

Concept Paper

# Closing the Loop Between Energy Production and Waste Management: A Conceptual Approach Towards Sustainable Development

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**Abstract:** Interactions between technological solutions for managing waste and energy supply chains are multilateral and can vary significantly, depending on multiple criteria and different characteristics. This concept paper puts forward a conceptual framework for sustainable development based on the notion of “intelligence” for Waste-to-Energy (WtE) strategies. The pillars of intelligence are defined and the quadruple helix model for energy transitions based on waste management is established. The “smart” nodes of a WtE supply chain management are analytically presented and discussed. Nevertheless, the intelligent notion for a supply chain cannot stand on its own. Systematical support of a participatory process is needed via Information and Communication Technology (ICT) tools and e-techniques to be promoted for collective facilitation and sustainable management. This process encompasses intelligent residents and professionals as producers of waste and smart managers to supervise the supply chain towards sustainable management of energy and waste resources. It is argued that the ICT participatory interface has a multiplying effect, especially when adopting the middle pathway approach in local and/or decentralized level towards smart energy production from waste. Innovative solutions to maximize waste efficiency through the collaborative power of ICT networks is critical to be deployed within local communities. These can be based on internet of things, big data, operational modeling, complex systems science, games and narratives, and social networks. The conceptual framework presented herein provides a basis for decision support towards sustainable development and interaction through a creative pathway of collaboration applicable to all the levels of potential synergies. Main conclusions and future challenges indicate that more research effort is required by the scientific community to leverage on the collaborative power of social networks and to efficiently apply ICT methods for adopting the “socially-oriented” middle pathway approach within communities’ empowerment. Only on this basis may the tale of two challenges have a happy end, both for energy transition and waste management.

**Keywords:** middle pathway approach; ICT; intelligent pillars; quadruple WtE helix; participatory management interface; synergies

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## 1. Introduction

Adequate, secure, and stable energy is the driving force for sustainable development; a vital element for quality of life and longevity of humanity. Sustainability presupposes economic development by ensuring both environmental protection and social cohesion e.g., [1]. Sustainable management of energy resources is a provocation that humanity is still encountering significant political, economic, social, technological, environmental, and legal angles e.g., [2] and necessitates structural transformations in the energy sector. Motives, objectives, and priorities for succeeding “metamorphosis” of the energy sector are interconnected to the 7th Sustainable Development Goal (SDG) of the 2030 Agenda for Sustainable

Development; to ensure access to modern, sustainable, reliable, and affordable energy for all [3]. This goal directly or indirectly supports all 17 SDGs of the 2030 Agenda for Sustainable Development. Themes such as distributed generation distributes energy systems, and energy communities are acquiring an increasingly important role, both in scientific literature and in the construction of scenarios and policies [4].

Energy consumption and the corresponding pressures to the environment and climate is accompanied by many unsustainable practices that humanity adopted during the past, which are still present in the energy system e.g., [5,6]. Global urbanization has contributed to social transformation and economic transition strongly associated with increased consumption of resources, heat island effect, and environmental deterioration in urban areas e.g., [7]. A main environmental concern is waste, an ineluctable output of our society [8]. Waste is a problem that will exacerbate as the phenomenon of urbanization intensifies, the level of population income rises, and the economic model is consumer-centric [9]. Predictions regarding the generation of total waste worldwide illustrate increased rates. It is projected that waste generation will increase from nearly 2 billion metric tons estimated in 2016 to about 4 billion metric tons by the year 2050 [3]. Thus, sustainable management of these huge amounts of waste is one of the most important challenges to handle for the next generations to come.

Having in mind that more than 50% of the global population lives nowadays in urban conurbations and urbanization is a continuous process, the need for transitions in the energy and waste sectors is more than imperative. This transition is related to the entire spectrum of circular economy, decarbonization of energy, climate variation, and sustainable development. Interactions between technological solutions for managing both waste and energy supply chains are multilateral and can vary significantly, depending on multiple criteria and different characteristics. Strategic issues of the energy supply chain related to design and optimal configuration are crucial [10]. Waste-to-energy (WtE) is a technological option that increases the utilization of available resources, by using the waste element as input and energy production is the output; mainly heat, power, a combination of those (Combined Heat and Power-CHP), electricity, and transport fuels. Technological advances and energy efficiency considerations are targeting to lead to less waste generation, smaller “footprints”, and eco-friendly and safer processes [11].

