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The trilemma of waste-to-energy: A multi-purpose solution

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ABSTRACT

This paper explores the multi-purpose nature of Waste-to-Energy (WtE), which adheres to three different policies in the EU: 1) waste management; 2) energy union; 3) air quality/climate change. While WtE is subject to different EU policies and must comply with different sets of EU regulatory frameworks, the policies are largely intertwined and share common objectives enabling the achievement of a sustainable European future via the circular economy. With support from the theoretical foundation for the potential to unite climate, energy, and environmental justice, the paper calls for a streamlined policy in the context of WtE. The paper also highlights the value of this linkage from a practical perspective illustrating how these different policies could be bridged through the new technology - the patented micro-scale Home Energy Recovery Unit (HERU), which has been invented to process all unwanted domestic materials and generate energy for the household.

1. Introduction

As modern society moves towards urbanisation, and with a growing population that demands higher consumption of goods and greater energy needs, the topic of waste management and energy recovery from waste becomes vital for future sustainable development (World Energy Council, 2016). The rapidly increasing quantities of waste generated in Europe are a major concern for the environment. For instance, the average amount of municipal solid waste (thereafter MSW) generated by each of about 512 million inhabitants of the European Union was accounted as 482 kg per year in 2016 (Eurostat, 2016). As far as energy is concerned, about 1530 million TOE of primary energy was consumed by the EU countries in 2015. Given that the average energy content (calorific value) of MSW is approximately 10 MJ/kg (i.e. plastics has 35 MJ/kg; textiles – 19; paper – 16; organic materials – 4), waste is a useful source of energy. Even though municipal waste represents approximately 7%–10% of the total waste generated in the European Union (measured by weight) (Eurostat, 2018), this waste stream is amongst the most complex ones to manage and therefore, this waste stream will be the main focus of this paper.

Since the Treaty of Amsterdam sustainable development has been an overarching objective of EU policies, reconciling economic efficiency, social inclusion and environmental responsibility. Sustainable development has then been mainstreamed into EU policies and legislation. In line with EU commitments under the 2030 Agenda for Sustainable Development, at the end of 2015 the Commission launched its ambitious "Closing the Loop — An EU Action Plan for the Circular Economy" (thereafter the Circular Economy Action Plan) (European Commission, 2015), aiming at, *inter alia*, fostering sustainable consumption and production patterns (European Commission, 2015). Building on this, the EU calls for waste management to be transformed into sustainable material management which embeds the principles of the circular economy, enhances the diffusion of renewable energy, increases energy efficiency, reduces the dependence of the Union on imported resources and provides economic opportunities and long-term competitiveness. Currently, in some Member States more than 80% of household waste goes to landfill ("Waste - Environment - European Commission," n.d.). This means that the great amount of MSW whose energy content could otherwise be fed back into economy, is escaping from a circular economy model. Therefore, in this context WtE (Waste-to-Energy) could play an important role.

The dual purpose of WtE (where EU waste policy coincides with energy policy) has already been addressed by several scholars (Talus, 2016) (Reins, 2016) (Stengler, 2016). The paper, however, argues that dual purpose of WtE is no longer sustainable. No WtE facilities should survive if its benefits, such as eliminating a waste problem, replacing fossil fuels with 'waste' fuel to produce energy, are offset by social environmental costs. WtE technologies should not neglect how this energy is produced and should minimise carbon dioxide and methane emissions, therefore, contributing to air quality (and broader environmental issues, such as the protection of groundwater, soil, flora, and human health etc.). Therefore, the paper explores the multi-purpose nature of WtE, in the context of three different policies in the EU: 1) waste management; 2) energy union; and finally, 3) air quality/climate change supported by environmental, energy, and climate justice respectively. While WtE is subject to these different EU policies and must comply with different sets of EU regulatory frameworks, the policies are largely intertwined and share common objectives enabling the

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Abbreviations

CoP	Coefficient of Performance
EE	Energy Efficiency
EU	European Union
GHG	Greenhouse gas
HERU	Home Energy Recovery Unit
MSW	Municipal solid waste
RED	Renewable Energy Directive
REFIT	Regulatory Fitness and Performance programme
TOE	Tonne of Oil Equivalent
WFD	Waste Framework Directive
WRAP	Waste and Resources Action Programme
WtE	Waste-to-energy

achievement of a sustainable European future via the circular economy. Far from denying the usefulness of having these separate European policies, the paper aims to demonstrate that a new generation of policy can be designed based on the insights from an innovative multi-functional technology. It contributes towards the discussion on the need to streamline the existing separate EU regulatory frameworks, which is in line with the Commission's overarching Regulatory Fitness and Performance programme (REFIT) that aims at simplifying EU regulation in streamlining monitoring and reporting obligations in environment policy (Commission, 2016a). For instance, there have been some studies undertaken on the EU Energy Union framework and its overlaps and duplications between the planning and reporting requirements under the Monitoring Mechanism Regulation, the Energy Efficiency Directive and the Renewable Energy Directive (Umpfenbach, 2015). While this paper is in favour of streamlining planning and reporting (known as P&R), financing, permitting, planning and reporting fall outside the scope of this research.

Specifically, the paper, first of all, places the WtE in a broader context and seeks support from a united front of climate, energy and environmental justice with waste management falling under the latter as well as the principle of the environment, human health and combating climate change. Secondly, it explores the European policies and regulatory frameworks related to environmental, energy and climate issues, and most notably, the European Commission's recent communication on the role of waste-to-energy in the circular economy (thereafter, the WtE Communication) (European Commission, 2017a), which indicates that WtE can play a role in the circular economy subject to the guiding principle of waste hierarchy. The paper also advances the existing literature discussed in section 2 from a practical application. The negative label attached to WtE due to incineration, should change, as there are various improved waste treatment processes (i.e. pyrolysis, gasification, anaerobic digestion), to generate environmentally friendly energy (e.g. in the form of electricity and/or heat or producing a waste-derived fuel). These processes could be further optimised through new technologies with further circular economy potential, such as a patented ("WO/2015/104400," n.d.) micro-scale Home Energy Recovery Unit (thereafter, HERU), a heat pipe-based waste treatment unit, designed to process all unwanted domestic materials to generate energy for the household. The paper argues that new emerging technologies, such as HERU, which provide multi-purpose solutions should receive further support for their contribution to the trio policies of waste management (the environment), energy, and climate change including meeting various EU set targets such as renewable energy, energy efficiency, greenhouse gas (GHG) emission reduction, and diversion from landfills.

