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Review

Waste management challenges in transition to circular economy – Case of Croatia

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A R T I C L E I N F O

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A B S T R A C T

Despite the obligations assumed by Croatian accession to the European Union in 2013, municipal waste still mainly ends at landfills, even in regions where significant investments were made in waste management centres based on mechanical-biological treatment, and in which mixed waste is collected and processed into refuse-derived fuel and disposed at so-called bioreactor landfills. Waste management sector in Croatia necessitates substantial restructuring if it is to achieve compliance with circular economy. Since Croatia is far from achieving specific targets, in 2016 an attempt was made to adopt a strategic waste management document that would have paved the way to reaching circular economy targets, but its contents were substantially modified in course of its adoption, preserving the concept devised a decade and half ago. The paper presents waste and circularity indicators for Croatia, analyses national policies, targets, achievements and EU recommendations, and proposes the measures which would accelerate Croatia's path towards circular economy, resource efficiency, reduction of marine litter in the Adriatic and bio economy. The model is applicable to other countries in transition and those which still rely on landfilling and linear economy concept.

Contents

1. Introduction

The volume and complexity of waste associated with modern economy poses serious risk to ecosystems and human health. Every year, an estimated 11.2 billion t of solid waste is collected worldwide and decay of the organic proportion of solid waste is contributing about 5 per cent of global greenhouse gas emissions (UNEP, 2019). Even though municipal waste only represents about 10% in weight of the total waste generated or about 30% of the generated amount of waste excluding major mineral wastes (mainly arising from mining and construction), following up on its evolution can give a good indication of changing consumption

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patterns, national waste prevention performance and where citizens' actions and involvement is most relevant (EC, 2018a).

Circular economy (hereinafter: CE) which implies waste prevention, reuse, and recycling, or upper tiers of waste hierarchy, directly contribute to clean production because of less overall waste produced and discarded from both manufacturing and raw material processing. Furthermore, as many as six Sustainable Development Goals (hereinafter: SDG) (UN, 2019) are related to solid waste management: Quality education (SDG 4) in the sense of equal access to technical, vocational and tertiary education with the focus on circular economy, systems thinking, design for circularity, entrepreneurship and innovation, Decent work and economic growth (SDG 8), Industry, innovation and infrastructure (SDG 9), Sustainable cities and communities (SDG 11), Sustainable consumption and production (SDG 12) and Partnerships for the goals (SDG 17).

The concept of a circular economy is thus a powerful bridging concept to foster the fundamental links among resource use, waste, and emissions, and to contribute to integrating environmental (output-related) and economic (input-related) policies (Mayer et al., 2019). In 2015 the European Commission adopted its action plan (EC, 2015a) aimed at accelerating transition of the EU towards circular economy, boosting global competitiveness, promoting sustainable economic growth and generating new jobs. The plan supports circular economy in each step of the value chain – from production to consumption, repair and manufacturing, waste management and secondary raw materials that are fed back into the economy (EC, 2018a). Greater recycling and reuse are the main actions contributing to closing the loop. The Republic of Croatia made its accession to the EU in 2013, assuming considerable environmental commitments, particularly in the sector of municipal waste. In spite of substantial investments in the sector made during the last decade, modest progress has been achieved so far, that being reflected by the values of circular economy indicators.

The purpose of this paper is to propose waste management model for the Republic of Croatia, that is integrated at the national level, sustainable, and compliant with circular economy principles as well as European Union recommendations and requirements. Elements of proposed concept were enshrined in a proposal of national waste management plan (MENP, 2016) in whose drafting the author was personally involved. The draft underwent public consultation, got necessary approvals by stakeholders, but was not adopted by the Government. The measures that the concept implies would facilitate the achievement of defined targets and obligations in an accelerated manner and also the implementation of circular economy. It is innovative in the sense that all national strategic documents to date have been based on a linear concept and focused on mixed waste and bottom tiers of waste hierarchy. The departure from such a mainstream had to date been undertaken only by few municipalities, which were either confronted with shortage of landfilling space or which timely understood that their budgets and citizens would sooner or later face booming prices of waste disposal.

The paper also presents the analysis of drivers for current underperformance with regard to municipal waste management in the Republic of Croatia. It reviews waste management policies adopted to date, current status and country-specific features. Particular accent is placed on marine litter since Croatia has a very long indented coast on the semi-enclosed Adriatic Sea and is highly oriented to tourism. The potential of biowaste and bioeconomy in packaging sector, both of which contribute to compliance with waste hierarchy is elaborated as well.

Given holistic focus of the topic, the author applied qualitative research based on direct observations, author' previous research and experiences, official documents from different levels of authorities, literature surveys and the reports on current research on the subject, with an emphasis on the Republic of Croatia.

Following introduction, review of the state of the art in research is provided in second chapter. The third chapter presents waste and circularity indicators for Croatia, while the fourth chapter analyses national policies, targets and achievements. The fifth chapter which presents an overview of EU recommendations is followed by the proposal for achieving circular economy targets in Croatia through implementing advanced sustainable waste management approach. Last two chapters deal with marine litter and packaging waste, both of which have the potential for significant improvement through introducing proposed concept.

2. State of the art

In early seventies in Europe, priority objective of removing waste from urban spaces in the interest of public hygiene was succeeded by environmental protection objective. By the end of seventies and early eighties, the production of enormous quantities of waste commanded for the provision of appropriate capacity. Prevention and closed material circles started in the nineties (Massarutto, 2006). In Croatia, where communal services in a number of towns have long tradition (Runko Luttenberger, 2011), the transition period and globalization in early nineties resulted in huge demand for solving the problem of increasing quantities of mainly packaging waste. Professional and scientific debate concerning various options available in waste management, such as waste incineration, landfilling, mechanical-biological treatment (hereinafter: MBT), source separation, recycling and composting pursued societal and technical demands described above.

Any research for optimum solution in municipal waste management obviously has to take into consideration prevailing local features. Namely, hardly any local arrangement is fully applicable for another site, regardless of possible geographical proximity. Another characteristic of scientific research to date is that it has been more concentrated on hardware and its technical aspects, than on organizational issues of waste management. Such software aspect was then often elaborated by practitioners in the field and environmental non-governmental organizations.

The life cycle thinking (hereinafter: LCT) concept and quantitative tools such as life-cycle assessment (hereinafter: LCA) can provide an informed and science-based support to a more environmentally sustainable decision-making in waste management. Unfortunately, when LTC/LCA are applied to waste management services, typically the assessments focus on a comparison of different waste management options, not covering the entire life cycle of a product, in which waste management may play only a minor role (JRC EC, 2011).

Also, the extent of the involvement of public and private sectors in waste management that varies across the states deserves exploration in terms of the effects on contract structures, costs, and the reasons why the different sectors play their different roles as frequently neither private nor external costs and benefits are well characterized (Hogg, 2002). Municipal solid waste (hereinafter: MSW) management solutions must be financially sustainable, technically feasible, socially, legally acceptable and environmentally friendly. Solid waste issue presents the biggest challenge for the authorities in both small and large cities (Abdel-Shafy and Mansour, 2018).

The research concerning municipal waste management very often compares different options of dealing with waste, presenting their advantages and shortcomings, as briefly analysed hereinbelow. The first to be addressed here is MBT because such an option has been pursued in the Republic of Croatia ever since the nineties. Mechanical biological treatment of waste, also known as

biomechanical treatment, is a form of pre-treatment of residual municipal waste consisting of a group of solid waste treatment systems. Most facilities use a combination of mechanical processes, such as shredding, metals recovery, sorting and biological treatment. The biological processes consist of aerobic and anaerobic degradation of the organic fraction. MBT grew in popularity as a result of the EU requirement to reduce the amount of biodegradable waste. This pre-treatment method was supposed to reduce the mass and volume of waste to be landfilled (DWMA, 2017).