Based on the above, the main concept of this paper is to put forward a conceptual approach that strategically aims to close the loop between intelligent waste management and efficient energy production. More specifically, the main pillars for characterizing a WtE management strategy as “intelligent” are described and their features are critically discussed. For this purpose, the quadruple helix model is analytically defined as an important part of the developed conceptual approach, emphasizing the nodes of an intelligent WtE supply chain management. The interactions with residents, producers, and communities towards strategies that will lead to sustainable energy production are discussed under the middle pathway approach, which is the second milestone of the conceptual framework presented in this concept paper. Emphasis is given on community-based participatory effort based on the promotion of Information and Communication Technology (ICT) tools that allow collective facilitation and WtE management.

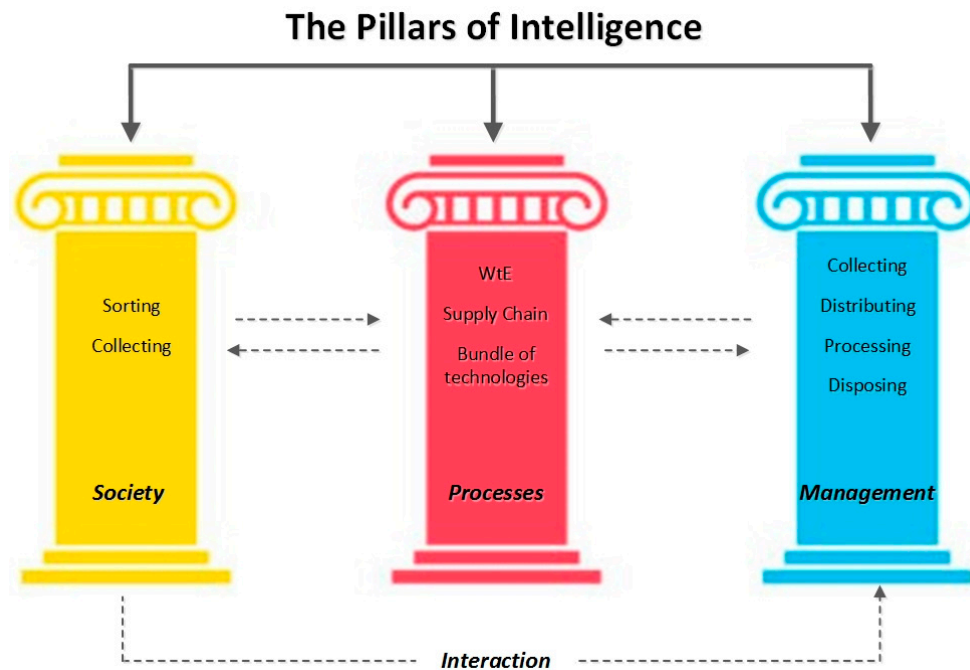
## 2. Pillars of WtE Intelligence and the Quadruple Helix Model

The main feature of an intelligent WtE management strategy is to respect the hierarchy [12], which describes the preferred course of action for the supply chain. Main directions—among others—should be that landfilling is associated with critical environmental load and must be minimized; recycling must be strongly motivated in local communities and performed in an organized way as much as possible; recovery of energy must be maximized from waste with considerable to high calorific content [13]. However, intelligence is a concept that should go beyond the hierarchy. It is based on three basic pillars of intelligence (Figure 1):

- (i) Intelligent supply chain management (processes, mixture of technological solutions),

- (ii) Intelligent managers, i.e., public authorities, private enterprises responsible for collection, distributing, processing, and disposing waste,
- (iii) Intelligent residents and waste producers, emphasizing on smart sorting and collection.

The interaction component between the three pillars of intelligence is the main enabler of “smart” WtE management strategies.



**Figure 1.** Pillars of intelligence for Waste-to-Energy (WtE) management strategies.

Anthropogenic waste streams are channeled through multiple available technological solutions (e.g., recycling, composting, incineration, anaerobic digestion, gasification, pyrolysis, landfilling) and transmute into useable energy carriers, organic fertilizers abundant in nutrients, and, in general, innovative materials [14]. A characteristic example is the production of biofuel (biogas or syngas), a major “vehicle” of energy recovery from biowaste streams [15]. WtE supply chain management pillar (Figure 1) supports fundamental transitions of the energy sector by maximizing the re-introduction of waste, as a beneficial resource, in the energy supply chain. This can be successfully achieved in the framework of a WtE quadruple helix model that is defined herein. It should be emphasized that the conceptual approach presented in this paper is based on four helices that focuses on the optimization of the interactions between energy transition and waste management. On this basis, it differentiates with other important papers that use more generic helix models for sustainable development; e.g., as more characteristic, the new theoretical–conceptual breakthrough known as the Quintuple Helix Innovation Model proposed in other important papers should be mentioned [16,17].