This paper employs an interdisciplinary approach combining both legal and scientific arguments from theoretical and practical perspectives. As far as the structure is concerned, after this introduction section 1 and placing WtE in a broader context of energy policy in section 2, section 3 is devoted to the background of WtE policies in the EU in order to identify the current EU approach towards WtE. Section 4 then focuses on the trilemma of WtE and the three policies adhered to it. The paper also contains a practical case study based on the HERU technology, which will be analysed in section 5 in the context of the trilemma identified in section 4. While exploring the potential of HERU, section 6 proposes to employ an integrative approach. Finally, the concluding remarks and future considerations are placed in section 7.

2. The literature review: WtE in a broader energy, environmental and climate change context

Traditionally, WtE has been discussed in the context of environmental justice, which begun initially in the USA as early as 1970s in connection to the unequal distribution of environmental 'evils', such as pollution, not properly managed waste treatment facilities (especially incineration facilities), and the environmental risks associated with them (Harvey, 1996) (Dawson, 1998) (Walker, 2012), including health issues (Jarup et al., 2002). These were often situated next to the poorest areas of the town or region populated by poor coloured communities (Getches and Pellow, 2002). Environmental justice as a discourse has expanded its influence and has been applied in two different contexts, such as broadening range of issues, and increasingly reaching a global level (Schlosberg, 2013). For instance, Davies referring to the Galway Safe Waste Alliance in Ireland, which resisted the expansion of energy-from-waste, identified an interwoven set of contingent conditions for the adoption of environmental justice, such as empowerment, social justice and public health (Davies, 2006). The concept has been further widened expanding the sphere of a discourse to climate change embracing climate justice (Dawson, 2010). Schlosberg, for instance, explores how climate change has pushed environmental justice to more broad considerations of both environment and justice, noting that "environment and climate justice have become more embedded in an understanding of the way that environmental conditions provide for individual and community needs and functioning" (Schlosberg, 2013).

Finally, there is also an evolving trend of energy justice broadly centred on the ethical, philosophical, and moral aspects of contemporary energy challenges defining the concept of justice as a global energy system (Sovacool and Dworkin, 2014) (Jenkins et al., 2016), (Sovacool et al., 2017). In a broader context, energy justice has emerged with an aim to "provide all individuals, across all areas, with safe, affordable and sustainable energy" (McCauley et al., 2013). The current conceptual energy justice framework distinguishes three main approaches the triumvirate of tenets (i.e. distribution, procedural and recognition justice) (Jenkins K, McCauley D, Heffron R, Stephan, H., Rehner, 2016) (Jenkins et al., 2014), the applied principles for practice of energy justice (i.e. availability; affordability; due process; transparency & accountability; sustainability; intra & inter-generational equity; and responsibility), and finally, cosmopolitan justice across energy life-cycle (systems) (Heffron and McCauley, 2017). Distributional justice is concerned with how the benefits and burdens of energy policy implementation are shared across society, for instance, where technologies (and infrastructure) are located and who can access their outputs (Sovacool and Dworkin, 2015), (Sovacool et al., 2016), (McCauley, 2018). Procedural justice relates to the various processes and elements of decision-making, whereas recognition-based justice deals with the equitable appreciation of stakeholder groups involved in energy systems (McCauley et al., 2013). For instance, a WtE facility may face effective local protest (known as a NIMBY (Not In My Backyard) syndrome) especially if a sufficient case for nuisance through noise or odours can be made (Ren et al., 2016). There is also an emerging concept of restorative justice, which ensures that energy justice is applied in practice at each stage of the energy life-cycle (see Fig. 1)

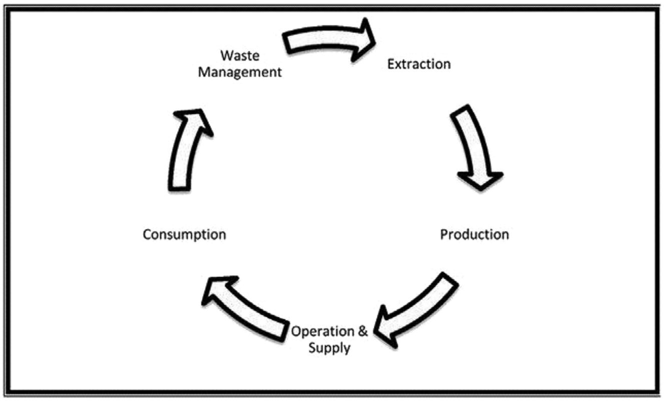


Fig. 1. The energy life-cycle. Source: Adapted from Heffron and Talus (2016), The evolution of energy law and energy jurisprudence: Insights for energy analysts and researchers (Heffron and Talus, 2016).

(McCauley and Heffron, 2018) with some further studies on decommissioning, where decommissioning is about restoration - returning the energy site as close as possible to its previous state (Heffron, 2018). Restorative justice seems essential to address, especially in the current context of a circular economy and is highly supported in this paper.

Energy justice has also been positioned in the literature of energy law as one of the main principles. While building on the lessons from environmental law and climate change law, Heffron et al., in their quest for advancing a set of principles for energy law identified seven principles of energy law (i.e. National Resource Sovereignty; Access to Modern Energy Services; Energy Justice; Prudent, Rational and Sustainable Use of Natural Resources; Energy Security and Reliability; Resilience, and finally, Protection of the Environment, Human Health & Combating Climate Change) (Heffron et al., 2018). The last principle as well the energy justice (i.e. mainly restorative justice) with their overlaps across different disciplines are at the heart of this paper with energy and the environmental (not excluding the climate change) being linked in the natural fuel cycle from exploration and extraction via production and distribution to consumption and finally waste management. Disposal does not have a place in a circular economy as energy waste should be brought back into the economy. The scholars seem to agree that there are trade-offs between energy and the environment and the climate change that should be addressed and most importantly overcome (Okun, 1975). Therefore, energy law and policy, the environmental law, and climate change should not be treated as distinct areas of regulation.

Along similar lines, further studies have also recently embarked on the potential for uniting climate, energy and environmental justice to provide a more comprehensive framework for analysing and ultimately promoting fairness and equity throughout the just transition away from fossil fuels (McCauley and Heffron, 2018) (Heffron and McCauley, 2018). McCauley and Heffron concluded that the just transition framework through the new triumvirate of justice tenets (i.e. distributional, procedural, and restorative) enables to reflect upon the intersectionality of environment, climate and energy as well as assess justice issues from a truly interdisciplinary perspective further contributing to long-term solutions (McCauley and Heffron, 2018).