One of the products of MBT is unclean compost which contains elevated levels of heavy metals, pieces of plastics, metals and other unwanted fractions unsuitable for land use. The advantages of MBT are that it reduces volumes destined for landfill, stabilizes organic fractions, reduces atmospheric emissions from landfills, and the plants have easily adaptable technologies for future transformation into quality composting plants, that is for the transition phase. However, through MBT organic faction is disposed in landfill. Another product of MBT is refuse-derived fuel (hereinafter: RDF) which is difficult to sell for burning. MBT is after all a disposal option (Newman, 2009). Treatment in the MBT plant with incineration of RDF in the waste-to-energy plant compared to incineration in new waste-to-energy plant show that the scenario with lower overall environmental impact is MBT with incineration (Grzesik, 2018). Such analyses should obviously account for all externalities.

Separate collection on the other hand is labour intensive but has low capital costs. Systems based on recycled production plus recycling offer substantial system-wide or life-cycle environmental advantages over systems based on virgin production plus either incineration or landfilling. Early opponents included solid waste officials who were resistant to change, and trash haulers and incinerator operators who resented the new competition (Denison, 1996). The municipal costs for collection and treatment of waste are reduced with increasing recycling, mainly because high costs for incineration are avoided. However, solutions for mitigation of air pollution caused by increased collection and transport should be sought (Larsen et al., 2010).

Biowaste, according to Waste Framework Directive (EU, 2008), includes garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises as well as comparable waste from food processing plants. It does not cover forestry or agricultural residue. Biowaste should not be confused with the broader category of biodegradable waste. Biodegradable waste, as defined by the Landfill Directive, includes any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard. One of the main drivers detected during the study for improving management of biowaste is the combination of efficient and effective political, economic and legal programs, which leads to efficient use of resources as well as environmental protection. Energy recovery is then mainly oriented at improving the efficiency of the whole management system rather than as a priority to be pursued in waste management (Kumar Ghosh and Di Maria, 2018). Once the goods become trash, burning them in an incinerator destroys those resources for good. Recycling most materials from municipal solid waste saves on average three to five times more energy than does burning them for electricity (Morris, 1996). Countries with the highest rates of garbage incineration all incinerate at least 50 percent of their waste, but they also tend to have high rates of recycling and composting of organic materials and food waste. Were it not for large-scale incineration, the environmentally conscious countries would have even higher rates of recycling. Major problem with incineration is the long-term contracts that waste-to-energy plants sign with the cities that supply them with trash as incinerator operators need a guaranteed stream of waste since incinerators are extremely expensive to build. Committing too much trash to incineration too soon by instituting landfill bans results in competing with incineration for the available waste (Yale Environment, 2013).

Furthermore, for many materials in the household and business waste streams the release of carbon pollution from burning wastes for energy is more environmentally damaging than storing their carbon in modern landfills. In other words, it often is better to use more efficient fuels to generate energy in order to maintain storage of carbon already sequestered in waste materials. The LCA study shows that burning wood wastes to produce electricity and/or heat as a substitute for natural gas fuel is more environmentally harmful than burying wood in a landfill with a landfill gas collection system. Recycling into reconstituted wood products or papermaking pulp is environmentally best when those options are available (Morris, 2016). On the other hand, there is research that discusses the role of energy recovery of waste in the circular economy and closing the loop concept (Tomić, 2019).

When confronting incineration and landfilling, the experts advocating incineration ascribe it the advantages of land conservation and preservation of non-renewable resources, and claim that carbon emitted is roughly equal, but only a third of the carbon in the waste is fossil-based, so fewer non-renewable resources are used. However, incineration converts less than 25% of material energy in garbage into marketed electricity compared with about 35% for coal and as much as 45% of some natural-gas systems. Even landfill methane burns with about 35% efficiency. Waste-to-energy plants require costly air-pollution controls to reduce emissions of hazardous metals and chemicals. Incineration inhibits recycling and composting efforts (Scientific American, 2011). According to the U.S. EPA, landfills are the third-largest source of methane in the US, behind industry and agriculture (Yale Environment, 2013).

Given that the transition to circular economy is a necessity for achieving resilience and resource efficiency, focusing on the case of Croatia is of particular interest precisely because its delay to implement any particular waste management policy overlapped with substantial policy and regulatory changes at the level of the European Union based on its Circular Economy Package. Such a transition from a failed model of landfilling and wasting precious resources should be simpler and less costly than was the case for countries that through the years made significant investments in waste management infrastructure described above and which, being linear, have not complied with now prevailing circular economy principles and waste hierarchy. However, official policy in Croatia is by inertia still on the path of an outdated option, as analysed in chapter 4, together with evidences of that failure presented in chapters 3 through 5. The transition proposal at national level presented in chapter 6 can hardly have alternatives which would be compliant with acquis Communautaire, regulations in force and sustainability principles. Obviously, solutions at the levels of communities could vary, but always within the limits of acceptable by legal, ecological, health and economic criteria.

3. Waste and circularity indicators for Croatia

Circular economy is an umbrella concept incorporating different meanings, but despite different types circular economy strategies can be grouped according to their attempt to preserve functions, products, components, materials, or embodied energy (Moraga et al., 2019). Macro scale indicators proposed by EU in its 'CE monitoring framework' (EC, 2018d) involve 10 indicators divided into four thematic areas: production and consumption, waste management, secondary raw materials, as well as competitiveness and innovation. Eight indicators form the CE monitoring framework are present in other European frameworks and are not unique

to CE. The other indicators are under development: 'Food waste' and 'Green public procurement'. The measurement of food waste was foreseen in the revision of the EU Waste Directive (EC, 2015b) while for Green public procurement (hereinafter: GPP), data are still unavailable. Significance of GPP for CE may depend on the inclusion of relevant requirement (e.g. reparability, durability, and recyclability) in public contracts and procurements. Both indicators are also in the scope of the Sustainable Development Goals for responsible consumption and production (Moraga et al., 2019).

Table 1 shows the comparison of available 'CE monitoring framework' indicators that are associated with municipal waste, for Croatia, EU-28, Italy, Germany, Hungary, and Austria. Countries selected either are in the vicinity or have achievements that Croatia should strive for in an accelerated manner. Also shown are the values of best achievements. Specific waste streams considered are overall packaging, plastic packaging, biowaste, and construction and demolition waste.

Total quantity of municipal waste produced annually in the Republic of Croatia in 2017 was 1.7 million tons (HAOP, 2018). Generated municipal waste per capita of 416 kg is lower than EU average and other countries considered, except Hungary. The highest value of 781 kg is for Denmark and the lowest of 272 kg for Romania (Eurostat, 2019).

However, generation of waste per GDP unit in Croatia is higher, except for Hungary. This indicator reflects the waste intensity of the economy, providing a measure of "eco-efficiency", or shows that level of decoupling of waste generation from GDP growth. The lowest value of 24 kg per thousand euro is achieved by Norway (Eurostat, 2019).

Generation of waste per domestic material consumption (DMC) for Croatia is the lowest among the states considered and EU-28 average. The indicator serves as a material efficiency indicator by comparing the quantity of waste generated to DMC. The smaller the value of the ratio, the better the performance. DMC provides a basis for policies to decouple the growth of the economy from the use of natural resources. However, DMC is defined as the total amount of materials directly used in the economy (used domestic extraction plus imports), minus the materials that are exported. Also, the ratio is strongly influenced by the non-metallic mineral component of DMC intensively used in the construction sector. Croatia for instance, being located on a vast karst territory, exploits limestone, as well as marl for cement industry and gravel. The more complex the material mix of a manufactured product, the more critical its attribution to a "dominant" material category (UN, 2007). Thus, low indicator value could be the result of relatively low production of municipal waste generated, divided by DMC. The lowest values in EU are achieved by Romania (4.7%) and Norway (5.6%).

