Circular systemic solutions and their adaption in a regional innovation scheme

A. Peppas, C. Politi*, M. Taxiarchou

School of Mining and Metallurgical Engineering, National Technical University of Athens (NTUA), Zografou, 15780 Athens, Greece

Corresponding author email: chrysapol@metal.ntua.gr tel. +30 210 772 2216

Abstract

The COVID-19 outbreak has revealed the worldwide weaknesses of the current production and consumption model, which is currently built on dissipation of natural resources, relocation of production, disconnection with territories and communities for the realization of short-range objectives. The adoption of a Sustainable Consumption and Production model linked with circular economy serves the objectives of resource efficiency promotion by realising economic growth along with environmental and societal harmony through reduction of resources usage and waste generation. The key elements of this approach is involve subjects like cleaner production, waste management, energy and material flow analysis, and effective collaboration among them. The circularity on regional level will be achieved through the deployment of highly replicable, modular and scalable circular systemic solutions based on a multi-stakeholder approach putting citizens' needs at the centre of development. This systemic approach addresses four key strategic sectors linked with the decarbonisation of Europe, namely: Wood Packaging, Food and Feed, Water and Nutrients as well as Plastics and Rubber. In this study, these flexible and modular circular systemic solutions toward an inclusive and resilient climate-neutral and systemic circular (bio)economy transition are presented and will be demonstrated in the framework of the "FrontSH1P" project in the Lodzkie Region. The synergy of these solutions prepares the ground for a sustainable circular economy which will be reflected in delivering important energy savings and environmental benefits for the region and creating local jobs and opportunities for social integration.

Keywords: Circular economy, bio-based economy, systemic solutions, circular governance model

1. Introduction

The COVID-19 outbreak has revealed the worldwide weaknesses of the current production and consumption model, which is currently built on dissipation of natural resources, relocation of production, disconnection with territories and communities for the realization of short-range objectives. To address these challenges, the European Green Deal set the blueprint to build a new economic model. All European Member States (MS) have committed to turning the European Union (EU) into the first climate neutral continent by 2050. On this account, they dedicated to reduce emissions by at least 55% by 2030, compared to 1990 levels, setting the EU on a course for achieving its climate targets by 2030 in a fair, cost effective and competitive way. [1] However, the 2030 outlook indicates that the 2030 and 2050 climate and energy targets will not be achievable given the current rate of progress. Therefore, EU needs to elaborate a new growth strategy targeting a modern, resource-efficient, and competitive EU economy. [2]

1.1. Regional challenges to sustainable development

The current global production and consumption trends are not economically sustainable. [3, 4] Despite the innovation and technological breakthroughs in the field of sustainable energy development, the COVID-19 pandemic in 2020 has decelerated the sustainable energy transition progress. [5] In fact, global energy consumption fell by 4% in 2020 while for the EU it reduced by around 7% (strong drops in the largest markets such as Spain, France, Italy, and Germany), due to lockdown measures and transport restrictions. [6] Nevertheless, the economic and social development over the last century has led to deterioration of the environment and depletion of natural resources. It is indicatively mentioned that an estimated one third of all food produced in an annual basis turns into waste, or spoiled due to poor transportation and harvesting practices. [4] In this context, many European regions face long-term threats to their natural resources, quality of life and, not least, their economy. [7] The existing models contributed to create a disconnection between the urban area and rural neighbourhoods which today results in a growing poverty and confinement of people in degraded social housing blocks which requires deep retrofitting, energy efficiency and social regeneration. In addition to the economic and financial crisis, Europe is confronted with major challenges including the globalisation, the demographic change, the climate change, the lack of secure, sustainable and competitive energy, and the social polarisation both in the medium and long term. **Figure 1** depicts the mapping of regional challenges in EU and the related EU 2020 growth strategy strands for each region.

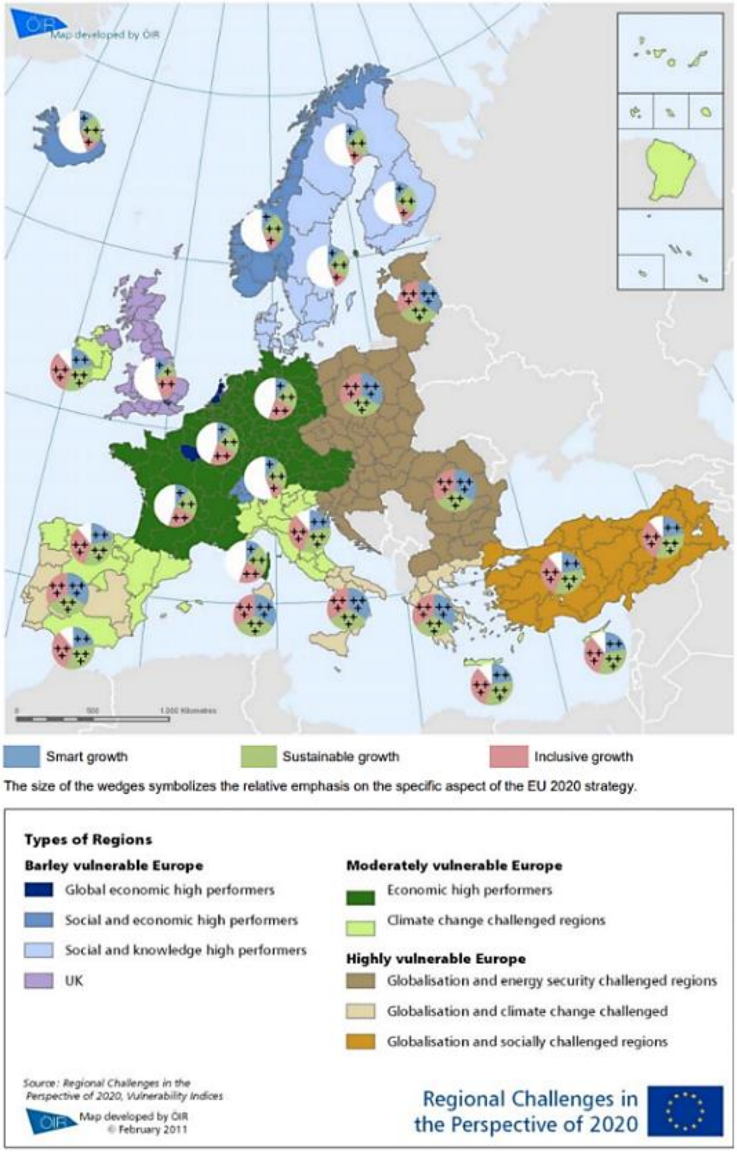

Figure 1 *EU 2020 growth strategy strands with relation to regional challenges in Europe*

Especially quality of life, health and long-term environmental changes raise major concerns for most regions requiring the cohesion policies in order to be addressed. Other aspects are still the balanced development of regions (i.e. balanced distribution of economic sectors contributing to the regional economic income) and their embeddedness in strong socioeconomic unions and cooperation, which seems to decrease vulnerability and strengthen the adaptive capacities of regions. [7] Regions need to initiate actions towards sustainable energy development in order to address the all regional challenges by concentrating on them and setting the right priorities for the investments and find the right policy mix.