Building on these previous studies, the paper aims to deliberate further discussion for a joint conceptual space for reflection from a practical perspective supported by a new innovative multi-functional technology which connects different policies on waste management (i.e. environmental aspects), energy and climate change. It further signifies restorative justice across these disciplines in the contexts of both *ex post* and *ex ante* approaches. First of all, the paper strongly supports an *ex ante* nature of restorative justice and agrees that waste management hierarchy (one of environmental justice principles) should be respected, as reducing waste also decreases the cost of waste collection, resorting and treatment. Furthermore, WtE can also prevent potential harm of 'waste' by transferring it in a valuable renewable source of energy, most importantly clean energy, therefore, replacing fossil fuels and contributing to the economy, security of energy, climate change and human health. Even in the context of *ex post* approach, WtE has a role to play in the circular economy, by destroying (compliant with emissions standards), for instance, toxic organic substance from residual waste (for instance, after recycling) that are harmful to human health and the environment by removing them from the circular material flow. In practice, these challenges cannot be overcome without further advancements of innovative technologies (i.e. such as HERU to be discussed in section 5) that contribute to this linkage between energy, the environment, climate change and most importantly to human health.

3. Background of WtE policies in the EU

The European Commission with its ambitious circular economy package has set tasks to close the loop of product lifecycles, 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, as what used to be considered as 'waste' can be turned into a valuable resource (European Commission, 2015). Therefore, a circular economy should lead to lower energy consumption and carbon dioxide emissions and to the avoidance of using fossil fuels. This in turn means that the circular economy has strong synergies with the EU's objectives on climate and energy.

With regard to WtE, the Circular Economy Action Plan articulates that WtE can "play a role and create synergies with EU energy and climate policy" (European Commission, 2015). Along similar lines, the European Commission's Energy Union Strategy defined in 2015 also aims to "further establish synergies between energy efficiency policies, resource efficiency policies and the circular economy", which should also include exploiting the potential of "waste to energy". Similarly, scholars also seem in agreement that the dilemma of energy demand, waste management, and greenhouse gas emission could be simultaneously solved by the WtE supply chain which is a viable method towards a circular industrial economy (Pan and Alex, 2015).

Yet, there is no legal framework in the EU specifically attributed to WtE, except in 2017 issued the Commission's soft law – the WtE Communication, which was promised by the Circular Economy Action Plan. This is a welcoming step in the acknowledgement of WtE's contribution towards the circular economy. However, soft laws are not legally binding and therefore, the Member States do not need to follow them. Nevertheless, they can be highly influential, especially if supported by binding measures defined by directives. First of all, the foundation is set by the recently amended Waste Framework Directive (thereafter WFD) (The European Parliament and the Council of the European Union, 2008) (Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 Amending Directive 2008/98/Ec on Waste (Text With Eea Relevance), N.D.), which puts measures to improve waste management systems in the Member States ensuring that waste is valued as a resource. Secondly, also recently amended the Landfill Directive (The Council of the European Union, 1999) (Directive (EU) 2018/of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste, 2018) which contains a stricter target (up to 10%) to ensure that by 2030 waste (especially MSW) suitable for recycling or other recovery will not end up in landfills. Along similar lines, the two other recently amended directives, such as the Packaging Waste Directive (Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste (Text with EEA relevance), n.d.) and the Directive (EU) 2018/849 amending the three previous directives on end-of-life vehicles, on batteries and accumulators and waste batteries and accumulators, and on waste electrical and electronic equipment set further targets in the EU's transition towards a circular economy. It is important to note with the latter directive, the EU is also aiming to streamline the reporting obligations for the Member States. Thirdly, there are generic energy policy related directives with binding measures, such as the Renewable Energy (Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 2009, 2009), the amended Energy Efficiency Directive (The European Parliament and the Council of the European Union, 2012) (Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency, n.d.), where the former also proposes a list of eligible feedstocks, *inter alia*, the MSW that can be used to produce, for instance, advanced biofuels (Vedder et al., 2016). Finally, the Industrial Emissions Directive (European Council, 2010), which, among other things, is based on an integrated approach, combing the whole environmental performance of the plant, covering e.g. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure.

Referring to the recent WtE Communication, the Commission acknowledges that WtE can play a role in the transition to a circular economy provided that EU waste hierarchy is used as a guiding principle and ensuring that higher levels of waste prevention, reuse and recycling are not precluded (see Fig. 1). The Communication further stresses that only by respecting the waste hierarchy that WtE can maximise the circular economy's contribution to decarbonisation, in line with the objectives set out in the Energy Union Strategy and the Paris Agreement. This is because disposal, in landfills or through incineration with little or no energy recovery, is usually the least favourable option from a climate perspective, as for reducing GHG emissions; and conversely, waste prevention, reuse and recycling have the highest potential to reduce GHG emissions.

The WtE Communication is written within a spirit of WFD to ensure that the waste hierarchy is respected and that prevention, reuse, and recycling are not averted. However, WtE can be attributed to different labels, such as ‘disposal’, ‘recovery’ and potentially ‘recycling’ for anaerobic digestion (as proposed by the WtE Communication, shown in Fig. 2). For instance, MSW incineration plants have been reclassified to a recovery operation by the revised WFD, provided they generate energy and the plants meet the efficiency thresholds calculated using the ‘R1’ formula. The energy efficiency (EE) of the installation must be ≥ 0.65 for facilities in operation since 2009 and ≥ 0.60 for facilities in operation before 2009, where EE is calculated from equation (1)

$$EE = \frac{[Ep - (Ef + Ei)]}{[0.97 \times (Ew + Ef)]} \tag{1}$$

Where:

EE = Energy efficiency
Ep = Energy produced (electricity or heat) in GJ/year
Ef = Energy consumption as fuel in GJ/year
Ew = Energy content of wastes in GJ/year
Ei = Annual imported energy excluding Ew and Ef in GJ/year

To this category are also allocated other technologies, such as gasification and pyrolysis with the final products of syngas, oils and chars, which can be recovered from the process and used as fuel. The WtE Communication (European Commission, 2017a) clearly favours anaerobic digestion (a process that converts biodegradable waste to biogas that can be used as fuel for transport and also for heat and power generation) and raises some concerns about other waste conversion technologies that may undermine recycling. Currently, the WtE facilities in Europe are unevenly spread out (most of them located in the northern part of Europe, whereas the south eastern part of the EU showing barely any capacity at all) (Commission, 2016b). Nonetheless, the study conducted in 2016 by Scarlat et al. found that there is a potential to build around 248 new WtE plants in the EU and 330 in all Europe, with a total capacity of 37 and 50 million tonnes, respectively (Scarlat et al., n.d.). Therefore, there is still potential for WtE facilities, especially those that embrace innovative treatment processes.