Recycling rate of municipal waste which provides a good indication of the quality of the overall waste management system is significantly lower for Croatia than for other countries and is half of that achieved by EU. Germany has the highest recycling rate (67.6%). Recycling waste of overall packaging is also the lowest. In EU, Belgium achieved the highest rate (83.6%). Recycling waste of plastic packaging is lower than EU average, Italy and Germany. Lithuania reached the highest plastic packaging recycling rate of 74.2%.

Recycling of biowaste per capita for Croatia in 2016 was only 9%, that being one of the lowest in EU. So much so that for EU-27 (2007–2013), without Croatia, it amounts 82 kg per capita, while for EU-28, with Croatia it is 81 kg per capita. Austria scores as much as 182 kg of recycled biowaste per capita. Mentioned indicator is highly relevant for the circular economy. Kitchen and garden waste in Croatia constitute more than 35% of mixed municipal waste (HAOP, 2015). Separate collection of biowaste and its subsequent recycling (usually in the form of composting or digestion) is essential to achieving high recycling rates of municipal waste. Furthermore, biowaste from households is often mixed with other waste and landfilled, contributing significantly to climate change.

Table 1
Circular economy indicators associated with municipal waste, data from (Eurostat, 2019).

Production and consumption	Croatia	EU	Italy	Germany	Hungary	Austria
Waste generation						
Generation of municipal waste per capita *(kg* per capita*)*	416 [2017]	486 [2017]	489 [2017]	633 [2017]	385 [2017]	570 [2017]
Generation of waste excluding major mineral wastes per GDP unit *(kg per thousand euro)*	75 [2016]	65 [2016]	69 [2016]	55 [2016]	98 [2016]	52 [2016]
Generation of waste excluding major mineral wastes per domestic material consumption *(percentage)*	8.2 [2016]	13.5 [2016]	22.1 [2016]	12.1 [2016]	9.2 [2016]	9.9 [2016]
Waste management						
Recycling rates						
Recycling rate of municipal waste *(percentage)*	23.6 [2017]	46.4 [2017]	47.7 [2017]	67.6 [2017]	35 [2017]	57.7 [2017]
Recycling/recovery for specific waste streams						
Recycling rate of overall packaging *(percentage)*	50.5 [2017]	67 [2017]	66.9 [2016]	69.9 [2017]	50.8 [2017]	65.6 [2017]
Recycling rate of plastic packaging *(percentage)*	37.3 [2017]	41.9 [2017]	42.4 [2016]	48 [2016]	32 [2017]	33.4 [2017]
Recycling of biowaste *(kg* per capita*)*	9 [2017]	81 [2017]	98 [2017]	117 [2017]	32 [2017]	182 [2017]
Recovery rate of construction and demolition waste (percentage)	76 [2016]	89 [2016]	98 [2016]	94 [2012]	99 [2012]	88 [2016]
Secondary raw materials						
Contribution of recycled materials to raw materials demand						
Circular materials use rate *(percentage)*	4.4 [2016]	11.7 [2016]	17.1 [2016]	11.4 [2016]	6.4 [2016]	10.6 [2016]
Competitiveness and innovation						
Private investment, jobs and gross added related to circular economy sectors						
Gross investment in tangible goods *(percentage of gross domestic products (GDP) at current prices)*	0.11 [2016]	0.12 [2016]	0.13 [2016]	0.09 [2016]	0.17 [2016]	0.08 [2016]
Persons employed *(percentage of total employment)*	2.19 [2016]	1.73 [2016]	2.05 [2016]	1.47 [2016]	1.93 [2016]	1.49 [2016]
Number of patents related to recycling and secondary raw materials	0 [2014]	355.62 [2015]	18.91 [2015]	89.87 [2015]	1.33 [2014]	8.22 [2014]

Composting is considered recycling if it meets quality protocols, otherwise it is other recovery (DEFRA, 2011). Sankey diagram for biomass flow based on the law of conservation of mass is currently available for EU28 economy only. An overview of EU food and waste flows is provided in (Caldeira et al., 2019).

Recovery rate of construction and demolition waste of 76% for Croatia is lower than that of EU-28 and other countries considered. Netherlands, Luxembourg and Malta score 100%.

Circular materials use rate which measures the share of material recovered and fed back into the economy, thus saving extraction of primary raw materials, in overall material use. Croatia is below EU average and the countries considered. Maximum performance of 29% is by the Netherlands.

Gross investment in tangible goods in the recycling sector, repair and reuse sector (as a share of GDP) and persons employed in the circular economy sector as the percentage of total employment for Croatia are respectively near average EU level and higher. That is probably the result of considering whole municipal utilities activity as circular economy. Namely, one of NACE (classification of economic activities issued by the European Commission) codes used to compute this indicator is collection of non-hazardous waste.

With regard to innovation related to circular economy, there is not one patent related to recycling and secondary raw materials from Croatia. Germany scores highest in EU. China for instance has 3,811, Japan 445, and South Korea 392.

In investigating principal historical and contemporary reasons for underperformance in Croatian waste management sector, as reflected in CE indicators, in December 2019 the author interviewed in written and by telephone the representatives of stakeholders in waste management sector, namely two representatives of municipal waste utilities who had scored the best in source separation at national level, above 60% according to HAOP (2019), and are thus the only ones who comply with EU standards, two representatives from the Ministry of Environment and Energy, and a representative from national association of cities.

The representatives of record-setting municipal utilities indicated the following principal reasons for substandard performance of waste management system at national level:

a. Poor and unfair regulatory framework drafted by officials from the ministry in charge of waste management with no field experience and no intention to consider suggestions from operators.
b. Lack of will within self-government units and utilities to embark upon waste processing, since it commands for greater effort on their side and higher prices for end users.
c. Current punishing policy is detrimental for municipalities successful in waste separation (incentive compensation for reducing mixed municipal waste explained later and no landfill tax).
d. Landfill tax revenues, had such an instrument been introduced, could be used by the state for financing circular economy activities and innovations. That would result in higher economic activity without dependence on subsidizing.
e. RDF from potential 11 receiving facilities may not be disposed of adequately in the country, so disposal costs become significant. The cycle may not be closed, and the product is piled up.
f. The market of recyclables is currently collapsing.

Representatives from the Ministry in charge of waste management stated the following:

a. To author's comment that landfill closures are taking place with no technological alternatives at higher level of waste hierarchy provided, so that new so-called bioreactor landfills are being created, the response was that there should be no more bioreactor landfills in addition to the existing two and that bioreactor landfills are the result of biowaste separation and its processing in the past. It should be pointed out here by the author that some 15 years ago it was thought that in the Eastern and south Eastern European states with a backlog demand for environmentally sound MSW management, simple MBT systems might provide a vital contribution to accomplishing the standards and targets set out by a future Europe-wide Framework Directive. Besides lower capital cost compared to thermal treatment, further potential advantages put forward were applicability in smaller catchment areas, flexibility and adaptability to meet increasing demands, controllability of material flows, and combinability with waste treatment technologies, see Steiner (2005). Thus, Croatia's system for residual waste management which was decided top down by 2007–2015 Waste Management Plan divided the country into 13 catchment areas (presently valid Waste Management Plan reduces them to 11) with one centre, designated as the Regional Waste management Centre (hereinafter: RWMC) in each area. The RWMCs are owned and are operated by public companies owned by the county, or counties connected to a centre.
b. Unresolved issue regarding disposal of biodegradable fraction of waste as a separate category in disposal of which Croatia is lagging behind.
c. The absence of advanced system for handling food waste.
d. The market for secondary raw materials is insufficiently developed and inadequately keeps abreast with door-to-door selection and circular economy principles.
e. Much effort is focused on building the infrastructure needed for waste management and very little on conscience raising that is indispensable for achieving purposeful efficiency of that infrastructure.

