systems and the proliferation of product-and business model design practices that generate more durable products, facilitate disassembly and refurbishment and, where appropriate, consider product/service shifts. In the past, reuse and service-life extension were often strategies in situations of scarcity or poverty and led to products of inferior quality. Today, they are signs of good resource husbandry and smart management (Ellen MacArthur Foundation 2014).

The Ellen MacArthur Foundation has estimated that implementing circular opportunities at a global scale could yield over USD 1 trillion per annum in material savings. Eco-design will be critical in the circular economy as it has been estimated that 80% of the environmental impact of a product is determined at the design stage (The Guardian 2014b).

Design, manufacture, purchase or use of materials to reduce their quantity or toxicity before they reach the waste stream is source reduction, a proactive approach which reduces material and energy use. Recycling, composting, waste-to-energy, and landfilling are reactive methods for recovering and managing materials after they are produced (EPA 1995; Runko Luttenberger 2010).

Sustainable long-term solution is to implement a range of strategies such as (The Future of Energy 2012):

- establish 'nutrient pathways' for ingredients, materials and products so they can be used as biological or technical nutrients,
- use of organic compounds and nutrients in biodigestion, composting, fermentation or gasification processes returning into biogeochemical cycles of carbon and nutrients so the energy savings is actually by-product of the use (cycle) of compounds,
- classify chemicals and materials in industrial products into those which can be safely released into the biosphere, those that can be recycled effectively and those that can be downcycled safely and avoid the use of any chemicals or materials that can't be treated in this way,
- design for disassembly – make things that are 'made to be made again',
- design processes that can profitably recover precious resources for re-use,
- recognise that different countries will have their own ways of doing this,
- establish ways that industries can co-operate in innovation and use of materials,
- ensure that all of these strategies are environmentally safe and not harmful to humans.

Until a few years ago, very few people would take green or circular economy seriously. Not anymore. The major driver of the circular economy is not so much environmental concern as the soaring prices of commodities that seriously threaten growth in the business sector. European Commissioner for the Environment put it as follows: improving resource use is not just an environmental imperative; it is an issue of survival for businesses, as for the planet. He also reminded those who still think that protecting nature is bad for business of the tens of billions euros lost from flooding because EA's were ignored, stating that circular economy is a 'marriage of necessity' between business and the environment (Ho 2012). The timing is no accident: Prices of oil and energy have more than quintupled since 1998, metals prices have tripled and food prices have risen 75 per cent (Gunther 2014).

## 4. WASTE

The way of approaching circular economy is strongly connected not only with the existing political and governmental systems in individual countries, but also with the determination and awareness of local communities. For instance, Germany follows a combination of top-down and bottom-up approach, Switzerland has chosen a more bottom-up and participative path, and China has implemented the CE concepts from the top down, thereby becoming one of the first countries in the world to introduce circular economy in its constitution (Circular Economy 2014).

Waste is not only an environmental problem, but also an economic loss and burden for the society. Labour and the other inputs (land, energy, etc.) used in its extraction, production, dissemination and consumption phases are also lost when the „leftovers“ are discarded. Moreover, waste management costs money. Creating an infrastructure for collecting, sorting and recycling is costly, but once in place, recycling can generate revenues and create jobs. There is also a global dimension to waste, linked to our exports and imports. What we consume and produce in Europe could generate waste elsewhere. In some instances it actually becomes a good trade across borders, both legally and illegally (EEA 2014).

A number of communities worldwide introducing, and practicing zero waste concept is increasing. Their networks provide necessary information for interested communities to pursue the idea (Zerowaste Europe 2015).