While the WtE Communication concludes that could play a role in the transition to a circular economy, there is a strong emphasis on waste hierarchy and therefore, new technologies may not easily find their place in the higher hierarchical position and consequently, may not attain sufficient support. Regretfully, the extent to which WtE can create synergies with other EU policies, such as energy policy and climate policy are not discussed. Therefore, the following section will further explore the multi-purpose nature of WtE.

4. The trilemma of WtE

WtE is multi-purpose by its nature and therefore, adheres to at least three main policies in the EU: 1) waste management; 2) energy union; 3) air quality/climate change. Even though WtE is subject to different EU policies and legal frameworks, all these policies are largely intertwined (as shown in Fig. 3). These three policies are essential for the establishment of a circular economy and directed towards the achievement of a sustainable European future. This paper argues that WtE can provide a solution to different EU policies and has an important role to play in the circular economy via injecting ‘waste’ back into economy as secondary raw materials, therefore reducing the environmental footprint of production and consumption and increasing the security of supply of raw materials, one of the main objectives of energy policy. Yet, the approach of the EU regulatory frameworks towards WtE is rather controversial, which will be discussed in this

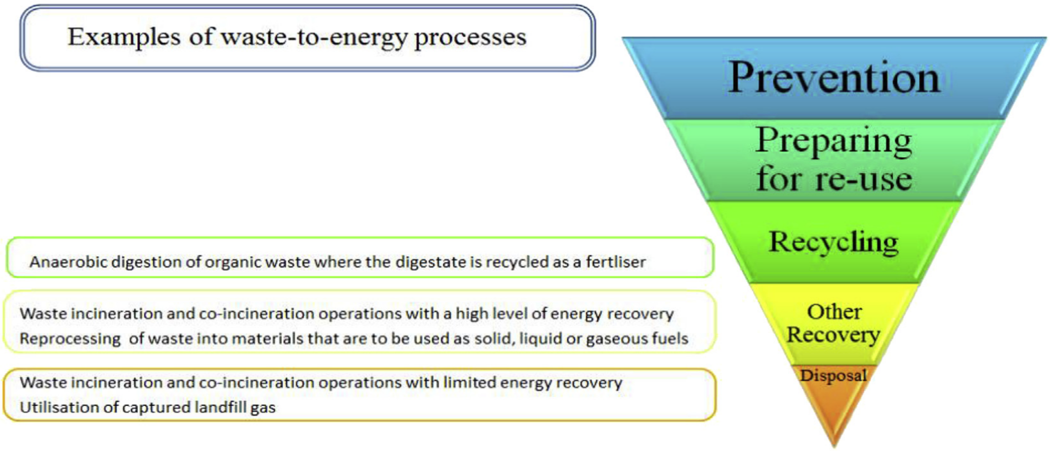


Fig. 2. WtE in the Waste Hierarchy (European Commission, 2017a).

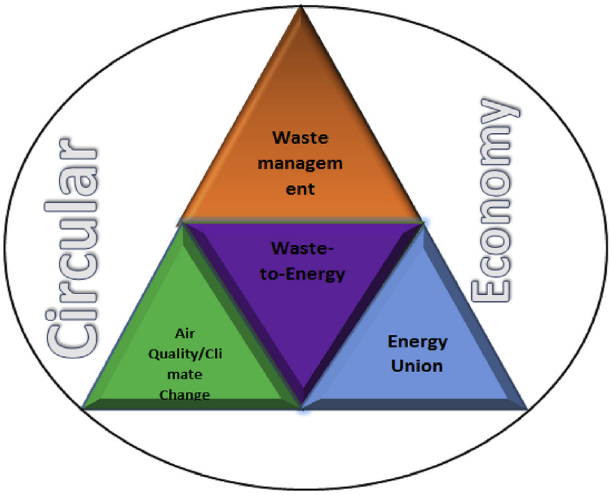


Fig. 3. Trilemma of the WtE the inspiration for this figure was taken from Heffron e al. the Energy law and policy triangle – the 'Energy Trilemma' (Heffron et al., 2015).

section.

4.1. Waste management

Waste management is one of the EU's biggest challenges due to its huge impact on the environment, causing pollution and GHG emissions that contribute to climate change, as well as significant losses of materials. On average, each of the approximately 500 million people living in the EU throws away around half a tonne of household rubbish every year (European Commission, 2010).

The challenges of municipal waste management also stem from the direct proximity of the waste generated to citizens, a very high public visibility, and an active involvement of citizens and businesses (i.e. willingness to recycle etc.). The notion of environmental justice can be recognised here in the context of waste hierarchy (Article 4 WFD) and the principles of self-sufficiency and proximity (Article 16 WFD) (Watson and Bulkeley, 2007), and other obligatory measures imposed by the WFD (i.e. Article 1 WFD (protection of environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use); Article 13 WFD (protection of human health and environment)). As discussed in section 3, waste management should be built in the context of waste hierarchy prioritising higher levels of waste prevention, reuse and recycling. This is because the selection of options higher up the waste hierarchy has the potential to mitigate risks to future generations leading to an environmentally sustainable growth path. Along similar lines, in the context of the principles of proximity and self-sufficiency, the waste management industry should aim for regional self-sufficiency in managing waste and avoid passing the environmental costs of waste management to communities which are not responsible for its generation. As part of its ambitious Circular Economy package the Commission has recently revised legislative proposals on waste and set new targets for the reduction of waste and established a long-term path for waste management and recycling in order to contribute towards reaching the Sustainable Development Goals and the global climate commitments. To achieve this, the EU has set some binding quantitative goals, such as an EU target for recycling 65% of municipal waste, a landfill target to reduce landfill to maximum of 10% of municipal waste, and a target of 75% of packaging waste for recycling by 2030. Equally, to encourage more recycling in January 2018, Brussels adopted the first-ever "European Strategy for Plastics in a Circular Economy". This is because Europeans currently generate 25 million tonnes of plastic waste, but less than 30% is collected for recycling, yet, it takes 500 years to break down plastics (Commission, 2018).