The representative from national association of cities emphasized the following:

a. There are some basic reasons for which the self-government units are not in a position to develop the infrastructure which they are conferred responsibility for by law and without which no sustainable system may be achieved, i.e. small local composting plants and sorting plants for preliminary sorting of separately collected potentially useful raw materials. Public calls for sorting plants and biowaste treatment plants by Energy Efficiency and Environment Protection Fund are deliberately or accidentally conceived in a way that self-government units may not even apply because minimum amounts of subsidy are inappropriate, exceeding in many cases the entire project costs.
b. Vicinity principle is being pronouncedly neglected in Croatia.
c. The education of service beneficiaries co-financed by the Fund in its very implementation simply circumvents the actual objective.
d. There exists no efficient "communal punishment" that would discipline also the non-obedient users as the state has not yet faced appropriately the problem of communal order and municipal police along with their competences.
e. The mayors are threatened with huge penalties, but no one has as yet been punished.
f. The state insists to interfere into price structure of public service and that proves to be a failure because in practice the thriving self-government units are being forced to take a step back.
g. There is no political nerve for introducing the landfill tax. What has been introduced is the so-called punitive incentive compensation. However, its prescribed algorithm is all but stimulating as similar charge is imposed on those who have no

separate collection and those who separately collect close to 60%. The reason is the criterium based on quantity of mixed municipal waste landfilled (and not the percentage of separate collection) and the data for base year set is far from accurate and reliable, so a number of municipalities are to be unjustifiably penalized. On the other hand, the Ministry refuses to rectify evident error and, by enacting poor, hasty and insufficiently informed regulations produces chaotic situation.

h. Recyclables market is currently becoming a problem in Croatia as well. The state should find the way to absorb staggering market prices and facilitate introducing own materials processing plants. Also, designing recyclable packaging is becoming crucial.

Therefore, in spite of often diverse stances and mutual blaming among stakeholders, the fact is that they share some common opinions regarding the reasons for inadequate performance of national waste management sector and necessary actions: non-existent landfill tax, poor market for raw materials, the need to finance own circular economy industry, the need for separate collection of biodegradable waste, and higher emphasis on education.

Furthermore, the 2013 Waste Act removed regional competence for developing waste management plans, so coherence between the policies made and implemented at different levels is still insufficiently clear. Next chapter analyses the discrepancy between present legislative obligations and state of affairs in waste management.

4. National policies, targets and achievements

Envisaged concept of municipal waste management in Croatia based on collection and processing of mixed waste in large regional/county MBT centres with bioreactor landfills and RDF production never completely materialized. In fact, it became outdated in technological and regulatory sense (Runko Luttenberger, 2018) even before its implementation. The concept was originally formalized by 2005 Waste Management Strategy of the Republic of Croatia (Republic of Croatia-OG, 2005) and Waste Management Plan of the Republic of Croatia for 2007–2013 period (Republic of Croatia-OG, 2007). The MBT centres as built, two of those being in operation (Marišćina in Mountain Littoral County and Kaštijun in Istria County), are not in compliance with EU Waste Framework Directive (hereinafter WFD). They may not achieve the targets set and they simply incorporate new landfills so valuable resources are irreversibly lost. Overall capacity of all centres built and planned is about 1.3 million tons (Runko Luttenberger, 2016), that exceeding total quantity of mixed municipal waste landfilled. Therefore 50% separation pursuant to obligations under WFD results in overcapacity. Furthermore, RDF requires either cement kilns or dedicated incinerators. In Croatia there is a lack of burning capacity, producers of RDF have to pay cement kilns to burn, and cement kilns accept only a very limited quantity of RDF of defined quality.

In the process of accession of the Republic of Croatia to the EU, Croatia assumed certain obligations to comply with the provisions set out in accession documents (EU, 2012), the 1999 Landfill Directive (EU, 1999), and the 2008 Waste Framework Directive. The time limits are imposed concerning the achievement of targets, that is (a) permissible quantities to be landfilled on substandard landfills, (b) limits concerning permissible quantities for disposal of biodegradable municipal waste, (c) providing for the operation of separate waste collection system, and (d) providing for appropriate processing of waste streams, see Table 2. National legislation scheduled for adoption, besides the 2013 Act on Sustainable Waste Management (Republic of Croatia-OG, 2013) was also the new six-year waste management plan (hereinafter: WMP) by 2014, waste prevention programme (hereinafter WPP) by 2013, and the implementing regulation on municipal waste management by 2014. The procedure of drafting and adopting mentioned documents got into substantial delay. Also, the 2015 Draft WMP (MENP, 2015) with regard to achieving EU targets resulted in excess capacity of waste management centres and the increase in unit cost of waste processing (Galović, 2016).

It was only in 2016 that the Republic of Croatia expressed for the first time its official support to EU Circular Economy Package proposal and started to produce new or review existing legislation in order to comply with circular economy concept and the EU documents in force.

Waste Management Plan 2017–2022 and Waste Prevention Programme were adopted only in January 2017 (Republic of Croatia, 2017). Shortly following its adoption, the WMP was partly modified by Government Decision (Government of the Republic of Croatia, 2017) that was never published in national official journal. Mentioned planning documents in fact endeavour to preserve previous policies based on mixed waste treatment with RDF production and landfilling of „treated“ waste. The Regulation on Municipal Waste Management (Republic of Croatia-OG, 2017a) was adopted in May 2017 and entered in force in November 2017. The amendments thereto (MEE, 2019) are currently undergoing public consultation.

According to data issued by Croatian Agency for the Environment and Nature (HAOP, 2018), the institution which in 2018 merged with the Ministry of Environment and Energy, recycling rate for municipal waste of 23.6% is far below target share of 50% for 2020 laid down under Sustainable Waste Management Act (Article 55). The recycling of four fractions – metal, plastics and paper from municipal waste (recycling quantities compared to manufactured quantity of such fractions) is 30%.

Only eight self-government units exceeded 50% recycling target, and those are mostly smaller-size communities. At counties level, the highest rates of municipal waste recovery have been reached by counties situated in north-west part of the country (Međimurje, Varaždin and Zagreb), and least rates by those located along the Adriatic Sea coast (Šibenik-Knin, Zadar and Split-Dalmatian counties), that being detrimental with regard to marine litter. Not to be underestimated are also the quantities of waste generated in tourism sector estimated to be 155,958 t in 2017 and constituting as much as 9.1% of total municipal waste.

The specific generation of municipal waste of somewhat above 400 kg/cap/yr comprises also tourism, which accounts for around 200,000 population equivalents. Due to the country's nature as a seasonal (mainly summer) tourist destination, this figure has to be tripled or quadrupled when, for example, considering the need for capacity to manage waste at the peak of the tourist season (JRC EC, 2011).

A total of 1.236 million tons of municipal waste was directed to 120 landfills in the Republic of Croatia and 6609 t to neighbouring Bosnia and Herzegovina. Overall, 72% of municipal waste produced has been transferred to landfills.

Out of the total of 1.091million tons biodegradable municipal waste produced, 34,891 t was composted in 10 composting plants, while 3625 t of municipal waste was digested in 5 biogas plants. The quantity of biodegradable municipal waste landfilled in Croatia was 0.8 million tons. Thus, the targets set in Article 24 of Sustainable Waste Management Act related to reduction of biodegradable municipal waste have not been achieved, see Fig. 1.

The greatest quantities of biodegradable municipal waste produced are recorded in the City of Zagreb, Split-Dalmatia County and Littoral-Mountain County. The ranking with regard to quantities

Table 2
National targets (MENP, 2016).