1.2. Sustainable Consumption and Production model

Limited of natural resources and growing levels of pollution jeopardise the prosperity and well-being of human society. [8] For all of these reasons, it is emphasised the necessity for remodelling the economy towards a Sustainable Consumption and Production (SCP) model linked with circular economy (CE). [9, 10] By definition, SCP models aim to reduce the consumption of resources and ensure the sustainable production of the products that are economic, environment friendly and beneficial for society. [11] CE encourages the repair, reuse and regeneration of a product after it completes its first life cycle and therefore enables the sustainable consumption and production. [12, 13] SCP is one of the fundamental challenges among emerging Sustainable Development Goals (SDGs) [14] and consists of two constituents, the consumption and the production. The Sustainable Consumption (SC) can be defined as the exploitation of related products and services with low to zero environmental impact in terms of natural resources, toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product. This can be considered on different levels including global, state, region, city, community, or enterprise, public institution, household or individual levels. [9, 15] Sustainable production (SP) is "the generation and development of products and services utilising processes and systems with low to zero environmental footprint, which are characterised by energy and natural resources saving, cost-effective, non-harmful for employees, communities, and consumers. [16] Interest for resource efficiency has risen since the World Summit on Sustainable Development in Johannesburg, caused by a shift toward SCP and its inter-linkages and to respond to increasing scarcity of water, fuels, and other materials. [10] European MS have responded by broadening the scope of cleaner production centres or by establishing new agencies focused primarily on the promotion of resource efficiency. The adoption of a SCP linked with CE serves the objectives of resource efficiency promotion by realising economic growth along with environmental and societal harmony through reduction of resources usage and waste generation. [17, 18, 19] The key elements of this approach is involve subjects like cleaner production, waste management, energy and material flow analysis, and effective collaboration among them. Life cycle approach is also considered fundamental for SCP systems as it seeks to minimize environmental impact by looking at all phases of a product's life cycle and taking action where it is most effective and enables sustainability of production processes, products, and sufficient information flow to consumers. [10]

In such a context, the Horizon2020 European Research project "FrontSH1P" [20] with a total cost of 19M€ aims to demonstrate how innovative models of circular (bio) economy can act as catalyst for socio-economic growth in response to the current pandemic crisis while addressing environmental urgencies in the Lodzkie Region. A group of key partners from the region [1] have extensively analysed the CSS potential delivering the solutions presented in this study with which the circular economy will be achieved through the deployment of four highly replicable, modular and scalable circular systemic solutions based on a multi-stakeholder approach putting citizens' needs at the centre of development. This systemic approach addresses four key strategic sectors linked with the decarbonisation of Europe, namely: Wood Packaging, Food and Feed, Water and Nutrients as well as Plastics and Rubber.

2. Material and methods

A SCP system is proposed aiming at ensuring transition towards decarbonisation and territorial regeneration through demonstration of highly replicable circular systemic models in order to accelerate the transition to a greener, resilient economy, able to provide sustainable responses to the need of the involved regions. [21] The ambition is summarised into the modernisation of the regional economy by decoupling its intensity as much as possible from resource use in order to limit the negative externalities on environment (e.g. greenhouse gases (GHG) emissions, biodiversity loss) in full symbiosis with rural activities. This systemic approach is enabled by the flexibility and modularity of four systemic circular solutions (CSS) guaranteeing a high replicability and scalability to other territories across Europe and beyond. Some of the key industrial sectors that can easily aligned with CE schemes with severe impact to the environmental strategies includes wood packaging, food and feed wastes, wastewater and plastics.

2.1. Circular approach to Wood packaging (CSS1)

Wood packaging can be incorporated to a SCP model through refurbishing, reusing, recycling, energy recovery, and material valorisation. Wood is identified amongst the most used packaging materials due to its very competitive characteristics (i.e. versatility, strength, durability, reusability, low environmental impacts, etc.). Undoubtedly, wood crates, boxes and pallets are commonly utilised to store, handle, and transport a wide variety of good including fragile and heavy goods as well as products coming from diverse sectors. However, after long-term use, wood packaging decays eventually becoming not repairable nor reusable anymore and, once it becomes unsuitable for its original purposes, it is usually discarded and disposed of as waste.

Regarding innovative and circular wood valorisation (hereinafter referred to as CSS1), the current situation is based on exploiting low-quality wood and wooden residues in energy conversion plants. The CSS relies on a biomass gasifier able not only to produce gas to be further combusted for delivery renewable thermal energy to the final users, but also char, a solid, black, porous, carbonaceous material, which could be used as an additive for compost and black pigment/filler for polymers. The integration of gasification technologies provides poly-generation potential in three basic energy streams as well as for the valorisation of potential by-products as part of the circular economy and the renewable heat production as the decarbonisation of heat sector is a priority in coal phase out regions. Manufactures already provide wood-fuelled biomass gasifiers at a scale up to 1 MW. Other manufacturers have also commissioned large-scale gasification facilities (e.g. gasifiers for wood residues up to 200 MW). Up until recently, downdraft gasifiers with cold gas filtering where the norm in terms of small-scale gasification solutions. [22] In terms of biomass and wastes, fluidized beds (FB) gasifiers are the most popular due to their wide particle size range, crucial for wood wastes and residues. Other advantages of the FB are the versatile and robust technology with relative low cost, constructional, and operational ease, as well as the scale-up and high efficiency potential. The process is typically optimised for the conversion in syngas; however, other by-products such as char and tar are also produced and generally disposed as wastes. Furthermore, CO_2 in the flue gases produced by gas combustion, could be captured by means of a compact post-combustion capture (PCC) unit and further valorised as a foaming agent in the plastic industry.In this line, communicating an awareness raise of the potential use of this so-called "wastes" is critical. Char in particular, could replace activated carbon (AC) in different fields of application due to their many similarities. [23] Although commercially available systems for carbon conversion efficiencies

[1] K-FLEX POLSKA SP ZOO, CENTRUM BADAN I INNOWACJI PROAKADEMIA STOWARZYSZENIE, CENTRUM PROMOCJI I ROZWOJU INICJATYW OBYWATELSKICH OPUS, POLITECHNIKA LODZKA, UNIWERSYTET LODZKI, WOJEWODZTWO LODZKIE, ZWIAZEK MIEDZYGMINNY BZURA, GMINA PARZECZEW, KPMG ADVISORY SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA SPOLKA KOMANDYTOWA, SIRMAX POLSKA SP Z OO, LIBERA UNIVERSITA DI BOLZANO.

exceeding 95% have been developed [24], the performance of small and medium scale gasifiers of different fuels is found to be significantly lower. Investigations taking place in South Tyrolean region, suggested an overall combined heat and power (CHP) efficiency of approximately 70%. [25]

Wood packaging wastes valorisation through a poly-generation scheme for the simultaneous wood waste process and production of bio-energy, bio-syngas, biogenic CO_2, as well as char (solid by-product including carbonaceous and metal elements) and sides product such as tar is realised enabling circularity and numerous advantages in regional level. This approach contributes in creating a new value chain for wood packaging waste valorisation, involving the whole community and implementing the circular economy approach while it results in low impact products (wooden goods (e.g. furniture), renewable heat, char as compost or as pigment/filler in the plastic industry). The multiplication of this concept will not only allow effective decarbonisation in the heat sector targeting both centralised and decentralised applications, with or without district heating networks but can be also replicated for power and biofuel production. Furthermore, this solution can address regional challenges in relation to citizen's needs in creating new business opportunities in the wood value chain, and promoting the transition from a linear to a circular economy.