Waste management planning and implementation is the cornerstone of any national, regional, or local policy on waste management (subject to the EU obligation to report of waste management plans, which must reflect the principles discussed above). The Member States also must ensure that they will meet the target set by the EU. Governments may introduce, for instance, a high tax and landfilling fee, to divert the 'waste traffic' from landfills (the least favourite option in the waste hierarchy) in order to make it more economically viable to reuse waste in order to produce energy. For instance, by introducing a landfill tax Estonia has moved from landfilling almost all its MSW just after the Soviet era to only 5% in 2015, whereas its WtE has increased from 16% in 2012 up to 56% in 2014 (Fischer, 2013) (European Commission, 2017b). Interestingly, Norway abolished its landfill taxes in 2015, since the amount of waste being landfilled was so low that the costs for local governments and businesses to implement the tax was greater than the financial revenue the tax created (EEA, 2016) (J. Malinauskaite et al., 2017a). Clearly, WtE can divert waste from landfills. Yet, the Commission is concerned as discussed above that this diversion can potentially have a negative impact on separate collection and recycling schemes of MSW. This is not always the case, as the countries, such as Sweden, Denmark, and the Netherlands illustrate, which have the most WtE facilities and have some of the highest recycling rates in the EU. Estonia could also be added to this list with its WtE facilities and its recycling performance (at least in the capital city Tallinn which was named as one of the best performers in separate municipal waste collection in 2016) (Fh, 2016). Therefore, the paper argues that WtE can complement each other.

4.1.1. Recycling and WtE

Recycling does not function in silos. Recycling and WtE are complementary waste treatment methods, as thermal treatment is needed for residual waste that is not suitable for recycling. When waste cannot be prevented, prepared for reuse or recycled, recovering the energy embedded in it and injecting it back in the economy is the next best environmental and economic option. Currently, household waste and sorting residues account for more than three quarters of the energy wasted in landfills in the EU. In the United Kingdom (UK), WRAP's recent '3Rs tracker survey' on recycling attitudes and reported behaviour revealed that roughly half of respondents claimed to recycle materials that are actually items of contamination (WRAP, 2015). Therefore, Councils in the UK were unable to recycle 338,000 tonnes of waste in 2014–15 - up from about 184,000 tonnes in 2011–12 due to contamination, which ended up in landfills (BBC, 2016). The cost to local authorities of re-sorting so-called contaminated recycle bins is said to be the primary reason the vast majority of the waste is being rejected; with 97% of the rejected waste being incinerated or sent to landfill in 2012–2013, undermining the overall purpose of recycling. Therefore, WtE can help to divert waste from landfills, as secondary raw materials can be fed back into the economy.

Yet, there is an inherent tension between the waste hierarchy and WtE, as the Commission is concerned that, by increasing WtE capacity, recycling will be jeopardised, hence, undermining the waste hierarchy. This tension can be overcome, as demonstrated by the number of countries where high recycling coexists with high energy from waste, at the expense of landfill (Affairs, 2014). The paper argues that recycling and WtE instead of competing can be complementary. First of all, this is because there are some non-recyclable resources in the household waste with harmful consequences to humans and the environment, such as, for example, disposable nappies. It is estimated that 8 million nappies are being disposed of per day in the UK; resulting in an average of over half a million tons of waste in the UK every year being produced from just one source. The main components of disposable nappies are fluff pulp (cellulose fibre) and a water-absorbent polymer (SAP), sodium polyacrylate, which take a long time to break down once in a landfill site (Environmental Agency, 2008). Secondly, there are some products that contain both recyclable and non-recyclable materials and their separation cannot be economically feasible. Lastly, re-sorting contaminated ‘waste’ cannot also be economically justified, as more resources and energy would be needed jeopardising the whole purpose of recycling, as benefits may not outweigh costs. Therefore, this provides an excellent source for WtE. This in turn suggests that the narrow vision of WtE - the need to “feed the beast” in order to maintain economic energy from waste operation is not founded and WtE does not impede prevention and recycling, thus, leading to a conclusion that WtE has a role to play in waste management.

4.2. Energy policy

WtE is not just about waste management. WtE helps to make Europe less dependent on fossil fuel imports and contributes to security of energy supply, a major goal of the Energy Union policy alongside sustainability and competitiveness, which are also concerns of energy justice. The EU's determination is to become a low-energy economy to ensure that the energy consumed is competitive, safe, locally produced and most importantly sustainable. This is because the EU currently imports more than half of all the energy it consumes at a cost of €350 billion per year; in particular more than 90% of crude oil is imported and 69% of natural gas is imported, which contributes to higher prices (Commission, 2017).

In the context of energy justice, especially restorative justice, there is a strong emphasis on renewables (including biomass, which embraces the biodegradable fraction of municipal waste) by the EU to meet its energy needs and make its energy production more sustainable. In contrast to a negative label attached to WtE for its potential diversion from waste recycling to waste recovery, biomass is largely encouraged as a renewable energy source (RES) in Renewable Energy Directive (known as RED) (Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 2009, 2009), including the newest proposal of known as REDII (European Commission, 2016). ‘Waste’ can cease to be a problem and become a valuable resource. The inclusion of the organic portion of MSW in the definition of potential sources of renewable energy has enabled the Member States to meet their national renewable energy targets via the WtE incineration industry. Statistically speaking, biomass and waste are the largest sources of ‘renewable energy’ (also referred to as a low carbon energy source) in Europe amounting to 63.1% of the total share of renewable energy sources (Eurostat, 2014).

Even though under Article 194 TFEU of the Lisbon Treaty, the EU lacks specific energy competences with respect to the national policy mix, the Commission sought to bridge this gap with its most recent relevant legislation framework, “Clean and Secure Energy for All Europeans” or the so-called “Winter Package” of November 2016, to work towards its goals of decarbonisation and the Europeanisation of climate and energy policy. The package pushes the Member States in the direction of more ambitious and better-coordinated climate and energy policies to ensure that they contribute towards achieving the EU binding targets, for instance, the newly revised targets of 32% for renewable energy by 2030 pursuant to REDII (European Commission, 2016), and at least 32.5% improvement in energy efficiency.

Therefore, WtE enables the use of waste as a valuable domestic source of energy contributing to energy security, transforming waste management into sustainable material management with the embedded principles of the circular economy, the diffusion of renewable energy, energy efficiency, improved economic opportunities and long-term competitiveness (European Parliament, 2017).

4.3. Air quality/climate change

Finally, WtE is also linked with climate policy and climate justice. The current challenges include the continued use of fossil fuels in Europe, which is a cause of global warming and pollution. At the same time, energy related emissions account for almost 80% of the EU's total greenhouse gas emissions. Indeed, CO_2 emissions are increasing at an accelerated rate from the energy sector over the last century. This is why the EU aims to reduce its emissions by 45% by 2030 (compared to 1990).