LANDFILLING
• Landfilling no more than 1.01 million tons of waste on substandard landfills in 2016
• Landfilling no more than 0.8 million tons of waste per annum on substandard landfills in 2017 and 2018
• Discontinuing landfilling of waste on substandard landfills by 31 December 2018
DISPOSAL OF BIODEGRADABLE MUNICIPAL WASTE
• Disposal of no more than 0.378 million tons of biodegradable municipal waste1 on all landfills in the Republic of Croatia during 2016, 2017, 2018 and 2019 calendar years
• Disposal of no more than 0.265 million tons of biodegradable municipal waste on all landfills in the Republic of Croatia during 2020 and 2021 calendar years
SEPARATE WASTE COLLECTION
• Paper, metals, plastics and glass
• Special categories of waste[a]
• Separate biowaste collection system for the sake of composting and anaerobic digestion
APPROPRIATE PROCESSING OF WASTE STREAMS
• Ensuring that at least 50% of the mass of waste paper, metals, plastics and glass produced during calendar year in households and from other sources is recovered in the process of preparing for reuse or processed in a recovery process considered to be recycling (for 2020, 2021)
• Ensuring that at least 70% of the mass of non-hazardous construction waste is recovered in the process of preparation for reuse or is treated in a recovery process that is considered to be recycling or the process that involves the use of such material for backfilling (for 2019, 2020, 2021)
• Introducing compulsory sorting of waste that is not separated or is partially separated in a household
• Providing for appropriate treatment of waste that remains after extracting waste paper, metal, plastics and glass from mixed municipal waste

[1]refers to paper and cardboard, timber, kitchen waste, waste from canteens, biodegradable garden waste, waste from green markets and mixed municipal waste with established biodegradable part.
[a] electrical and electronic waste, waste batteries and accumulators, end of life vehicles, end of life tyres, waste lubricating oils, waste textile and footwear, medical waste, asbestos waste.

landfilled for two of them is also the highest. The last one has an MBT waste management centre operative and it is probable that it does not record landfilling of biodegradable waste as such.

In April 2019 public consultation was launched concerning the Proposal amending the Plan of use of funds earned through sale of carbon emission units by auction in the Republic of Croatia till 2020 by the Ministry of Environment and Energy (MEE, 2019a) which attributes waste management centres processing mixed waste the priority measure with highest allocation (26.8%) of funds. It is indeed unclear by which criteria such centres which themselves do not comply with vicinity and pay-as-you-throw (hereinafter: PAYT) principles, which emit methane and other greenhouse gases to the atmosphere, may qualify for financing earned by sale of emission allowances.

5. Overview of EU recommendations

In its Country Report Croatia for 2019 (EC, 2019), the European Commission notes that far too much waste is put on landfills and too little is recycled. It also states that in environmental services, around half million people received access to newly built waste-management centres and around half million people already

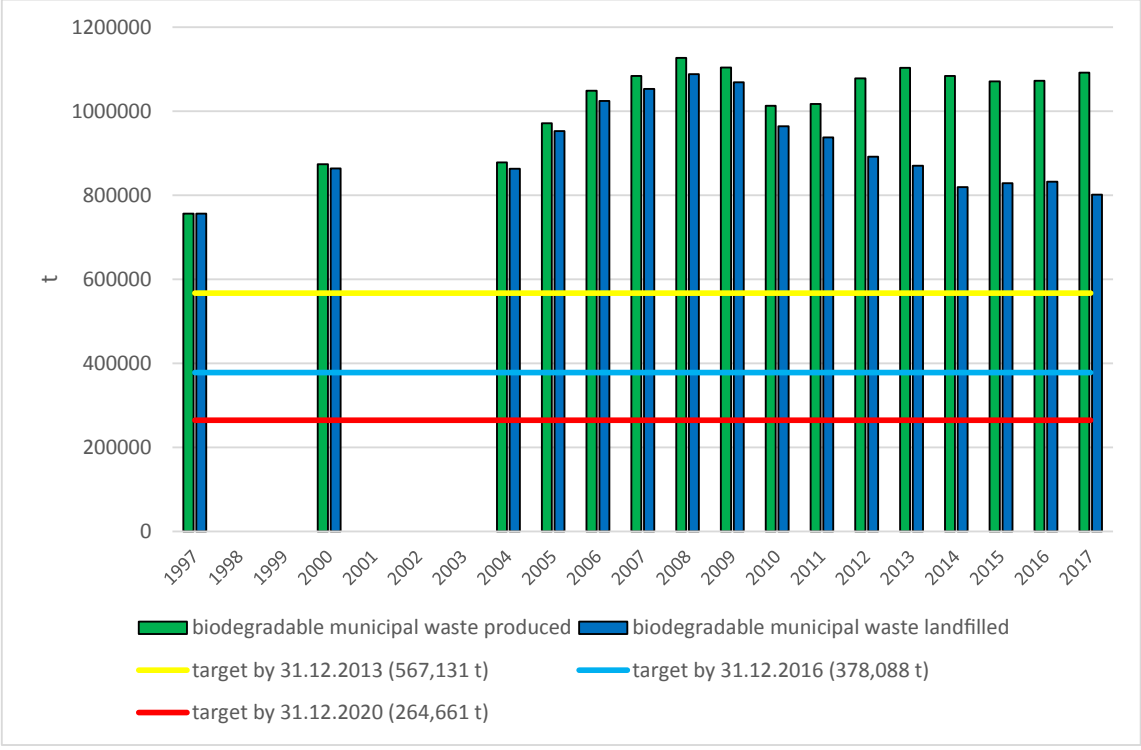

Fig. 1. Biodegradable waste produced and landfilled since 1997 till 2017 with regard to targeted quantities and deadlines laid down under Waste Framework Directive (HAOP, 2018).

gained access to modern water treatment and supply services, all amounting to a cleaner and healthier environment for citizens.

The Report furthermore states that Croatia requires substantial investment in waste and water management, which are underdeveloped and that the shift away from landfilling towards separate collection and recycling is slow. Landfilling of municipal waste is considerably above the EU average of 24%. Croatia also scores low in terms of recycling, with only 23.6% of municipal waste materials recycled, compared to an EU average of 46.4% (Eurostat, 2019a). Therefore, Croatia is at risk of not reaching the 50% preparation for re-use/recycling target on municipal waste by 2020. Reaching the even more ambitious and binding target of 65% by 2035 will require shifting investments further up the waste hierarchy. It also states that in 2017, the long-awaited national Waste Management Plan 2017–2022 was adopted, but its implementation faces delays and that improving Croatia's performance in waste management requires substantial investment in waste infrastructure.

In its Annex D under policy objective concerning low carbon and greener Europe it points out that the shift away from landfilling towards separate collection and recycling is stalling. Also, high priority investment needs have been identified to promote the transition to a circular economy, and in particular to (a) support systems of separate collection, composting and sorting plants and other measures preparing for reuse and recycling, develop alternatives to raw materials and increase demand for recycled content, (b) modernise and upgrade existing recycling and waste treatment infrastructure to adapt to new long-term recycling targets, (c) raise citizen awareness to sustainable consumption practices and behaviour and improve capacity for all stakeholders including though cooperation and share of experiences between Member States, and (d) improve the knowledge base and monitoring of waste and material streams.