2.2. Circular approach to Food and Feed (CSS2)

Food waste valorisation (hereinafter referred to as CSS2) is considered an environmentally-friendly waste treatment that benefits the bio-based economy, through the recovery and substitution of pure and expensive nutrient sources. With the term "food waste" industrial, commercial and domestic mixed food residues, bread and other bakery wastes meant for human consumption are described. On the other hand, "organic waste" is related to waste matters (e.g. peels and rapeseed meal) not meant for human consumption. The term "biomass" also comprises all biological materials, excluding the food and organic wastes, while "microalgal biomass" refers to microalgae-derived biomass. Around 100 Mt of food waste and residues from food processing industry are generated every year in the EU. [26] A circular approach for valorising and recovering food and feed wastes through the development of biochemical and by-products from renewable origins through the integration of chemistry and agriculture prepares the ground for the economic and environmental sustainability of the food production chain. Numerous valorisation schemes have been investigated to explore food wastes and by-products potential as biomass suppliers for different bio-based products. Among them, circular systemic solutions have been introduced as one of the most promising approaches to address zero-waste targets and accelerate the transition of the food industry to a circular bioeconomy. [27]

To address this challenge at demonstrating the valorisation of agricultural, feedstock, food industry waste and urban biowaste into a variety of eco-designed products in a circular bioeconomy approach, the following can be performed through: 1) production compostable bioplastics from food industry wastes, applicable in the production of compostable bags for the separate collection of urban bio-waste in social houses [26]; 2) Valorisation of oil crops for the obtaining of biodegradable bio lubricants and animal feed. [28] Furthermore, additional information deriving from literature can be examined concerning the different methods and approaches for the valorisation of food industry wastes such as polyhydroxyalkanoates (PHA) production, enzymatic hydrolysis and others. [29] Industry, Food and agricultural waste can be managed through the realization of Organic Fraction of Municipal Solid Waste (OFMSW) treatment plants using compostable bioplastics from regional industrial food waste as a tool to increase quality and quantity of separate collection of urban bio-waste to be converted into compost for soil regeneration and bio-oils for insulating materials compost.

Furthermore, oil seed processing by-products comprise approximately 35 million of tons seed for oil in EU. [30] Despite the residue of oilseed crops being extremely significant due to their various valuable ingredients, the concerned bio-waste is mainly used as animal feed or fertilizer. Due to these aforementioned ingredients (i.e., carotenoid, phenolic, and tocopherol), oil crops wastes find use in many varying fields such as the food or even the cosmetics industry. [31] One significant application for the oil crops wastes is the making of various bio lubricants, due to their biodegradable properties in comparison with other lubricants. Most plant oils have shown to biodegrade more than 70% within a month, as compared to petroleum oils biodegrading at nearly 15 to 35%. [32] It is therefore evident that the implementation of oil crops in more sophisticated applications than animal feed is highly positive in environmental terms and requires further study.

2.3. Circular approach to Wastewater and nutrients (CSS3)

Water constitutes more than 70% of the Earth's surface, whereas only 2.5% of the planet's water is fresh, and less than one third of it is potentially available for human purposes. [33] Moreover, due to the demographic explosion, increased agriculture, industrialisation and deforestation triggering pollution, climate change and global warming, the scarcity of water with satisfactory quality is becoming a global challenge with severe impact on humankind and ecosystems, contributing to a degradation of quality of life. According to a UN report on wastewater treatment, the wastewater is not exploited or treated at the global level and in particular in the least developed countries where less than 8% of the wastewater is treated. [34] Furthermore, the industrial sector is responsible for depleting water quality and disposing untreated sewage and inadequately treated wastewater. [35]

In terms of wastewater management (hereinafter referred to as CSS3), using micro-algae with the production of high added-value products such as fertilizers and bio-stimulant being the ultimate goal, also aiming for the optimization of the efficiency of such fertilizers, baring the biggest resemblance with other fertilizing products than most categories of plant protection products, and the reduction of the nutrient application rates. The possibility of using wastewater as nutrient source for microalgae does not enter into competition with food and feed production. Furthermore, microalgae is involved into performing Carbon Capture and Storage (CCS) as the only sustainable biological mean for redirecting carbon into valuable biomass and contributing to decarbonisation SDG. Several research studies have been performed in relation to micro-algae in order to treat industrial wastewater to address the waste-to-bioenergy economy. Such studies have been mainly investigated the removal of key nutrients such as nitrogen and phosphorus. [36]

Microalgae have been seen as a potential sustainable source of biofuels, bioenergy and a wide array of biobased products such as plant biofertilizers and biostimulants. The common approach includes containerized plants implementing tubular Photo Bio-Reactors (PBRs) technology (phototropic production) for slurry treatment and wastewater. Microalgae can utilize photons to convert CO_2 and nutrients into biomass, which include high-value added products such as lipids, proteins, carbohydrates, polyunsaturated fatty acids and natural pigments through the photosynthetic effect. These bio-products can be used for the production of healthy human foods, animal feeds, aquatic feeds, cosmetics and bio-pharmaceutical. [37] It is found that certain microalgae such as Tetradesmus obliquus can reduce Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) by 96% and 91% respectively, while also reducing other substances like ammonia or phosphorus by more than 99%. [38] In addition to that, the exposure of algae to artificial lightning can enhance the treatment as studies have shown that light is crucial for the growth and photosynthesis of microalgae. Specifically, it has been concluded that for the maximum growth rate of microalgae, a light/dark alternation of specific phase durations is the most sufficient and therefore an artificial controllable lightning is necessary. [39] A typical PBR consists of a four-phase system: solid phase (microalgal cells), liquid phase (growth medium), gaseous phase (CO_2 and O_2) and superimposed light-radiation field. [40]

The most popular closed systems are the horizontal tubular PBRs due to advanced features such as the surface to the volume ratio, the amount of gas in dispersion, the gas-liquid mass transfer characteristics, the nature of the fluid movement and the internal irradiance levels. [41] Such systems are designed for the cultivation of various microalgal species and the prevention of the fouling of the reactor such as Chlorella, Spirulina and Desmodesmus cultivations. [36] Microalgae cultivation together with wastewater treatment is performed in laboratories equipped and licensed for the maintenance and scale-up of genetically modified microorganisms (GMO's). GMO's show great potential in the enhancement of the bioremediation of environmental pollutants through the creation of different new routes of metabolism for the intensification of pre-existing degradation pathways. [42] Among others, the objective is the assessment of the new strategies concerning the generation of valuable bio-based products by integrating the treatment of brewery wastes and other wastewaters such as poultry, swine, cattle, brewery, dairy and urban with the production of microalgae biomass.