The quadruple helix model encompasses the main driving forces for this fundamental transition (Figure 2), and it is the basis for adopting the optimal mixture of technological solutions adopted in an intelligent WtE supply chain. The helix embeds technological, economic, social-political, environmental, and legal aspects. These are characterized by strong correlations and it is more than imperative to be seen in a holistic and integrated manner. The main driving forces for maximizing the interactions between energy production and waste management are as follows:

- (i) Securing waste (input) and energy (output) in an optimized supply chain,
- (ii) Protecting the environment and climate,
- (iii) Strengthening the competitiveness of energy market with cost-efficient technological solutions,
- (iv) Pursuing social participation and interaction.

The adequacy and advantages of each technological solution should be taken into account to support treatment decisions, considering the type of waste, its calorific value, local conditions, and characteristics [18]. Nevertheless, excess or end-of-life materials previously regarded as waste should secure the continuous flow of the energy, also keeping in mind that WtE installations are operating in continuous flow [19].

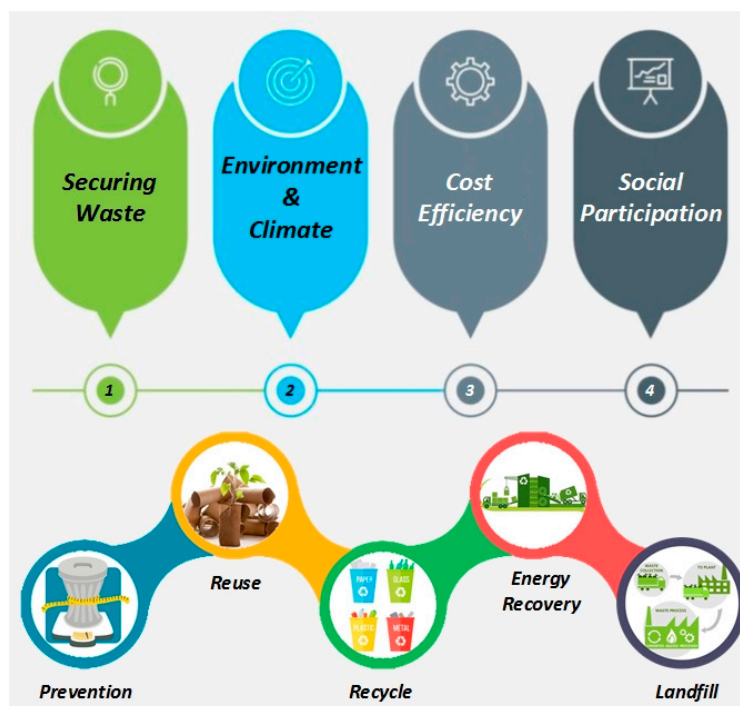


Figure 2. WtE quadruple helix model.

Environmental protection and climate change mitigation is also a main characteristic of the WtE quadruple helix model. Life cycle thinking considerations are embedded, which are a critical feature of an intelligent WtE supply chain management. The significance of Life Cycle Thinking (LCT), Life Cycle Assessment (LCA), and Life Cycle Impact Assessment (LCIA) is emphasized in various relative case studies e.g., [14,19–25]. LCT theory identifies processes and/or flows that result in greater environmental load in the overall environmental effect of the supply chain and LCIA modeling provide a robust basis to quantify different environmental impacts attributed to each link of the chain. This mitigates footprints and contributes to the optimization of the supply chain. In our case, the intense environmental load imposed during the waste supply chain management activities should be modeled and incorporated in the intelligence effort e.g., possible air pollution and Greenhouse Gas (GHG) emissions from processes, intense carbon footprint in waste transport [26], soil and water contamination, reduced land values and landscape blight, and esthetic degradation. Thus, intelligent is “green”, by integrating the environmental thinking into the supply chain.

Strengthening the competitiveness of energy market with cost-efficient technological solutions (and least-cost when possible), must also be a priority, considering the pillars of WtE quadruple helix model. The economic dimension is vital, considering the differences between high-, middle-, and low-income economies. In addition, energy recovery of waste remains an alternative with considerable cost, compared to the other established power generation from conventional energy resources. Generalization of initial capital for investment and operation costs is not advised, since for each technological solution, regional differentiations in market dynamics, governmental motives, economic instruments such as subsidies or carbon taxes, and renewable targets do exist. Important variations also exist across electricity prices, recovery markets for recyclables (e.g., metals from Waste Electrical & Electronic Equipment (WEEE)) and access to district electricity and heating network;

factors that have a strong influence on the internal rate of the investment. Investment capital for specific projects will differ significantly on financing means and conditions in the internal market, maturity of individual technological solutions, and the level of risk associated with political situation in the region. Governmental support motives such as renewable certificates and favorable feed-in-tariffs are significant [27]. Zero-emission strategies and disincentivizing landfill have strongly supported WtE initiatives in markets worldwide.