Country-specific roadmap for Croatia issued in January 2016 report (EC, 2016) points out that in respect of packaging management Croatia is one of the few European countries that has a deposit for disposable beverage packaging in place. The practice, introduced in 2006 for non-refillable beverage packaging is less important in terms of yields (measure by weight) than it is on the appearance of public space, with a generally perceived reduction of littering in, and beyond, touristic areas. It also notes that current approach seems to be to support the provision of recycling through financial disbursements rather than giving a clear incentive to prevent and recycle waste through increasing the costs of disposal of residual waste. Thus, the cost for implementing the RWMCs will be borne by the Environmental Protection and Energy Efficiency Fund (hereinafter EPEEF) which is established for the purpose of financing of the preparation, implementation and development of programmes and projects and similar activities in the field of conservation, sustainable consumption, protection and improvement of the environment, and in the field of energy efficiency and use of renewable energy sources. It also points out that gate fees at the RWMCs reported might turn out to be an underestimate when compared with gate fees in other countries. The point highlighted is that the centrally managed EPEEF covers – together with support from the EU – the investment expenditures of the RWMC, whilst the remaining investments (in collection equipment, recycling yards, remediation of landfills) are funded to the tune of 40–60% by EPEEF depending on the financial status of the municipalities.

The Report also points out that specific proposal in MBT plants is for a bio-drying technology linked to bioreactor landfills, that being a strange combination, not least since the use of bioreactor landfills would suggest the waste is not stable when placed in the landfill, implying that little would have been done to move towards landfill Directive targets. The facilities show generous, spacious layouts and contain equipment perceived as the "high end" of MBT technology, suggesting that a considerable amount of over-engineering may have occurred. In addition, total treatment capacity of about 1.3 million tons/y is extremely high given the current level of MSE generation (of 1.7 million tons). Even allowing for waste growth, this level of treatment will make it extremely difficult for the levels of recycling being proposed in the revised legislative proposal in the circular economy package to be met. Given that the Commission has ambitions to increase recycling targets to 65% of all MSW, the capacity planning could potentially limit the scope for recycling in the coming years. That raises questions regarding the value for money of planned investments, appropriate infrastructure to allow prevention, preparation for reuse, and recycling activities to flourish (i.e. separate collection at the local level) and meeting new targets.

With regard to further updates to National Waste Management Plan, mentioned roadmap recommended that clear specification is needed of what is required in respect of separate collection at the local level, a clear strategy for the management of municipal waste in the future taking into account future higher targets, a consideration of approaches to collecting food waste, and the introduction of a plan to extend the roll out of door to door collection systems. It also recommended a clear devolution of responsibilities down to the local level, including the establishment of a framework for monitoring performance, reform of funding mechanisms, including consideration of the introduction of a residual waste tax as a replacement to the current EPEEF, the activities to support waste prevention and re-use, roll of PAYT systems, programme to support municipalities and educate householders, and improvements in data quality and transparency.

EU's early warning report (EC, 2018b) issued in 2018 makes part of the Commission's overall implementation report and aims to assist Member States at risk of failing to meet the 2020 target of 50% preparation for reuse/recycling of municipal waste set out in Article 11(2)(a) of Directive 2008/98/EC. It provides an overview of possible actions to improve performance, which involve data reporting, extended producer responsibility, separate collection with an emphasis on door-to-door service, regulation and incentives for local authorities, pay-as-you-throw schemes, communication and awareness-rising, technical support to municipalities, and the use of EU funds. It points out that current allocation remains too heavily focused on residual waste treatment infrastructure provided at the regional waste management centres instead of support for separate collection of dry recyclables and of biowaste and that funding should be oriented towards delivering results while sub-standard and underperforming systems should not qualify for funding. With regard to regional approach to waste management, it states that specific operational considerations be taken into account to improve waste management.

6. Proposed model for achieving circular economy targets in Croatia

Official Croatian decision in 2016 to embark upon circular economy path resulted in an attempt to devise in a holistic approach the method ensuring reversal of inadequate waste management policy and fast-track achievement of targets at minimum cost. The concept was then basically enshrined in Draft Waste Management Plan 2016–2022 and Waste Prevention Programme (MENP, 2016). The measures envisaged for achieving national targets are listed in Table 3.

The recycling target for municipal waste was at minimum one half of the quantity of mixed municipal waste landfilled annually, with potential for recycling the materials contained in that quantity estimated to be even higher than 50%. In order to achieve recycling targets, it would be necessary to collect separately a significant part

Table 3
Measures for achieving national targets.

NATIONAL TARGET	MEASURES
Landfilling	• Adopting the criteria concerning compliant landfills • Defining the compliance status for each landfill • Defining the mass of waste allowed to be disposed on each particular substandard landfill • Monitoring the quantity of waste disposed on substandard landfill in real time by means of electronic system recording the production and flow of waste (e-ONTO) • Preventing the disposal of quantities exceeding those permissible on substandard landfills by introducing gate fee • Procurement of works, services and equipment aimed at bringing landfills into compliance • Introducing a ban on waste disposal on substandard landfills after 31 December 2018
Disposal of biodegradable municipal waste	• Designating the mass of biodegradable waste allowed for disposal at a particular landfill • Designating the share of biodegradable waste in mixed municipal waste • Reducing the quantity of mixed municipal waste produced • Reducing the share of biodegradable waste in mixed municipal waste (stimulating composting in a household, stimulating the construction and outfitting of local plants for biological treatment- composting yards, anaerobic decomposition, etc. of biodegradable waste from restaurants, parks and from green markets, cessation of waste status for compost and anaerobic digestate) • Reducing the quantity of mixed municipal waste for landfilling (sorting plants for dry fraction and for mixed waste, introducing the standard for minimum processing of waste prior to landfilling, introducing new methods of municipal waste bins content control and user identification) • Stimulating the reduction of total quantity of waste landfilled by introducing the landfill gate fee
Separate waste collection	• Providing for the operation of separate collection of paper, metal, plastics and glass • Providing for the operation of separate collection of special categories of waste • Providing for the operation of separate biowaste collection • Providing for the operation of local mixed municipal waste collection system
Appropriate processing of waste streams	• Ensuring that at least 50% of the mass of waste paper, metals, plastics and glass produced during calendar year in households and from other sources is recovered in the process of preparing for reuse or processed in a recovery process considered to be recycling (for 2020, 2021) – presently we are at 17% • Ensuring that at least 70% of the mass of non-hazardous construction waste is recovered in the process of preparation for reuse or is treated in a recovery process that is considered to be recycling or the process that involves the use of such material for backfilling (for 2019, 2020, 2021) • Introducing compulsory sorting of waste that is not separated or is partially separated in a household • Providing for appropriate treatment of waste that remains after extracting waste paper, metal, plastics and glass from mixed municipal waste

Source of data: MENP, 2016.

of plastics, paper, metal, glass and also textile and biodegradable waste, which constitute municipal waste. In other words, dry fraction such as paper and cardboard, metal, plastics, glass and textile or all waste packaging and similar materials should be collected separately from biodegradable waste and mixed municipal waste. It is also necessary to increase the capacities for separating waste – sorting plants (for dry fraction and where appropriate mixed waste) and the capacities for treating biodegradable waste (composting plants, biogas plants).

The structure of designed waste management concept is shown in Fig. 2, with targeted material flows quantified in Fig. 3. Estimated 0.39 million tons of bio waste would be an input for home and municipal composting as well as biogas production. Minimum resources were left for disposal, meaning that significantly less capacity in MBT waste management centres with regard to those planned would be necessary.

In support of proposed concept and with regard to greenhouse effect, a study for the EU Commission comparing different waste management options from a greenhouse gas perspective concludes that overall, source segregation of mixed solid waste (MSW) followed by recycling (for paper, metals, textiles, and plastics) and composting/AD (for putrescible wastes) gives the lowest net flux of greenhouse gases, compared with other options for the treatment of bulk MSW (AEA Technology, 2001). Such finding is in favour of the concept proposed.

It must be pointed out that the Regulation on municipal waste management (Republic of Croatia-OG, 2017a) currently in force in some respects represents sound basis for embarking upon achieving improved waste management system, challenging the long ago planned and now gradually implemented MBT waste management centres. However, and as pointed out through the interviews, in its present form it also has significant shortcomings.