Therefore, reducing resource waste can lower both resource consumption and GHG emissions. For instance, renewable energy from biomass can make significant greenhouse gas emission savings compared to fossil fuels. Compared to the option of landfilling, WtE can significantly reduce the contribution of MSW on GHG emissions through avoiding the release of methane from landfills since CH_4 has much higher potential as a GHG than CO_2 and the global warming potential from CH_4 is 21 times higher than from CO_2 (IS, 2016). For example, diverting one tonne of waste from landfill towards anaerobic digestion to produce biogas and fertilisers can prevent up to two tonnes of CO_2 equivalent emissions (A. Bernstad and la Cour Jansen, 2012).

Moreover, MSW treated through WtE processes also reduce the transport of waste to distant landfills, thus, the fuel is saved and the associated emissions are lower. The Industrial Emissions Directive (Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control) (Recast), 2010) is the main EU instrument regulating pollutant emissions from industrial installations, which aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU.

To conclude, WtE as a key to the circular economy, as apart from its position in waste management, it has strong synergies with the other EU objectives on climate and energy, especially in the context of resources and energy efficiency. It is also instrumental in supporting the EU's commitments on sustainability and its transition to a low carbon economy simultaneously meeting the principle of the protection of the environment, human health and combating climate change. Yet, its role in the circular economy cannot be defined without capturing the importance of technologies in this process, which will be addressed in the following section.

5. HERU in the context of the trilemma

This practical section will discuss the patented micro-scale HERU technology designed to process all unwanted domestic materials to generate clean energy for the household in the context of the trilemma discussed above and its ability to meet the requirements set by different policies. HERU uses Heat Pipe technology to pyrolyse unwanted domestic materials. Furthermore, the innovation of the HERU system is that efficient pyrolysis of unwanted domestic materials is possible at low temperatures (below 300 °C) without the need of any pre-treatment of the feedstock prior to its loading. The key feature of the unit is that the heat injection into the treated materials operates by providing a controlled working temperature (shown in Fig. 4).

5.1. HERU: waste management

Waste management will not be effective without society's involvement. Equally, it is essential to provide incentives to influence individuals' actions by changing their behaviour and their perception of ‘waste’. The studies on individuals' behaviour on recycling found that the lack of concern for the environment is not the issue (Thomas et al., 2003). Yet, human errors are not avoidable, as the statistics on the contamination of recycling materials indicates. The study found that recycling can happen if it is ‘convenient’ to do so (Thomas et al., 2003).

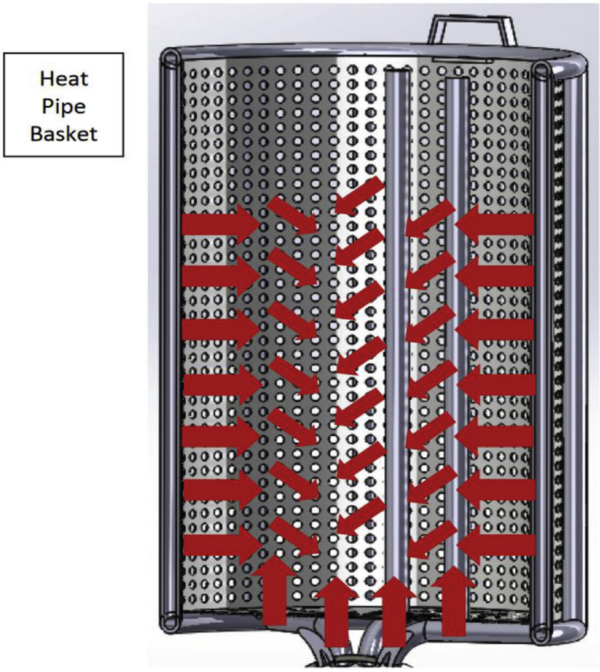


Fig. 4. Cross section of HERU's heat pipe basket. The red arrow show the heat flow within the chamber (Jouhara et al., 2017b). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

This in turn raises two main questions, as to whether individuals have incentives, for instance, to recycle (or treat waste in different ways) and how easily it can be implemented in practice. For example, HERU enables citizens to actively participate in dealing with their own unwanted materials. The Heat Pipe within the pyrolysis chamber allows the process of converting the feedstock into hot water (Jouhara et al., 2017b). The unit is designed to fit seamlessly into domestic properties, resembling a washing machine. Based on the current prototype, HERU can process a small amount of unwanted materials once, approximately 7 kilos. It would involve a regular use of the HERU boiler, as it is estimated that in the two-person household, all unwanted domestic materials would have to be treated about every 3 days. As far as ‘convenience’ is concerned, this technology does not require any prior treatment or sorting, as any unwanted materials can just be loaded into the boiler, therefore, any risks of contamination are avoided. Even materials that are difficult to dispose of, such as nappies, can be converted into a small amount of char. There is one exception, as batteries, cans, and glass cannot be pyrolysed, yet, these materials do not play any role in the ‘energy production’ due to their calorific value being close to 0.

5.2. HERU: energy policy

With the emergence of advanced, smarter technology, consumers can now make more informed choices about energy usage and become energy producers themselves – known as “prosumers”, who consume, produce, and control their energy use. While renewable energy sources such as solar panels are the most common, the HERU technology uses unwanted domestic materials to produce energy in the household. Therefore, in the HERU context, individuals will have a financial incentive not to dispose of their unwanted materials, but place them for further use, in this case to process these materials into clean energy to generate hot water or provide other options for energy conversion for their household. Consequently, it is estimated that the household fuel bill could be reduced by up to 15%, helping address fuel poverty.

Specifically, pyrolysis experiments carried out by Jouhara et al. (Jouhara et al., 2018, 2017b) on the HERU unit show that the reactor requires 5.5 kWh of electricity to treat 7 kg of MSW. Therefore, the power consumption per kg of feedstock is 0.78 kWh/kg. This means that on average 1.6 kWh of energy is generated for every 1 kWh required to power the unit (Jouhara et al., 2017b).

5.3. HERU: air quality/climate change

WtE can contribute to reducing GHGs from the waste sector. The CO_2 emission factor in the UK is 0.41305 per 1 kWh of electrical consumption (IS, 2016). It is estimated that the HERU system emits between 0.0782 and 0.3873 kg CO_2 per 1 kg of waste depending on the moisture content. Based on the CO_2 emission values, it is clear that the highest CO_2 emission is lower than that of the UK's figure.

By treating unwanted domestic materials (save batteries, cans, and glass) with the HERU technology the total CO_2 emissions production can be reduced by approximately 60% (58.88%) enabling the Member States to meet the EU legal requirements for carbon reduction. Provided that HERU was perfectly insulated and no heat losses were observed, the power consumption of the chamber would be around 3.5 kWh, leading to the total carbon footprint reduction of the waste management sector reaching up to 72.22%.