2.4. Circular approach to urban and industrial plastic/rubber waste [CSS4]

The use of plastics in our day-by-day world has increased rapidly over the last decades and represents one of the core elements of the wellness generated. The lightweight, high mechanical performance and cheap raw material and production processes made the polymers essential in our lives. On the other hand, being fossil-based with energy harvesting production, the level of emission of the plastic process put high attention on the impact on our ecosystem, without underrating the end of life of the products realised. The unprecedented rate of production and accumulation of plastic products in the natural environment has arisen from the irrational production, indiscriminate use, inadequate recycling, and inappropriate deposal in landfills. According to 2019 data, almost 370 million tons have been produced at a global scale, while only 9% of it being recycled, 12% being incinerated, and the remaining left in the environment or landfills. [43, 44] It is estimated that by 2013 a minimum of 5.25 trillion plastics particles with a weight close to 269,000 tonnes was floating the surface of the world's oceans. [45] Biodegradable and compostable plastics biodegrade in certain conditions, playing a significant role in the reduction of the aforementioned plastic waste pollution.

From this perspective, the urban and industrial plastic/rubber waste (hereinafter referred to as CSS4) can be exploited to produce sustainable insulating materials to increase energy efficiency at affordable costs. Furthermore, the integration of community-based repairing schemes for regenerating small households' appliances with 3D printing and decarbonizing the foaming processes utilizing neutral CO_2 instead of fossil-based blowing agents. The overall circular concept includes the treatment of plastic waste through pyrolysis in order to extract thermal energy, oil, char, and CO_2. Pyrolysis has been researched for decades and has increasingly come to the attention in recent years as a solution for various residual flows, where mechanical recycling offers insufficient relief. Particularly, waste plastics recycle can be challenging to recycle or non-recyclable and chemical recycling must be considered. Pyrolysis enables organic materials chemical decomposition at temperatures ranging from 200ºC to 1000ºC in slightly under pressure conditions and in the absence of O_2. This is utilised for the production of components such as char and syngas, followed by the process of extraction via supercritical CO_2 compressors that uses CO_2 sequestrated at the end of the pyrolysis and the gasification system. For plastic wastes in particular, typical pyrolysis temperatures are around 500ºC. [46] As a result, carbonaceous solid, oil and a gas of varying proportions are produced. Such techniques find many industrial applications, such as in polymer foams, due to the pioneering use of supercritical CO_2 as a physical blowing agent in place of highly polluting chemical agents, combining both climate change mitigation and low-cost benefits. [47] The most common chemical blowing agent is azodicarbonamide (ADCA). Foaming is achieved during ADCA decomposition to yield a gaseous mixture of N_2, CO, CO_2, CHNO and NH_3. [48] Additionally, additives and activators (OBSH, zinc stearate, zinc oxide, urea etc.) can be implemented to lower its decomposition temperature. [49] These can be used in polymer-foamed compounds for low impact insulation biomaterials and 3D printing repairing of household appliances. This solution provides multiple benefits including the energy efficiency increase in social housing blocks, reducing waste to landfill and related environment and sanitary benefits. In parallel, it supports the engagement of citizens in social housing degraded blocks in repairing schemes promoting social cohesion in the communities and solidarity.

3. A potential CE scheme for a Polish region

Circular economy is an approach that has been gaining popularity recently. The CE is perceived as utilising a product continuously by lengthening the product's life through managing its End of Life (EoL) effectively. Such schemes could including the recycling of the product into a new form, and the further management of waste and pollution it may produces. Ideally, this means that a region where a circular model is implemented can function in complete isolation from its surroundings and exploit its resources in a "circular" way in a closed-loop process. This section presents the aims to create closed process loops in the Łódzkie region in the spirit of the circular economy and the estimated impact deriving from each proposed activity.

3.1. Test case: The Łódzkie region

The Łódzkie region (LR) is one of 16 regional self-government authorities in Poland, with most of the major cities of Poland being within a radius of 200 km, and almost all European capital cities being within 1500 km. According to reports and statistical data (**Figure 2**), Łódź is one of the fastest growing cities in Central and Eastern Europe with numerous international investors from Łódź and the region taking an active role in the most important industries including: energy industry, production of household appliances, pharmaceuticals, agri-food processing, production of medical equipment, packaging and construction ceramics. [50]

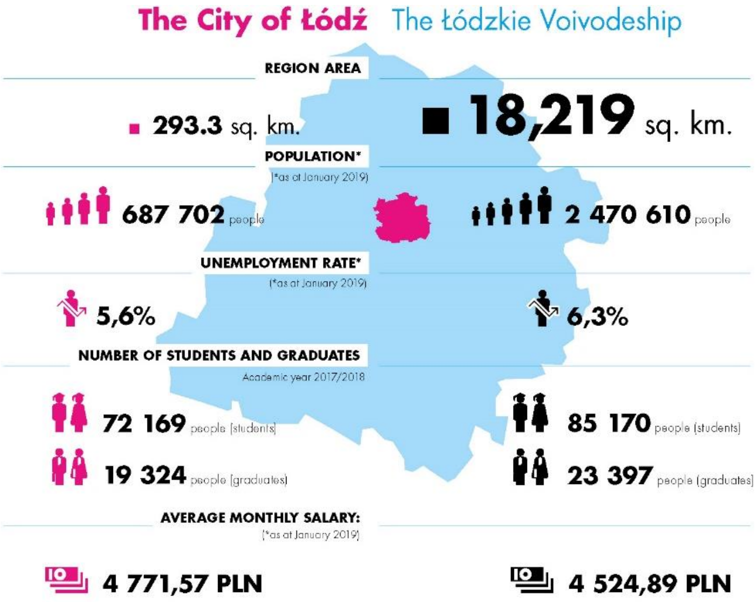

***Figure 2** The Łódzkie region in figures [50]*

The region's location is very important, offering great potential for investors at the national and European level. [51] Along these lines, LR is also implementing several international projects in relation to areas such as circular economy, transition from the carbon-intensive era towards the clean energy future, strategies of water reuse, innovations in SMEs and development of competitive and sustainable economy. Nevertheless, the LR is strongly impacted by a linear model of economic and industrial development, with fossil fuel sources and feedstock. Several environmental challenges have been identified in four main fields including social, land use, water resources as well as the decarbonisation of local economy and built environment. From a social point of view, the LR experience difficulties including demographic and economic migration associated to labour standards, unemployment and poor opportunities for knowledge-based jobs, which contribute to mobility internationally. [51, 52] In addition to that, systemic land use issues are identified with particular reference to agricultural and rural areas including the reduction of soil quality due to intensification of agricultural production, abandonment, afforestation, and desertification of agricultural lands [53] as well as the mining sites contributing to degradation of neighbouring areas. Furthermore, climate change with severe weather events (droughts, water shortages) also combined with mining activities and food industry waste contributes negatively to the lands marginalization and raise a consequent environmental burden. [54] In parallel, the LR faces increasing flooding during rain events, as well as accelerated runoff and water eutrophication. The quality loss of water has led to decreased quality of urban greenery and life in urbanised areas, which consequently has an impact on the expansion of sustainable industrial districts. This issue also contributes to the land use field through the chemical degradation of lands and the loss of biodiversity. [55] Lastly, as highlighted by EU Recommendations in the EU semester for LR, moving away from coal extraction would require additional efforts towards economic diversification, reskilling and upskilling, counteracting depopulation and focusing on revitalization. Most of the buildings are large blocks in the neighbourhoods at the interface between the city and the rural areas. These buildings require a deep and sustainable retrofitting by introducing Renewable Energy Sources (RES) and by reducing energy consumption through upgrading envelope insulation using low embodied energy and circular materials. [56]