As mentioned earlier, Draft Waste Management Plan 2016–2022 based on circularity principle was not adopted in its original form, it having been substantially modified in the new draft that was later presented and adopted (Republic of Croatia-OG, 2017).

Quantitative and qualitative comparison of RWMC MBT and proposed resource efficient system proposed by Draft WMT is presented in Table 4.

7. Marine litter

Marine litter in the Adriatic Sea presents a significant problem for Croatia. Although Adriatic Sea washes the coasts of other countries as well, Croatia is with its long coast more affected by the problem and significantly contributes to its very generation. Namely, marine litter to a great extent mirrors waste management problem on the land. Therefore, trying to resolve marine litter problems means adopting appropriate policy with regard to waste generated at sea, principally by boating tourism, insufficiently regulated and expanding marinas, cruising and fishing, and at land. Relying on collection, transport (very often seaborne from the islands) and treatment of mixed waste in order to produce RDF of low quality for which there is no market as is the case in Croatia means movement of waste over great distances, non-compliance with proximity principle, its potential leakage, production of waste in a new form, and the creation of new landfills. Considering the impact of such a system on service price it could also result in creation of illegal landfills in karst terrain, in the vicinity of watercourses and along the coastline, meaning that destination of such waste will probably be the sea with all the impacts on marine ecosystems, public health, standard of living and tourism (Runko Luttenberger, 2018). Marine litter is one of the clearest symbols of a resource inefficient economy, because valuable materials are polluting beaches and damaging the environment instead of being

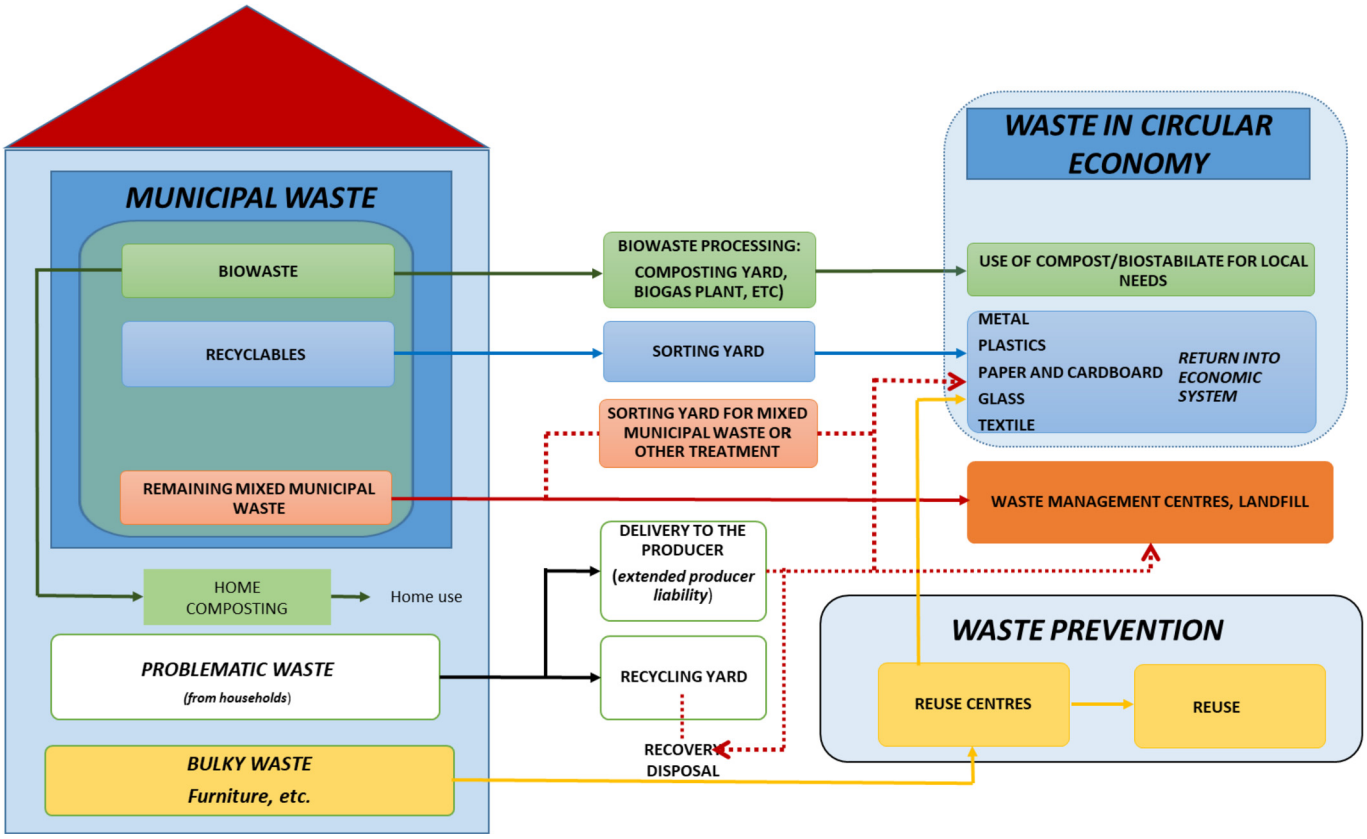

Fig. 2. Structure of designed municipal waste management system (MENP, 2016).

pumped back into the economy (EC, 2017).

Valid 2017–2022 WMP admits that the system of marine litter management has not been established and that currently there are neither official data nor appropriate assessment regarding the quantity of marine waste in the Republic of Croatia. Marine Strategy Framework Directive (EC, 2008a) which among other things defines important descriptors on pressures on marine environment, marine litter being one of them, lays down obligation on the Member State to adopt a marine strategy, which obligation the Republic of Croatia has not yet fulfilled.

Very important aspect in abating marine litter is waste prevention. In that respect as well, the concept proposed through Draft WMP (MENP, 2016) was more specific (compared to valid WMP) in that it stipulated the legislation which should be adopted or amended, specified the number of waste prevention centres to be established, the institutional and regulatory actions to be taken for preventing food waste, and emphasized the importance of personal consumption of population, particularly in the part related to habits when provisioning for food and drinks, clothes, footwear, furniture and market supply.

8. Packaging waste and food

Another important contribution in reducing marine litter,

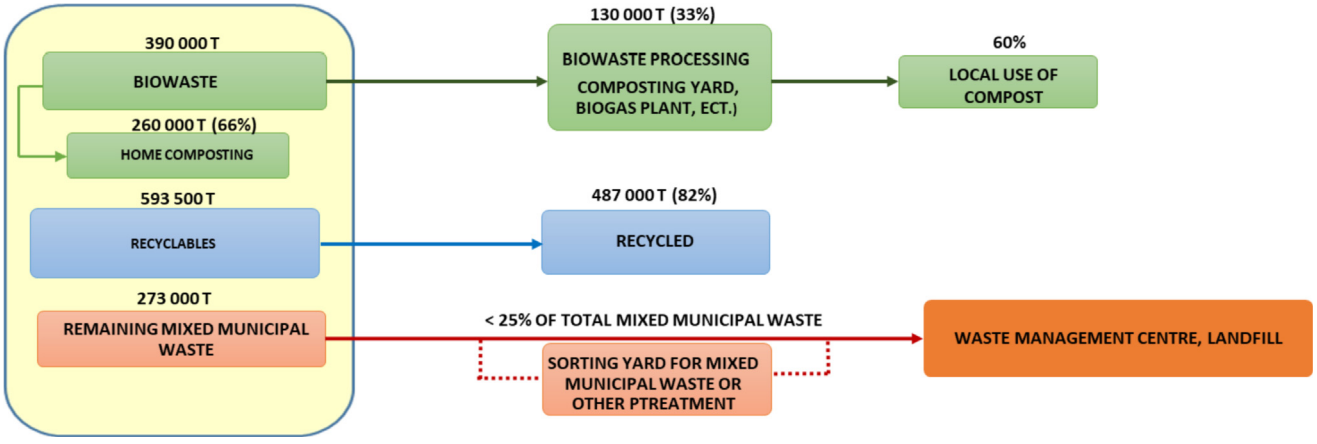

Fig. 3. Targeted waste flows (MENP, 2016).