Pursuing social participation and interaction characterizes the societal pillar of intelligence (Figure 1); aspect embedded in the quadruple helix model (Figure 2). This can be accomplished in the framework of a “vertical” approach to empower residents and professionals as waste producers in local communities to become “smart sorters and collectors”. This is also crucial considering that potential environmental burden of WtE initiatives can generate social implications and concerns about the implementation of a related technology, which can lead to large delays or even to the final annulment of an installation. This situation can be found when installations are adjacent to inhabited areas (Not In My Back Yard (NIMBY) syndrome). NIMBYism is strongly associated with proximity considerations and visual contact. This situation can also be met in other (non WtE) use of energy resources, e.g., towards wind farms promotion and settlement [28]. In the case of WtE, social concerns about carrying potential health safety risks are emerging, especially from the local community’s activists, public health consultants, non-governmental organizations and parts of the general public [29]. There are also worries that WtE facilities disincentivize recycling and are not in accordance with a “zero-waste” economy. Disseminating reliable information to form public opinion and construct consensus for WtE installations is vital, especially for the location and the technology adopted [30].

### 3. Intelligent WtE Supply Chain Management

The intelligent WtE supply chain management is illustrated in Figure 3. It is defined as a smart network of residents, waste producers, sorters, collectors, and distributors to specific processes, which are engaged in different activities. Apart from residents that produce in domestic scale, waste producers can be mainly classified based on categories of types of waste i.e., agricultural (from farmers), facility operators from municipal services, and professional from similar sectors e.g., forestry and fisheries, commercial, healthcare and medical services, industrial, and construction companies. These producers need to be collectively mobilized and empowered. The entire spectrum of chain activities ranges from collection to final disposal of a heterogeneous waste mixture that originates from different products/services. Both private and public participants follow a step-by-step systematic routine where rethinking, redesigning, preventing, minimizing, reducing, reusing, and recycling are consecutively prioritized.

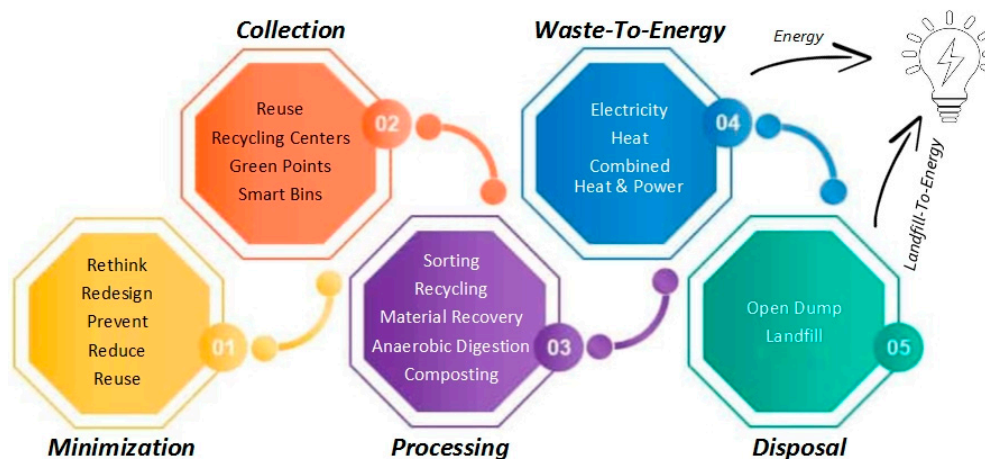


Figure 3. Intelligent WtE supply chain management.



An intelligent WtE supply chain should satisfy different environmental, economic, social-political, technological, and legislative factors. This can be interpreted as constructing a consensus between different opinions, considering that the optimization depicts a strong multi-criteria dimension [31–39]. It goes without saying that waste is a product of society, with significant social and political dimensions, as relevant multi-criteria approaches clearly depict in many regions around the world. The specific characteristics in national, regional, and local level must be considered, provided that they have a different influence in the generation process.