6. An integrated approach – one technology three solutions

As discussed in section 3, WtE technologies are assessed in the context of waste hierarchy. Pursuant to WFD, pyrolysis is allocated to the ‘recovery’ category. Conventional pyrolysis decomposes materials at elevated temperatures relying on direct heating techniques, such as electric heaters, heating with naked flames or exposure to hot media. However, the temperature distribution within the reactors that are heated using an electrical heater is non-uniform, which allows for the production of toxic gases. By contrast, there are no toxic gases produced when using the heat pipe basket to provide the heat for the HERU reactor. This is the biggest advantage of using heat pipes to pyrolyse domestic unwanted materials, which enable uniform heat fluxes from all directions from the heat pipe basket which converts the feedstock into fuel more efficiently (Jouhara et al., 2017a). Therefore, the HERU technology is more advanced than conventional pyrolysis.

It can be further argued that HERU could fall under the ‘prevention’ category of the waste hierarchy, which is determined by both quantitative and qualitative criteria. While a quantitative element is self-evident, as HERU is capable of eliminating all unwanted domestic materials in the household (except batteries, cans, and glass), qualitative aspects require further testing. In accordance to the principle of the protection of the environment, of the human health and combating climate change the qualitative requirement should embrace the reduction of the adverse impacts of generated waste on the environment and human health. The CJEU has also held on several occasions that a substance or object is waste when a further treatment is required to ensure that the WFD objectives of the public health and environmental protection are met (C-418/97, 2000). As discussed above, the HERU technology does not require any further treatment. The system was assessed in the three rounds of tests (i.e. testing the final product, such as char, oil, and ash) with the same composition and weight of MSW. According to the chemical analysis of the pyrolysis residues, no toxic elements were found in any of the tested materials. The main component of char was calcium, the fluid oil obtained from the initial stages of pyrolysis had a similar composition to that of water, while the dense oil produced during the final stage of the process showed traces of iron and a potential composition match to additive oils. The power consumption of the heat pipe based pyrolysis unit was similar to that of an electric oven, while the carbon emissions of the unit were slightly more than a microwave and lower than many household appliances (ETC, 2015). Despite these advancements to transfer unwanted domestic materials to valued resources without posing any threat to the environment, the concept of 'waste' is broadly interpreted in the CJEU (Case C-129/96, 1997) and waste used as fuel to generate energy is currently attributed to a recovery operation.

Therefore, the waste hierarchy is not without its controversies and new technologies may have difficulties trying to fit to the 'higher hierarchical category'. Furthermore, the waste hierarchy is not necessarily the most sustainable route (i.e. the 'best environmental option') for waste management (Lee, 2005). Waste management involves a complex infrastructure (i.e. collecting, transporting, sorting, storing and processing waste), usually organised by local authorities. For instance, local authorities in the Member States may accumulate high environmental costs either transporting waste long distances to recycling facilities (i.e. if GHG emissions from the waste collective vehicles are taken into account) or recycling on a small scale that cannot outweigh the benefits of recycling (Pongracz, 2002). Trade-offs need to be assessed in all waste management options, as the balance between benefit and cost (including environmental cost) will vary depending on sector, place or other issues. These should be calculated embracing, for instance, the *equimarginal* principle, as two waste treatment options, for instance, landfilling and recycling is not sufficient. Yet, economic considerations fall outside the scope of this paper, as it embraces qualitative not quantitative approach.

Unravelling it further, new multi-functional technologies, such as the HERU should be assessed in their ability to address the various EU set targets such as renewable energy, energy efficiency, GHG emission reduction, and diversion from landfills (as shown in Fig. 6).

Waste prevention/diversion from landfills. The waste prevention argument of the HERU technology has been raised in a previous paper (Jurgita Malinauskaite et al., 2017b). This technology can treat any unwanted domestic materials except batteries, cans, and glass leaving a small amount of ash at the end of the process, which can safely be flushed to sewer accounting to about 1–3% of the original feedstock mass. Therefore, HERU could divert MSW from landfills enabling the Member States to meet the strict EU target of a maximum of 10% being sent to landfill. For instance, 59 million tonnes (116 kg per capita) in EU-28 in 2016 were still sent to landfills (Eurostat, n.d.).

Energy recovery/energy efficiency/CO_2 reduction. Energy efficiency (EE) is calculated using the WFD 'R1' formula. Yet, it is designed for continuous processes, whereas the HERU technology uses a batch process, where the unit is used when needed. Therefore, the Coefficient of Performance (CoP) is employed in this paper to identify the efficiency of a system (i.e. the simplified formula calculates the energy output divided by the energy input). It is essential to note that moisture content of the feedstock should be taken into account while calculating the CoP. Fig. 5 shows the CoP of the HERU system, which demonstrates that CoP decreases with increased moisture content of the feedstock. When moisture content is at the minimum, the CoP is at the highest value, whilst the CO_2 emission is at the lowest. This is explained by the fact that the more water is present in the feed, the more power is required to boil the water and thus more CO_2 is released.

The CoP of the HERU unit is 9.4 when moisture content is at 0% and 0.53 when moisture content is at 100%. This in turn means that the average CoP for the HERU unit based on mixed municipal solid waste is 2.6.

Based on a moisture content of 40%, which is typically found in mixed waste, the energy efficiency is 70.5%. This value can be calculated using the following equation:

$$\begin{aligned} Enegy\ Efficiency &= \frac{Useful\ energy\ output\,(kJ)}{Total\ energy\ input\,(kJ)} \\ &= \frac{Heat\ out\ (kJ)}{Electrical\ consumption\ (kJ) + Energy\ in\ char\,(kJ)} \\ &= \frac{14544}{4428 + 16200} = 0.705 \end{aligned}$$

7. Concluding remarks and future considerations

Studies on the importance of the intersectionality of environment, climate and energy as well as assessment of justice issues from a truly interdisciplinary perspective further contributing to long-term solutions have recently emerged (McCauley and Heffron, 2018) (Heffron and McCauley 2018). Embarking on the guiding energy law principles for the protection of the environment, human health, and combating climate change and energy justice (mainly restorative justice) with further studies on the unification of climate, energy, and environment justice with their clear messages that these policies should not be treated as distinct areas of regulation (Heffron et al., 2018), the paper has enhanced the discussion for a joint conceptual space in the context of WtE from a restorative justice perspective. Indeed, WtE is one of the areas that cut across different disciplines and can converge a number of EU policies contributing to the same objectives. For instance, the paper has argued that in the context of *ex ante* nature of restorative justice WtE can prevent potential harm of 'waste' by transferring it in a valuable renewable source of energy, most importantly clean energy, therefore, replacing fossil fuels and contributing to the environment, security of energy, climate change and human health. As per *ex post* approach, WtE has a role to play in the circular economy, by destroying (compliant with emissions standards), for instance, toxic organic substance from residual waste (for instance, after recycling) that are harmful to human health and the environment by removing them from the circular