Table 4
Multicriteria comparison of RWMC MBT system deployed and proposed resource efficient system.

	RWMC MBT system	Resource efficient system
Capital expenses	700 million EUR + land costs	350 million EUR
Operating expenses	100-150 million EUR per annum	Potential for reduction of present utilities cost of 40–70 million EUR
Processing capacity	1.3 Mt of mixed municipal waste annually (min 50% overcapacity)	390,000 tons biowaste, 600,000 tons recyclables, 270,000 tons of mixed municipal waste
Modularity	No	Yes
Final product	42,000 tons of RDF + new landfills	Compost, 450,000 tons recycled matter, <325.000 t mixed municipal waste for RWMC or compliant landfills
Employment	500–600	150,000–20,000
Impact on resources	Detrimental Linear economy Insufficient upgrade compared to landfilling	Beneficial Circular economy
Pollution	Degradation of natural capital – water, air climate (transport, methane emissions), soil	Natural capital preservation Reduced carbon footprint
Compliance with acquis and national regulations	No	Yes
Potential for achieving more stringent circular economy targets	No	Yes
Social impact	Sporadic	Strengthening local economy
Price for customers	Drastic increase (multifold)	Minimum increase compared to present unsustainable system[a]
Advantages	Business as usual	Boosting economic and environmental sustainability of the society, opportunities for SMEs, innovations, local businesses

[a] Based on comparison of prices of service in a community that had previously locally introduced resource efficient system and those in a city where RWMC MBT centre is operating.

particularly in a country that relies heavily on tourism with all its seasonality and periodical pressures on public services would be implementing the policies to reduce and modify packaging, the materials used therefor and to avoid one-use and disposable plastic materials of all types. Such an approach obviously implies the change of habits, intervention in supply chain and increasing domestic supply of agricultural goods in particular (Runko Luttenberger, 2018).

Sustainability and resilience depend on the circularity in food sector, see also (Tonini et al., 2018) and plastic sector which both exert a great impact on resources, waste, climate, soil, and pollution (Runko Luttenberger, 2019). Sustainable production and use of biodegradable bioplastics would greatly contribute to returning the resources contained in food waste to the soil. Biodegradable plastics would also decrease the amount of microplastics ending in the sea.

Although natural resources should be taken in consideration when assessing sustainability of bio-based plastics (fertile land and land-use change, both direct and indirect, water, phosphate, and energy), the use of biodegradable bio-based plastics in packaging applications and for food waste carriers may also significantly increase the quantity of separately collected food and garden waste. It may also reduce contamination of compost by non-biodegradable plastics. With such co-benefits its usage becomes attractive. Thus, bio-based plastics that has low carbon footprint and is sourced sustainably may link bio-based economy to circular economy.

Biodegradability thus represents an asset for specific purposes – agricultural and in stimulating separate food waste collection (CE Delft, 2017). Besides ensuring good environmental status of the sea, rivers, air, soil and land cover, such a task provides significant opportunities for eco-innovation, small local businesses and local agriculture. Besides that, green public procurement, localization, and access to and consumption of tap water could significantly reduce the leakage of plastics into environment (Luttenberger and Runko Luttenberger, 2018).

EU recently introduced new measures to address plastic waste and pollution through 2018 European strategy for plastics in a circular economy (EC, 2018c) and Single Use Plastics Directive proposal (EC, 2018d). Also, chemicals leaching from plastics pose a great hazard (Colborn et al. (1997) ; Steingraber, 2010; Scott, 2015).

Croatia is not proactive with regard to sustainable packaging, being concerned mainly with end-of-pipe solutions, however inefficiently. Prevention as the top priority measure in waste hierarchy is not tackled at all. At the same time, about 400.000 t of food is thrown annually in Croatia (HGK, 2019). In addition, current WMP and WPP incorporated therein do not place significant emphasis on neither packaging nor composting, while Draft food waste prevention plan (MA, 2019) has undergone public consultation only in 2019.

9. Conclusion

Croatia is the example of a country where substantial public money has been invested in an inefficient waste management system in spite of EU legal framework it has to comply with. Implementation proved to be the problem. The overcapacity in planned MBT plants for mixed waste is obvious given the obligations with regard to separation and processing. There is a lack of implementation of the waste hierarchy with over-emphasis on residual waste treatment. Also, roles and responsibilities among authorities at different levels are often not matching each other.

In spite of often diverse stances among different stakeholders involved, the fact is that they share some common opinions regarding inadequate performance of national waste management sector: non-existent landfill tax, poor market for raw materials, the need to finance own circular economy industry, the need for separate collection of biodegradable waste, and placing greater accent on education.

Waste management centres in operation in Croatia are not the best available technology and actually place heavy financial burden, both in terms of investment, operation and maintenance on taxpayers, service users, and municipalities. The achievement so far is increased landfilling, accumulating low quality RDF that has no market nor paid recipient, loss of recyclables, and loss of valuable biowaste. Furthermore, increasing quantities of sludge from inefficient energy and water consuming centralized wastewater plants are posing an additional problem for existing waste management facilities.

The issue of biodegradable waste which, when mixed with other waste creates enormous problems at so-called bioreactor landfills

of MBT plants in terms of emissions of methane and noxious substances, odours for nearby population, and space requirements can be resolved simply and inexpensively by home composting and municipal composting schemes, aerobic and anaerobic, for separately collected biowaste. Such a solution for both achieving the targets and for preserving the environment and soil is particularly suitable for Croatia, a country of numerous dispersed communities and few larger cities. Organic output from mechanical biological treatment having unsorted municipal waste as an input is not recycling. Quality compost is necessary for agriculture and adding organic content to impoverished soil, therefore landfill diversion targets should be associated with composting, aerobic and anaerobic.

Croatia should embark upon and accelerate its transition towards circular economy in order to meet its international obligations and also to preserve its precious environment. Such a task presents significant challenges on policy makers and operators, but at the same time also provides great opportunities for academia, innovators, SMEs and consequently quality employment.

Circular concept as proposed in Draft WMP 2016–2022 involving waste prevention, waste separation, sorting, and composting should be implemented, and resource inefficient mixed waste concept abandoned. Such an approach would be in line with official recommendations, roadmaps and warning reports issued by the EU. Valid WMP simply builds on the previous policies.

Marine litter issue which affects sea surface, water column, sea bottom, beaches and biota and thus the quality of environment for coastal communities and tourists would thus be embraced in an integrated manner. The country should also be proactive in adopting the policies to reduce and modify packaging, linking bioeconomy to circular economy through flows of food, waste food and plastics. Public authorities should use the instrument of green public procurement and promote the access to and consumption of locally produced food and tap water.

Proposed model is applicable to other countries as well which need to implement efficient transition from landfilling to circular economy and preferably avoid any mistakes possibly committed by those who had abandoned landfilling in search of alternatives long ago.

The task for future research is further development and refining of circular economy indicators in order that they reflect more realistic state of affairs with regard to waste management. Sankey diagram for biowaste and other material flows for individual countries should be produced. As each country has specific features, further research concerning Croatia and other Mediterranean countries should integrate in a holistic manner municipal waste management, food packaging and food waste, marine litter, tourism, local agriculture, and local economies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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