Intelligent supply chain must consider the dynamic character of population growth, urbanization rate, local climate, economic aspects and indicators (e.g., GDP), common lifestyles, and seasonality (e.g., the waste generation in a tourism area related to high seasonal consumption rate). Considering the differences in demography, behavioral patterns, climatological parameters, economic and cultural characteristics, and national energy systems between different communities, waste generation conditions also vary greatly. The economic status of an area plays a critical role in the amount of waste produced. There is a strong correlation between gross domestic product and waste generation per capita [40]. Taking into account the variations of waste sectors internationally, similar remarks can be made for global differences in the energy supply chain. For instance, different climatological parameters are associated with different energy demand in terms of cooling or heating. Increased economic development requires higher energy demand (electricity for industry, fuel for transport, and space heating, etc.) [27]. Population growth and increased demand in transport increases fuel demand.

The legislative framework defines the ruling basis for waste management and energy production. Directives and relevant laws, especially in the EU, demand eco-friendly and more efficient cycles of production [41,42]. They can be accomplished by the introduction of waste residues and by-products in the energy system. There are many parameters that have an influence in the choice of a technological mix. A holistic appraisal is required to put forward a very good or even optimal solution, suitable for the characteristics of each area. Given this, analyzing the interactions between technological, environmental (land use, water use, emissions), legal, and social parameters is decisive.

The intelligent WtE supply chain should be able to encompass the optimal mixture of technological solutions and related processes considering the corresponding interactions between waste and energy supply chains. Thus, intelligence is also about adjustment to the specific characteristics and conditions; a combination of requirements of the region's waste sector with demands of the energy sector. In political terms, the role of governmental policy targets can form the framework, especially in the promotion of WtE (or not) with local policies and regulations. An important issue is minimizing the phenomena of political entanglement that originate from different points-of-view and perceptions related to various technological solutions, phenomena that often impede WtE initiatives and can potentially reduce their feasibility [43].

The political-social dimension intensifies the initiation of synergies between the three pillars of intelligence (Figure 1). The interface between waste management and the energy sector overlaps with milestones that are strongly linked to the human communities. However, the intelligent WtE supply chain concept is important to be promoted but it cannot stand on its own. The chain also needs intelligent producers of waste (as already defined) and intelligent managing authorities (e.g., public authorities, responsible private companies, etc.). Emphasis is given on performing a “smart” sorting element, i.e., residents and professionals as waste producers who interact towards the intelligent use of available resources. In parallel, intelligent managers are needed, i.e., responsible authorities that facilitate intelligent collection, distribution, processing, and disposal. Based on this synergetic character of the three pillars of intelligence, the interaction between waste and energy as commodities are numerous with many different expressions. In any case, sustainable WtE production that minimizes related footprints are central objectives for policy-makers, public authorities, scientific community engineers, and community stakeholders in the overall challenge of promoting sustainable development [44].

#### 4. The Participatory Process in Decentralized Level

Intelligence is based on the interaction between residents, professionals, and managers. These are important links of the same chain. They should be empowered, make better-informed decisions, and depict an interactive attitude that supports the background for collective utilization of waste resources. Socially informed, integrated policy pathways are also encouraged by other scientific publications towards integration of systems thinking and transformative power dynamics [45]. Despite the fact that the main issues for advancement are acknowledged in the interface of waste and energy supply chains, maximizing resource (waste) efficiency to generate secure and sufficient energy is not deployed as it should have been. This issue is hitherto addressed mainly by scientists and stakeholders by a top-down prospect, i.e., solutions from the local, regional, and national authorities (top of the administration pyramid) that move down to the resident/producer of waste in local level. However, the advancement of alternatives encounters one significant impediment, which is the societal behavioral patterns and individual preferences. Amelioration of behavioral styles can be achieved if individuals are more exposed to data and information and are involved as a part of a community. This will be significant both for personal and collective behavior [46,47]. Choosing to introduce reusing and recycling as a way of living is a potentially significant major resource-saving strategy associated with lifestyles and common societal behavior. Individual habits that can result in a more environmentally friendly of living can save both waste and energy and other resources [48–50].

However, more advanced techniques should go along with simple lifestyle shifts; i.e., pursuing social participation and interaction in organized way, based on ICT tools and e-techniques. Disseminating simplified data reports or environmental facts is no longer an ample procedure for informing communities [51], as it is recognized by environmental research, policy, and concepts of participatory governance. This is enhanced, considering that we are going through an era of over-information and data “shooting”. Achieving this challenge, supplying residents/producers with incentives and smart tools will support the effort towards changing behavioral ways in a more sustainable way. Characteristic examples of smart tools are depicted in Table 1. Tools based on internet of things, big data, operational modeling, complex systems science, games and narratives, and social networks are main enablers in the transformation process towards intelligent waste production communities. E-techniques can play a crucial role in putting forward co-creation approaches and sharing of knowhow that can activate the collective intelligence of residence and waste producers and lead to highly cooperative behaviors and enhanced lifestyles.