3.2. CSS expected impact in regional level

LR has participated and deployed in the last years numerous projects co-financed by the EU, including projects on international scale to deal with the most pressing issues, develop active citizen participation and increase identity with the region. Several studies and publications related to sustainable development and environmental protection have been published providing the context of the Strategy and recommendations for the EU environmental policy including: 1. The Strategy for Responsible Development until 2020 (with the perspective until 2030) and 2. The National Waste Management Plan elaborated in 2014. [57]

The publications were primarily focused on the realization of key principles of the EU environmental policy instruments [58, 59, 60] ,and eventually the research covered issues of sustainable development in Poland, including aspects such as sustainable human resource management, natural resources, sustainable agriculture, effective water and wastewater management; international trade in environmental goods and services and counteracting adverse effects of climate change, including Poland's involvement in the achievement of the UN SDGs. [61, 62, 63, 64, 65, 66, 67, 68] In this frame, the key partnership of the region involved in FrontSH1P research project have extensively analysed region data for adapting a circular approach for managing different types of waste including: wood packaging, food, organic agricultural and municipal waste, sewage, plastic and rubber waste which will pave a path for the LR transition towards climate-neutral economy.

Each type of waste is addressed and treated by a specific CSS, while the integration of all four CSSs into a SCP will allow the decoupling of economic and human activities from the consumption of finite resources and GHG emissions. In specific, it is predicted that, carbon dioxide emissions in the Lodz region could fall by 2%-3%, 100,000 m^2 of water per day would be treated, the amount of wood recovered would be the equivalent of 180,000 pieces of furniture per year and the heat recovered would be 3240 MWh per year. It is estimated that indirectly the new technologies will create hundreds of new jobs in the region. By demonstrating the 4 CSSs, the LR will have a relevant impact at regional and local level first characterised by the utilization of innovative technologies and business and organizational models which facilitates and boost improvement of sustainability in the targeted territorial clusters and relevant sectors as Agriculture, (Bio)Chemical industries, energy, plastics recycling, insulating materials producers, biodegradable products developers, farmers, waste and wastewater management operators. For each CSS the stream of resources is expected to generate a new impulse to the economic growth of the region thanks to the creation of loops of materials transitioning from the concept of waste to be disposed to the concept of by-product that generates revenues and revitalized at the end of life as new feedstock.

In this context, the **CSS1** enables the exploitation of wood packaging to be reused as main material for the production of wooden goods, e.g. in the creation of furniture. A common practice involves wood originating from packaging such as pallets to be discarded after use for some defect or small damage. The reuse of this wood can generate a flux of recovered material up to 4,500 t/y creating jobs opportunities in the creation of furniture at low budget. The valorisation of wood packaging residues not only contributes to waste minimization and all the issues related to its management, as well as the preservation of natural resources and the reduction of GHG emissions, but also for the production of low impact products such as wooden goods, renewable heat, char and CO_2. Moreover, the engagement of citizens in each stage of the valorisation chain is crucial for increasing their awareness on sustainability and circular economy, and indirectly benefitting from the environmental advantages that the CSS will bring.

The valorisation of urban and food industry waste to producing bioenergy, compost and bioplastics is foreseen in the framework of **CSS2**. According to LR data, food production is one of the main regional industries and is responsible for the production of the 22% of the total organic waste in the region. Biomethane that is produced by the anaerobic digestion of OFMSW collection is estimated to produce 10 MNm^3/year of energy by 2030 for the decarbonisation of energy production in combination with 30 kton/y of compost and 1,000 ton/y of new generation compostable bioplastics. In parallel, agricultural land covers more than 48% of the region's area even though more than 0,8Mha in the region are to be considered as abandoned marginal lands. [69] The production of vegetable oils, biodegradable bio-lubricants and animal feed is able to support the agricultural sector and is expected to revitalise 5,000 ha of marginal lands by 2030 increasing soil organic content through compost/biochar application and sustainable agricultural practices. Furthermore, the use of biodegradable and compostable bags can in fact help remove organic waste from landfills, allowing it to be transformed into a valuable resource such as compost, a soil improver and a precious tool for tackling soil degradation.

Accordingly, **CSS3** applies to wastewater and nutrients and creates a closed water cycle to reuse wastewater more than once and to clean it before returning it to the environment. Wastewaters coming from agriculture and industrial processes in the region pollute water stream causing the depletion of the natural ecosystem and by extending the N:P ratio leading to increased acidification of arable land, the biggest contributor of which is intensified nitrogen fertilization. Maintaining extensive P fertilization in Lodzkie voivodships with a significant share of soil with agricultural phosphorus deficit leads to a considerable reduction of soil production potential, since Phosphorus scarcity is becoming a limiting factor for plant and animal production. [70] The CSS3 can provide several benefits in the region agricultural and industrial wastewater treatments with microalgae that will generate a revenue streams through the production of bio-fertilizers and bio-stimulant from algal biomass and will purify wastewater from eutrophication agents. The annual production of wastewater nutrients in the region approximates 360 thousand Mg/ha. The importance of this solution is highlighted given that the Lodzkie region has a substantial problem with chemical degradation of soils due to acidification, loss of organic material, excessive accumulation of heavy metals and organic xenobiotics. Accordingly, the solution provides high replicability potential for EU regions devoted to agriculture terms of eutrophication of water and soil depletion.

Lastly, **CSS4** aims to extending product lifetimes based on urban and industrial plastic and rubber through 3D Printing and repair. The impact of this solution to reduce plastics waste stream in LR is estimated up to 50% by 2030 focalizing on the use of additive manufacturing (AM) as innovative and fast solution for easy repair of plastic based consumer goods and components providing a longer lifetime and creating a new market. The utilisation of 3D printing will act as an enabler to the loops and cycles of maintenance, reuse, repair and remanufacture, extending product lifetimes and cycles. 3D printing with recycled materials will also challenge innovators and fosters business activities within social housing districts as makers villages to generate ways to reuse and ultimately develop systems that cascade other wasted and lost value. 3D printing can act as a tool for education and exploration aiding the transition towards a circular economy. In addition, a circular approach for valorising and reusing plastic waste to acoustic and thermal insulation foamed applications is included thanks to the possibility to utilize the scrap and end of life product making them new feedstock for polymer value chain. This will generate a virtuous loop that will tend to eliminate scrap and land fill waste as well as decarbonise the industrial process of approximately 150.000 ton/year of equivalent CO_2.