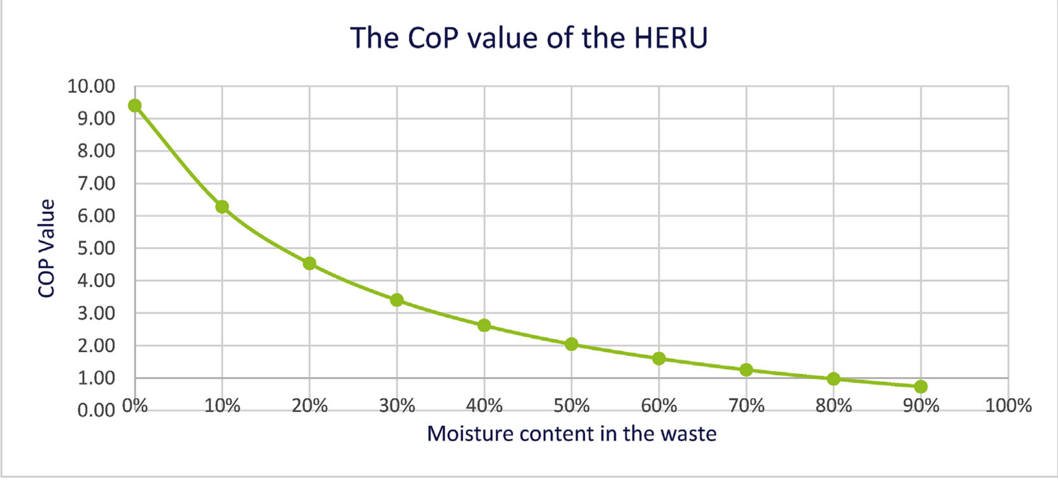
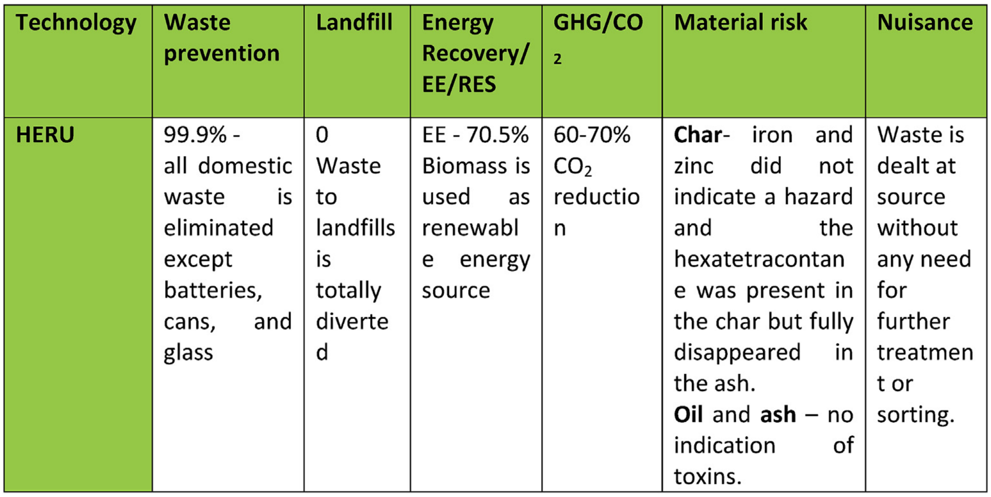


Fig. 5. Graph of the coefficient of performance (CoP) of the HERU system (Jouhara et al., 2017b).



Technology	Waste prevention	Landfill	Energy Recovery/ EE/RES	GHG/CO$_2$	Material risk	Nuisance
HERU	99.9% - all domestic waste is eliminated except batteries, cans, and glass	0 Waste to landfills is totally diverted	EE - 70.5% Biomass is used as renewable energy source	60-70% CO$_2$ reduction	**Char**- iron and zinc did not indicate a hazard and the hexatetracontane was present in the char but fully disappeared in the ash. **Oil** and **ash** – no indication of toxins.	Waste is dealt at source without any need for further treatment or sorting.

Fig. 6. The HERU – an integrated approach.

material flow.

Therefore, the paper explored the potential for a new generation of policy to be designed in the context of WtE based not only on two which are traditionally addressed in the literature but three EU policies – the trilemma of waste management (environment), energy union, and climate change. While the various EU policy documents note that WtE has a role to play in the circular economy, there is no legal framework to this effect, except the recently published non-binding WtE Communication document, which was largely explored in this paper. The paper argued that by placing a sole focus on the waste hierarchy, the Commission WtE Communication guidelines overlooked how new WtE processes can create synergies with other EU policies, such as energy policy and climate policy. Therefore, the paper has aimed to address this gap, especially with the support from a practical perspective. Specifically, it used a case study of the new innovative multi-functional technology, HERU, which can address different challenges, i.e. to eliminate unwanted materials ('waste') and enhance resource and energy efficiency whilst simultaneously reducing the carbon footprint in compliance with the principle of the protection of the environment, human health, and climate change. The paper proposed an integrated approach revealing how new technologies can bridge intricate different EU policies – waste management, energy union, and air quality (climate change) enabling the EU and the Member States to meet their targets linked to these policies, especially in the context of resources and energy security, energy efficiency, and GHG emission reduction.

The paper is not without limits, while it proposed a qualitative integrated approach to be explored and employed to simultaneously solve the dilemma of energy demand, waste management, and greenhouse gas emission in order to move towards the circular economy with further life cycle assessment ensuring just transition and providing the best outcome for the environment, more interdisciplinary research (i.e. especially, from economic and social practice theories) is needed to further enhance the development of a potentially new streamlined strategy. Further studies, for instance, could develop this joint policy framework in the context of just transition to a circular economy by using the quantitative analysis to calculate the social cost (which embraces the environmental cost) of various waste management treatment options and their contribution to meeting the targets of other energy and climate change policies. There is also the potential for further empirical research engaging justice in the transition to a low carbon economy by linking the societal needs and new technologies (i.e. affordability of technology).

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