## 5. ENERGY

In many countries, kitchen and gardening waste constitutes the biggest fraction of municipal solid waste. This type of waste, when collected separately, can be turned into an energy source or fertiliser. Anaerobic digestion is a waste treatment method that involves submitting biowaste to a biological decomposition process similar to the one in landfills, but under controlled conditions. Anaerobic digestion produces biogas/methane which can be used as fuel for cooking or even to run a car, or it can be delivered into the grid as gas or via generators as electricity. The residual nutrient rich digestate, which is also produced in bio-digestion, can be used for improved soil fertility. To move towards a circular economy we need to consider that materials are potentially too valuable to burn. If we incinerate rather than compost or digest organic material, at what point do we reach „peak soil“? Burning plastic (made from fossil fuels) isn't creating renewable energy – and it releases a lot of $CO_2$, just like burning coal or oil. Many metals used in various products are expensive materials which are mined with huge efforts from the earth and then burned – and the earth isn't making any more of them. It is estimated that up to 50 per cent of topsoil has been lost in the last 200 years. Burning organic materials like food and paper instead of composting them and returning their nutrients to the soil not only releases $CO_2$ but adds to this alarming loss of the undervalued stuff we grow our food in (The Future of Energy 2012; EEA 2014). Incineration is not waste to energy but wasting energy.

In implementing the concept, each city starts from a different point which depends on the existing infrastructure, political priorities and objectives. Within the EU projects, several European cities and regions have developed their concepts for biogas plants treating organic municipal waste and trained a number of municipalities, waste companies and consumers to move forward this implementation. Today, the greatest achievements of biomethane for road transport are found in Sweden however, a booming development has already started in the UK and France with Italy ready to join in (European Biogas Association 2014).

In fact, burning firewood for cooking also creates a lot of smoke and soot particles which contribute to air pollution which in turn causes health issues such as respiratory illness. Most of the pollution is due to poor combustion fuels and emitted greenhouse gases. Also increase in the concentration of hydrogen sulphide leads to headaches, dizziness, blurry vision, nausea and vomiting. Sulphur dioxide emissions lead to choking and sneeze-inducing effects. Biogas is a clean fuel compared to biomass or coal combustion. Cleanliness here refers to the cooking vessel not turning black in the bottom of the vessel. Air pollution by biogas is less because of few larger hydrocarbons. Most of small-scale digesters are concentrated in developing countries with India and China as leading countries accounting for the highest share. Many of small scale digesters do not require high maintenance and are more or less adaptable to the climate and condition of many of developing countries. However, adopting of biogas digesters is low in many countries (Rajendran et al. 2012).

## 6. WATER

Conventional sanitation solutions assume that the environment can handle the waste, or they shift the burden to downstream communities. Ecological sanitation, on the other hand, minimises the reliance on external inputs, while simultaneously reducing the output of wastes from the system. Many of the products (pharmaceuticals) may be partially or fully reconstituted when deposited into water, but when excreta are returned to soil, they appear to be broken down rapidly by soil microorganisms. Furthermore, both urine and faeces should be recovered and recycled to avoid long-term depletion of soils. Urine has been used in Europe for household cleaning, softening wool, hardening steel, tanning leather and dying clothes. The Greeks and Romans used it to colour their hair, and African farmers use it for fermenting plants to produce dyes. The Chinese pharmaceutical industry uses it to make blood coagulants (Esrey and Andersson 2001).

Water-borne sanitation as used in conventional sanitation systems is based on the collection and transport of wastewater via a sewer system, using (drinking) water as transport medium. The system mixes comparatively small quantities of potentially harmful substances with larger amounts of water and the magnitude of the problem is multiplied. In addition, the construction, operation and maintenance of the necessary hardware for the „flush and discharge“ options (sewer, wastewater treatment, drinking water treatment) are a heavy financial burden. Conventional sanitation systems have even more fundamental shortcomings than their high costs such as over-exploitation of limited renewable water sources, pollution of soil and groundwater, waste of valuable components in wastewater and the difficulty for an effective removal of pollutants. Ecological sanitation technologies may range from natural wastewater treatment techniques to separating toilets, simple household installations to complex, mainly decentralised systems (Langergraber and Muellegger 2005).

According to Wilderer (Wilderer 2005) urban water re-use is to be considered a most promising solution to the water shortage problems in the fast growing cities in the world; decentralized sanitation and re-use systems allow rapid and step-wise improvement of urban water and sanitation infrastructure when installed simultaneously with the building of new houses, housing complexes, residential areas, tourist resorts, etc.; the various possibilities are to be carefully taken into account and evaluated as there is no single method universally applicable; to be selected and applied is that method which fits best into the existing infrastructural, socio-economic and socio-cultural environment; research is necessary to develop the various technical options to a level that allows safe application and control; demonstration facilities should be built up to study and gradually improve the performance of the different methods under realistic conditions.