Overall, the transition of the LR towards sustainable development and climate neutrality through the SCP approach is achieved by supporting the transition from fossil fuels to circular syngas coming from wood waste for heating purposes, (CSS1) in combination with envelope retrofitting using sustainable insulating panels from captured CO_2 bio oils and bio char (CSS4). This synergy can enable a reduction of the GHG burden by 60% and the cost of energy by 50% compared to commonly used fossil fuels [71], contributing in lowering the number of energy-pours by 30% by 2030 in line with the European plan. [72] In addition to that, the environmental impact is improved by substituting fossil-based oils with circular biodegradable bio-lubricants (CSS2) to be applied as dielectric fluids and hydraulic oils will help in the decarbonisation of the industrial and agricultural sector reducing GHG by 64% [73] against mineral lubricants while increasing the resilience of LR agricultural sector thorough the revitalization of marginal lands for low input oil crops cultivation, increasing the occupation of young farmers in the area with potential to generate by 2030 up to 12M€/y of incomes for the sector. In parallel the enhancement of existing technological solutions (circular product of CSS1) will guide the substitution of Char to avoid the use of energy and chemicals for the production of fillers in thermal insulation materials (CSS4). This will avoid the direct emission in the atmosphere of 2,480t of CO_2 /y and will support the refurbishment and transformation of social housing degraded blocks increasing thermal performances and contrasting energy poverty. With regard to the collection and valorisation of OFMSW (diverted from landfilling) collected through compostable bags (CSS2) obtained from regional industrial waste support the prevention of releasing GHG emissions up to 49 tons of CO_2eq/ton compostable bags. In terms of chemical degradation of soil and water stress in the LR, the substitution of common fertilizers with circular ones is estimated to lower the GHG by 87%, the eutrophication of the waters by 92% and almost totally the chemical degradation of soils. Accordingly, the reduction of the blue and green water impacts working on the depuration of waste waters from agriculture and industry will contribute in closing the water cycle and recovering the 90% of the wastewaters (CSS3). Moreover, thanks to the microalgal depuration system the energy for wastewater treatments is 0.20 kWh m^{-3} lower than traditional methodologies. Therefore, the increased circular and climate-neutral practices will contribute in raising environmental awareness among citizens and promote their participation in systemic solutions.

4. Conclusions

Challenges which lead to adverse climate changes on our planet reflect on significant policy targets and objectives at the global and European levels requiring effective joint actions to counteract their effects. The transition circularity raises great opportunities for Europe and its citizens to transform and shift the economy towards a more sustainable direction. The identification and exploitation of CSSs at regional and European level provides numerous benefits and positive results for the environment in relation to improved sustainability and circularity of clusters' economic sectors, natural ecosystems, management and valorisation of local resources. In this study, four flexible and modular circular systemic solutions toward an inclusive and resilient climate-neutral and systemic circular (bio)economy transition are presented and will be demonstrated in the framework of the "FrontSH1P" project in the Lodzkie Region. The solutions are key enablers of a systemic circular model that fosters territorial deployment along five key elements: 1) multi-stakeholders, participatory community-based innovation schemes; 2) circular governance and business models for high replicability and scalability potential; 3) holistic economic, social and environmental assessment; 4) knowledge transfer and dissemination; 5) digital platform and methodology for data collection and sharing within GDPR and open data compliant frameworks, allowing transparent quantification of economic, social and environmental aspects and the benefits of the effective territorial circular business solutions in the fields of gasification process chain for waste wood valorisation, biodegradable and compostable eco-designed bio-products, nutrients recovery from wastewaters and plastic and rubber recovery. The synergy of these solutions prepares the ground for a sustainable circular economy which will be reflected in delivering important energy savings and environmental benefits for the region and creating local jobs and opportunities for social integration. Hence, it is closely interlinked with key EU priorities on jobs and growth, investments, the social agenda and industrial innovation.

Acknowledgments

This research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 101037031, project 'A FRONTrunner approacTransition to a circular & resilient future: deployment of systemic solutions with the support of local clusters and the development of regional community-based innovation schemes (FRONTSH1P)'

References

1. Delivering the European Green Deal: European commission; [cited 15/04/2022]. Available from: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en
2. Ensure sustainable consumption and production patterns: Eurostat; 2021 [cited 15/04/2022]. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=SDG_12_-_Responsible_consumption_and_production
3. Responsible consumption and production: European commission; [cited 15/04/2022]. Available from: https://ec.europa.eu/international-partnerships/sdg/responsible-consumption-and-production_en
4. Goal 12: Ensure sustainable consumption and production patterns: United Nations; [15/04/2022]. Available from: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/
5. Rosen MA. Energy Sustainability with a Focus on Environmental Perspectives. Earth Systems and Environment. 2021 2021/06/01;5(2):217-230. doi: 10.1007/s41748-021-00217-6.
6. Total energy consumption: Enerdata; 2021. Available from: https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html
7. Regional Challenges in the Perspective of 2020 – Phase 2: Deepening and Broadening the Analysis: European Commission; [cited 15/04/2022]. Available from: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/region2020_phase2/challenge2020_report.pdf
8. Human society under urgent threat from loss of Earth's natural life: The Guardian; 2019 [cited 15/04/2022]. Available from: https://www.theguardian.com/environment/2019/may/06/human-society-under-urgent-threat-loss-earth-natural-life-un-report
9. Glavič P. Evolution and Current Challenges of Sustainable Consumption and Production. 2021;13(16):9379. PubMed PMID: doi:10.3390/su13169379.
10. Staniškis JK. Sustainable consumption and production: how to make it possible. Clean Technologies and Environmental Policy. 2012 2012/12/01;14(6):1015-1022. doi: 10.1007/s10098-012-0535-9.
11. Ding Q, Khattak SI, Ahmad M. Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations. Sustainable Production and Consumption. 2021 2021/07/01/;27:254-268. doi: https://doi.org/10.1016/j.spc.2020.11.004.
12. Aguilar-Hernandez GA, Dias Rodrigues JF, Tukker A. Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies. Journal of Cleaner Production. 2021 2021/01/01/;278:123421. doi: https://doi.org/10.1016/j.jclepro.2020.123421.
13. Pieroni MPP, McAloone TC, Pigosso DCA. Circular economy business model innovation: Sectorial patterns within manufacturing companies. Journal of Cleaner Production. 2021 2021/03/01/;286:124921. doi: https://doi.org/10.1016/j.jclepro.2020.124921.
14. Tseng M-L, Chiu ASF, Liang D. Sustainable consumption and production in business decision-making models. Resources, Conservation and Recycling. 2018 2018/01/01/;128:118-121. doi: https://doi.org/10.1016/j.resconrec.2017.02.014.
15. Ofstad SWLBTNMvSoSC, editor Symposium: sustainable consumption1994 19-20 January 1994; Oslo, Norway: Ministry of Environment.
16. Sustainable Production Defined: Umass Lowell; [cited 15/04/2022]. Available from: https://www.uml.edu/Research/Lowell-Center/About/Sustainable-Production-Defined.aspx
17. Goyal S, Garg D, Luthra S. Analyzing critical success factors to adopt sustainable consumption and production linked with circular economy. Environment, Development and Sustainability. 2022 2022/04/01;24(4):5195-5224. doi: 10.1007/s10668-021-01655-y.