In perfect alignment with the above concepts, Figure 4 illustrates the middle pathway approach. This concept defines an innovative pathway with specific steps to put forward tools and e-techniques to ensure interaction of all nodes of the supply chain, both vertical and horizontal. A well-organized sorting procedure in individual level for important waste categories should be established i.e., glass, paper, plastic, food waste and organics, yard waste, frying oils, agriculture waste (for farmers), etc. The basic element of societal intelligence pillar is to monitor the supply chain at the grassroots echelon. Important parameters to monitor are the waste elements of the mixture produce and/or the production of waste categories per capita for a more meticulous analysis. The monitoring procedure illuminates facts that are to be associated with behavioral patterns, lifestyles, and business patterns for waste producers. This expresses a bottom-up approach and it is prerequisite to empowerment, which gives confidence to local communities to encounter sustainability problems, such as that of maximizing waste resource efficiency to produce secure and adequate energy.

The next level is enhancing the participatory process of residents and professionals as waste producers in the intelligent WtE supply chain by sparking the interaction element based on a social-oriented scheme. The importance of ICT, e-tools, and smart applications towards this direction is more than critical. The participatory process has a multiplying effect when adopting the middle pathway approach notion in decentralized level towards smart energy production from waste [52–54].

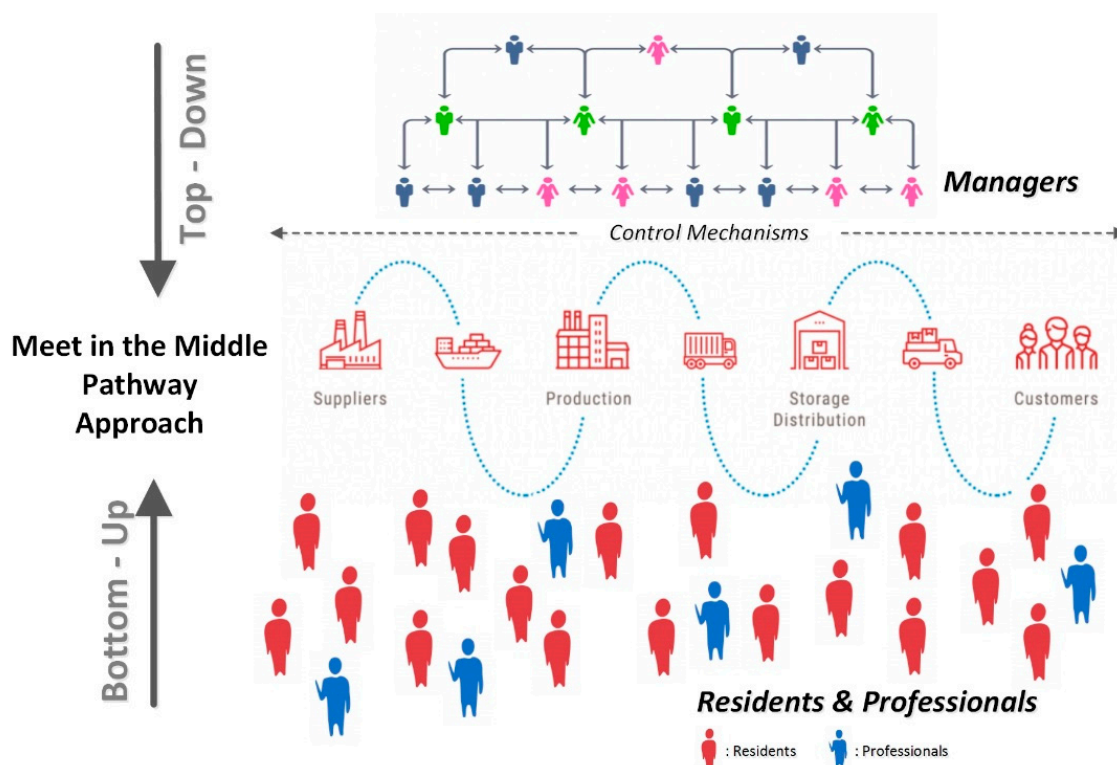
**Table 1.** Information and Communication Technology (ICT) tools and e-techniques for “smart consumers” and associated e-techniques.