Whilst most of the creativity and innovation in integrated decentralized water infrastructure is occurring at local levels, the barriers to innovation are severe: an engineering bias against decentralized systems, siloing of local agencies and national programs affecting local government, indifference of most of the public, and restrictive local ordinances. Many decentralized technologies are soil-based designs that are non-proprietary, so private companies cannot exclusively capture the benefits of any research. For example, research results on landscaping for stormwater retention, shallow trenches for wastewater treatment in soils, low-impact development systems, and other technologies could be used by any designer. They are not embedded in specific pieces of equipment that a manufacturer would produce. Therefore, no strong incentives exist for private firms to invest in this research. On the other hand private sector underinvests in basic research that could lead to fundamental redesigns in decentralized water infrastructures because such research is expensive and high-risk. Such research is appropriately conducted at non-profit universities, research institutes, or government laboratories, where public benefits and costs are properly aligned (Nelson 2008).

Various cases of ecological sanitation systems implemented may be found for instance in (CCB 2009; SuSanA 2015). The German Association for Water, Wastewater and Waste (DWA) recently released working paper on the basic rules for implementation of new alternative sanitation systems (DWA 2014).

## 7. WATER-ENERGY/NUTRIENTS NEXUS

Water and energy systems are interconnected in a number of important ways. Water provides energy through hydropower and most thermal energy systems require water for cooling and also for the extraction of fossil fuels and biofuels production. Water supply and treatment systems generally use energy for pumping. Critical elements of water infrastructure can be energy intensive. Moving water over distances and elevation gains, treating and distributing it, using it for various purposes, and collecting and treating the resulting wastewater accounts for one of the largest uses of electricity in many areas (Wilkinson 2014).

The traditional western paradigm for wastewater treatment has focused primarily on removal of nutrients and organic matter at all costs via the aerobic activated sludge processes. That is, use of extensive energy in aeration to nitrify, followed by the use of wastewater and external carbon to drive denitrification. This produces a final effluent of outstanding quality, but is intensive in energy requirements, space (mainly due to clarifiers) and removes the nitrogen in a destructive process. There is now a widespread recognition that the activated sludge principle as is applied is inefficient, and that there are better options available with current technology. These concepts are developed from the basis that wastewater contains resources which should be recovered, including nutrients (nitrogen and phosphorus), energy, and water; and there is generally sufficient energy in wastewater to drive complete treatment. In most cases, anaerobic processes mentioned earlier have been identified as the key biochemical process, since they are non-destructive of nutrients, do not inherently produce a biomass by-product, and produce methane. There are really no technical challenges to implementation of this process, as the organic solids being digested are far more amenable to digestion than activated sludge biosolids. The process can have both domestic applications and for the recovery if nutrients and energy from municipal solid waste, agriculture and industry (Batstone 2014).

The lesson from photosynthesis is simple: use solar power for your energy and manage your water supplies wisely. Solar power's big benefits of being affordable, distributed, and not producing carbon dioxide emissions tend to overshadow one of its lesser known benefits as a power generation source. Solar power does not actively use water. Water and energy are inextricably linked not only in the natural world but also in our modern technological infrastructure (Mosaic Blog 2014).

## 8. CONCLUSION

In order to achieve resource efficiency it is necessary to design innovations in waste management 'software', to introduce policy measures to enhance resource productivity and curb demand, focus research and development on the goal of increasing resource productivity, increase awareness of resource limits, initiate the process of rethinking lifestyles, and improve communication between policymakers and the scientific community. Systems where waste is not produced should be promoted and further developed and products should be reshaped with regard to durability, reparability, reuse and recycling. The Republic of Croatia as a country of great potential, particularly with regard to its geographic position, natural resources, small-scale agriculture, diversity of its ecosystems, length of the coast, karst, and aquifers should endeavour to benefit from this strategy and advance toward circular economy. It would therefore be necessary to implement decentralized sanitation with source separation, water reuse, separate collection of biowaste, the use of biogas and sludge, and to revive the collection, storage and consumption of rainwater from roofs and large collection surfaces and cisterns. Ecological sanitation would create numerous local work posts and be beneficial for the climate.

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