18. Tseng M-L, Chiu ASF, Liu G, et al. Circular economy enables sustainable consumption and production in multi-level supply chain system. Resources, Conservation and Recycling. 2020 2020/03/01/;154:104601. doi: https://doi.org/10.1016/j.resconrec.2019.104601.
19. Witjes S, Lozano R. Towards a more Circular Economy : Proposing a framework linking sustainable public procurement and sustainable business models. "Resources, Conservation & Recycling". 2016 09/01;112:37-44. doi: 10.1016/j.resconrec.2016.04.015.
20. FRONTSH1P-A FRONTrunner approach to Systemic circular, Holistic & Inclusive solutions for a new Paradigm of territorial circular economy: Frontsh1p; [cited 15/04/2022]. Available from: https://frontsh1p.eu/
21. Circular Economy and Health: Opportunities and Risks: World Health Organization; [cited 15/04/2022]. Available from: https://www.euro.who.int/__data/assets/pdf_file/0004/374917/Circular-Economy_EN_WHO_web_august-2018.pdf
22. Son Y-I, Yoon SJ, Kim YK, et al. Gasification and power generation characteristics of woody biomass utilizing a downdraft gasifier. 2011;35(10):4215-4220.
23. Benedetti V, Patuzzi F, Baratieri M. Characterization of char from biomass gasification and its similarities with activated carbon in adsorption applications. Applied Energy. 2018 2018/10/01/;227:92-99. doi: https://doi.org/10.1016/j.apenergy.2017.08.076.
24. Bansode A, Urakawa A. Towards full one-pass conversion of carbon dioxide to methanol and methanol-derived products. Journal of Catalysis. 2014 2014/01/01/;309:66-70. doi: https://doi.org/10.1016/j.jcat.2013.09.005.
25. Patuzzi F, Prando D, Vakalis S, et al. Small-scale biomass gasification CHP systems: Comparative performance assessment and monitoring experiences in South Tyrol (Italy). Energy. 2016 2016/10/01/;112:285-293. doi: https://doi.org/10.1016/j.energy.2016.06.077.
26. Pleissner D, Lin CSK. Valorisation of food waste in biotechnological processes. Sustainable Chemical Processes. 2013 2013/10/24;1(1):21. doi: 10.1186/2043-7129-1-21.
27. Ribeiro TB, Voss GB, Coelho MC, et al. Chapter 33 - Food waste and by-product valorization as an integrated approach with zero waste: Future challenges. In: Bhat R, editor. Future Foods: Academic Press; 2022. p. 569-596.
28. Meghwal M, Desai H, Baisya S, et al. Valorization of Waste Cooking Oil into Biodiesel, Biolubricants, and Other Products. Biotechnology for Zero Waste2022. p. 507-520.
29. Tsang YF, Kumar V, Samadar P, et al. Production of bioplastic through food waste valorization. Environment International. 2019 2019/06/01/;127:625-644. doi: https://doi.org/10.1016/j.envint.2019.03.076.
30. Şahin S, Elhussein EAA. Valorization of a biomass: phytochemicals in oilseed by-products. Phytochemistry Reviews. 2018 2018/08/01;17(4):657-668. doi: 10.1007/s11101-018-9552-6.
31. Cecilia JA, García Sancho C, Maireles-Torres P, et al. Industrial Food Waste Valorization: A General Overview. 2019. p. 253-277.
32. Salih N, Salimon J. A Review on Eco-Friendly Green Biolubricants from Renewable and Sustainable Plant Oil Sources. Biointerface Research in Applied Chemistry. 2021 2021/02/08;11(5):13303-13327. doi: 10.33263/briac115.1330313327.
33. Freshwater Crisis: National geographic; [cited 18/04/2022]. Available from: https://www.nationalgeographic.com/environment/article/freshwater-crisis
34. Ryder G. Wastewater: the untapped resource. Paris 07 SP, France: Unesco; 2017. English. (Programme) WUNWWA, editor. The United Nations world water development report, 2017).
35. The challenge of wastewater treatment around the world: Bio-sol; 2021 [cited 18/04/2022]. Available from: https://www.bio-sol.ca/blog/en/the-challenge-of-wastewater-treatment-around-the-world/
36. Gupta S, Pawar SB, Pandey RA. Current practices and challenges in using microalgae for treatment of nutrient rich wastewater from agro-based industries. Science of The Total Environment. 2019 2019/10/15/;687:1107-1126. doi: https://doi.org/10.1016/j.scitotenv.2019.06.115.
37. Ting H, Haifeng L, Shanshan M, et al. Progress in microalgae cultivation photobioreactors and applications in wastewater treatment: A review. International Journal of Agricultural and Biological Engineering. 2017;10(1):1-29. doi: 10.3965/j.ijabe.20171001.2705.
38. Miyawaki B, Mariano AB, Vargas JVC, et al. Microalgae derived biomass and bioenergy production enhancement through biogas purification and wastewater treatment. Renewable Energy. 2021 2021/01/01/;163:1153-1165. doi: https://doi.org/10.1016/j.renene.2020.09.045.
39. Al-Qasmi M, Raut N, Talebi S, et al. A Review of Effect of Light on Microalgae Growth. Vol. 1. 2012.
40. Gupta PL, Lee S-M, Choi H-J. A mini review: photobioreactors for large scale algal cultivation. World Journal of Microbiology and Biotechnology. 2015 2015/09/01;31(9):1409-1417. doi: 10.1007/s11274-015-1892-4.
41. Sirohi R, Kumar Pandey A, Ranganathan P, et al. Design and applications of photobioreactors- a review. Bioresource Technology. 2022 2022/04/01/;349:126858. doi: https://doi.org/10.1016/j.biortech.2022.126858.
42. Saxena G, Kishor R, Saratale GD, et al. Genetically Modified Organisms (GMOs) and Their Potential in Environmental Management: Constraints, Prospects, and Challenges. In: Bharagava RN, Saxena G, editors. Bioremediation of Industrial Waste for Environmental Safety: Volume II: Biological Agents and Methods for Industrial Waste Management. Singapore: Springer Singapore; 2020. p. 1-19.