Example	Short Description/Objectives
<p><b>SENSONEO:</b>  “Smart enterprise-grade waste management solutions for cities and businesses to cost-efficiently manage the waste lifecycle and improve the environment and well-being of people. ”</p>	<ul style="list-style-type: none"> <li>■ ICT tool for waste monitoring solutions.</li> <li>■ Uncovering and understanding the complex dynamics of waste production.</li> <li>■ Combines smart sensors, smart waste management system and citizen mobile phone application.</li> <li>■ Smart sensors use ultrasound technology to measure the fill levels in bins and containers several times a day and send the data to the smart waste management system,</li> <li>■ Cloud-based platform, via the Internet of Things (IoT) (Sigfox, NB-IoT, LoRaWAN, GPRS) providing cities and businesses with data-driven decision making, and optimization of waste collection routes, frequencies and vehicle loads and bin distribution that result in waste collection cost and carbon emission reduction.</li> <li>■ <a href="https://sensoneo.com/">https://sensoneo.com/</a></li> </ul>
<p><b>ALMANAC WasteApp:</b>  “ Reliable Smart Secure Internet Of Things For Smart Cities”</p>	<ul style="list-style-type: none"> <li>■ Service delivery platform with corresponding technologies that integrates Internet of Things (IoT) edge networks.</li> <li>■ The Smart City Platform (SCP) collects, aggregates, and analyses real-time or near real-time data from appliances, sensors and actuators, smart meters.</li> <li>■ Pervasiveness by defining a capillary radio network providing local Machine-to-Machine (M2M) connectivity to smart things.</li> <li>■ The SCP supports end-to-end security and privacy and two specific applications (waste management and water supply) have been selected for proof-of-concept implementation and evaluation.</li> <li>■ Business model framework based on the concept of dynamic value of actors based on public-private partnerships.</li> <li>■ <a href="https://www.almanac.in-jet.eu/news.php">https://www.almanac.in-jet.eu/news.php</a></li> </ul>
<p><b>“ SMART BIN” WASTE APPS:</b>  “A smart mobile app for waste management”</p>	<ul style="list-style-type: none"> <li>■ Develop easy to use, desirable ICT-based tools.</li> <li>■ Use of IoT for the urban waste collection management.</li> <li>■ Maps and position sharing assist finding the closest facilities.</li> <li>■ Recycle bins enable the responsible authorities to collect waste more efficiently and manage it in holistic way.</li> <li>■ Characteristic examples of smart bins can found in Prague, Dublin, Malta (iBins) and Lisbon.</li> </ul>
<p><b>FORAGE TRACKING:</b>  “Mapping the tacit knowledge and spatial organization of informal recyclers”</p>	<ul style="list-style-type: none"> <li>■ Location-detecting hardware and software to investigate how, informal recyclers in Brazilian cities, find and collect material in the city.</li> <li>■ Participatory platforms that organize activities and connect the cooperative to the citizens.</li> <li>■ <a href="http://senseable.mit.edu/">http://senseable.mit.edu/</a></li> </ul>



Table 1. Cont.

Example	Short Description/Objectives
<p><b>EveryAware:</b> “Measuring your way to a healthier environment”</p>	<ul style="list-style-type: none"> <li>■ Assists citizens to collect, share and understand their environment.</li> <li>■ Platform that allows organizing games as well as collecting and estimating environmental information.</li> <li>■ This new way of accessing environmental information can trigger changes in the citizens’ behavior due to an extended awareness of their environmental situation.</li> <li>■ An affordable low-cost sensor solution in combination with a smartphone and a web service have been developed.</li> <li>■ <a href="http://www.everyaware.eu/">http://www.everyaware.eu/</a></li> </ul>