43. Kumar R, Verma A, Shome A, et al. Impacts of Plastic Pollution on Ecosystem Services, Sustainable Development Goals, and Need to Focus on Circular Economy and Policy Interventions. 2021;13(17):9963. PubMed PMID: doi:10.3390/su13179963.
44. Enabling a sustainable future: Plastics Europe; [cited 18/04/2022]. Available from: https://plasticseurope.org/
45. Ciriminna R, Pagliaro M. Biodegradable and Compostable Plastics: A Critical Perspective on the Dawn of their Global Adoption. 2020;9(1):8-13. doi: https://doi.org/10.1002/open.201900272.
46. Anuar Sharuddin SD, Abnisa F, Wan Daud WMA, et al. A review on pyrolysis of plastic wastes. Energy Conversion and Management. 2016 2016/05/01/;115:308-326. doi: https://doi.org/10.1016/j.enconman.2016.02.037.
47. Li B, Zhao G, Wang G, et al. Biodegradable PLA/PBS open-cell foam fabricated by supercritical CO2 foaming for selective oil-adsorption. Separation and Purification Technology. 2021 2021/02/15/;257:117949. doi: https://doi.org/10.1016/j.seppur.2020.117949.
48. Hopmann C, Lemke F, Nguyen Binh Q. Foaming of EPDM with water as blowing agent in injection molding. 2016;133(27). doi: https://doi.org/10.1002/app.43613.
49. Maciejewska M, Sowińska A, Grocholewicz A. Zinc Complexes with 1,3-Diketones as Activators for Sulfur Vulcanization of Styrene-Butadiene Elastomer Filled with Carbon Black. 2021;14(14):3804. PubMed PMID: doi:10.3390/ma14143804.
50. Lodzkie: Polish Investment & Trade agency; 2021 [updated December 2021; cited 18/04/2022]. Available from: https://www.paih.gov.pl/regiony/wojewodztwa/lodzkie#
51. Szukalski P, Martinez-Fernandez C, Weyman T. Lódzkie Region: Demographic Challenges Within an Ideal Location. 2013. doi: doi:https://doi.org/10.1787/5k4818gt720p-en.
52. Grabowska I, Śliwowski P. Cutting the Gordian knot of families' exclusion in poor neighborhoods.

Policy lessons from qualitative research on excluded families – the case study of the Łódź

Municipality in Poland European Population Conference 2016 (EPC2016). 2015 (POLICY ISSUES).
53. Bergstrom JCGSJSJS. Land Use Problems and Conflicts : Causes, Consequences and Solutions. London: Routledge; 2009. English.
54. Niewiadomski A, Tołoczko W. Characteristics of soil cover in Poland with special attention paid to the Łódź region. Natural environment of Poland its protection in Łódź Łódź: Łódź University; 2014. p. 75-99.
55. Krauze K, Włodarczyk-Marciniak R. Defining the risk to water and natural capital in cities with risk component analysis tool (DAPSET): Case study Łódź. Journal of environmental management. 2018 Dec 1;227:62-72. doi: 10.1016/j.jenvman.2018.08.081. PubMed PMID: 30172160; eng.
56. Bouzarovski S, Tirado Herrero S. Geographies of injustice: the socio-spatial determinants of energy poverty in Poland, the Czech Republic and Hungary. Post-Communist Economies. 2017 2017/01/02;29(1):27-50. doi: 10.1080/14631377.2016.1242257.
57. Wysokińska Z. Wdrażanie głównych zasad gospodarki o obiegu zamkniętym w koncepcji zrównoważonego rozwoju w gospodarce światowej i europejskiej, ze szczególnym uwzględnieniem krajów Europy Środkowo-Wschodniej – przypadek Polski i regionu łódzkiego. Comparative Economic Research Central and Eastern Europe. 2018 09/18;21(3):75-93. doi: 10.2478/cer-2018-0020.
58. Fiedor B, Czaja S, Graczyk A, et al. Podstawy ekonomii środowiska i zasobów naturalnych. Vol. I. Warszawa : C. H. Beck; 2002. pol.
59. Fiedor B, Graczyk A. Instrumenty ekonomiczne polityki ekologicznej. Wydawnictwo Ekonomia i Środowisko, Białystok. 2006.
60. Wysokińska Z. Integracja europejska : dostosowania w Polsce w dziedzinie polityk. Warszawa : Polskie Wydawn. Ekonomiczne; 2004. pol. (Witkowska J, editor.).
61. Borys T. Nowe kierunki ekonomii środowiska i zasobów naturalnych w aspekcie nowej perspektywy finansowej Unii Europejskiej. Ekonomia i Środowisko. 2013 (1 (44)).
62. Burchard-Dziubińska M. Towards a green economy : from ideas to practice. Łódź: Wydawnictwo Uniwersytetu Łódzkiego; 2015. English.
63. Lipińska D. Gospodarka odpadowa i wodno-ściekowa. Wydawnictwo uniwersytetu łódzkiego; 2016.
64. Wysokińska Z, Witkowska J. Zrównoważony rozwój. Wybrane aspekty makro i mikroekonomiczne [Sustainable development. Selected macro and microeconomic aspects]. Łódź: Wydawnictwo Uniwesytetu Łódzkiego; 2016.
65. Wysokińska Z. The "New" Environmental Policy Of The European Union: A Path To Development Of A Circular Economy And Mitigation Of The Negative Effects Of Climate Change. Comparative Economic Research Central and Eastern Europe. 2016 06/30;19(2):57-73. doi: 10.1515/cer-2016-0013.
66. Grzesik M, Romanowska-Duda ZB. Ability of Cyanobacteria and Green Algae to Improve Metabolic Activity and Development of Willow Plants [journal article %J Polish Journal of Environmental Studies]. 2015;24(3):1003-1012. doi: 10.15244/pjoes/34667.
67. Grzesik M, Górnik K, Janas R, et al. High efficiency stratification of apple cultivar Ligol seed dormancy by phytohormones, heat shock and pulsed radio frequency. Journal of Plant Physiology. 2017 2017/12/01/;219:81-90. doi: https://doi.org/10.1016/j.jplph.2017.09.007.

68. Wysokińska Z. Millenium Development Goals/UN And Sustainable Development Goals/UN As Instruments For Realising Sustainable Development Concept In The Global Economy. Comparative Economic Research. 2017 03/01;20(1):101-118. doi: 10.1515/cer-2017-0006.
69. Krysiak S, Papińska E, Majchrowska A, et al. Detecting Land Abandonment in Łódź Voivodeship Using Convolutional Neural Networks. 2020;9(3):82. PubMed PMID: doi:10.3390/land9030082.
70. Kopiński J, Jurga B. Managing Phosphorus in Polish Agriculture – Production and Environmental Aspects [journal article %J Polish Journal of Environmental Studies]. 2016;25(6):2461-2468. doi: 10.15244/pjoes/64159.
71. Basu P. Biomass gasification, pyrolysis and torrefaction : practical design and theory. 2018. English.
72. Bocquillon P, Maltby T. EU energy policy integration as embedded intergovernmentalism: the case of Energy Union governance. Journal of European Integration. 2020 2020/01/02;42(1):39-57. doi: 10.1080/07036337.2019.1708339.
73. Cuevas P. Comparative Life Cycle Assessment of Biolubricants and Mineral Based Lubricants [Master's Thesis]: University of pittsburgh ETD; 2010.