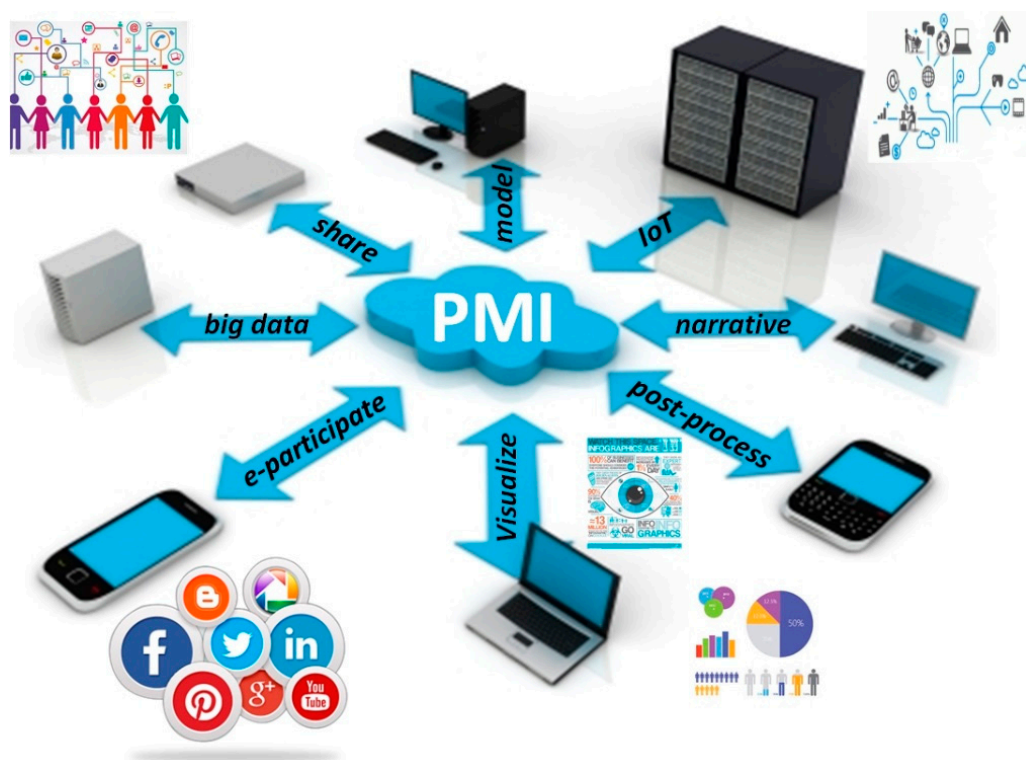


**Figure 4.** The middle pathway approach towards maximizing the participatory process.

However, heretofore, the participatory effort and the reciprocal action towards the transition to community of “intelligent” waste producers, is not adequate in multiple levels horizontally in the supply chain and vertically from top to down and bottom to up (Figure 4). This omission of synergies is accompanied—in some cases—by low rates in digitalization that depict a considerable effect on the speed and efficiency of sharing real-time important information and data in many regions globally. Keeping in mind that the participation of residents/waste producers is entirely absent, the maximization of waste resources towards the production of decentralized energy is seriously impeded. Considering also that behavioral patterns and socioeconomic factors influence participation in community-based waste management programs [55,56], incentives and e-tools for a hybrid participatory effort should be put forward to facilitate the middle pathway approach in an e-framework. Assembling the network of nodes of the intelligent WtE supply chain in one ICT platform can be helpful. This illustrates an inter-dimensional problem and is characterized by a strong multi-disciplinary character. Methods can be deployed within local groups to nurture interaction via an innovative pathway of creativity and synergetic contribution, applicable to the levels of potential synergies along the WtE supply chain.

## 5. Collective Management Towards WtE

Figure 5 depicts the logical scheme of the collective management for strengthening the application of the middle pathway approach. This is based on innovative solutions to maximize waste efficiency through the collaborative power of ICT networks. Various producers of waste in terms of different types and volumes generated need to become empowered for participatory facilitation and management. The center of the scheme is an interface of the three pillars of intelligence, the Participatory Management Interface for Intelligent WtE production. This interface synthesizes the processes and nurtures teamwork based on an “e-participation” framework that consists of sharing data for interaction, post-process available data (aggregate, analyze, interpret), infographics, dashboards, and visual objects for simplified and comprehensible information, explaining and guiding.



**Figure 5.** Logical scheme of the collective management for strengthening the application of the middle pathway approach in the framework of the presented conceptual approach.

Figure 5 illustrates that intelligent residents and professional as waste producers adopt e-techniques, to keep under systematic monitoring their waste production. The conceptual approach is based on “Actual Groups” i.e., waste producers in local communities with similar characteristics in terms of residential behavioral patterns and business patterns that influence waste type and volumes. Apart from residents, that produce in domestic scale, waste producers can be mainly classified according to waste type categories i.e., agricultural (from farmers), forestry and fisheries, commercial, healthcare and medical services, municipal services (facility operators), industries, construction companies (professionals), which should be collectively empowered and mobilized. This societal framework based on the participatory management interface (PMI) in Figure 5 raises individual awareness, especially for residents to become intelligent waste producers and sorters, but also collective awareness to the supply chain. Comprehensive games and narratives assist in transferring information and knowhow by observing the impact of behavior patterns related to waste production and available alternatives to make resources management more efficient. This would be crucial, especially for the metabolism of domestic producers, appraised from the energy aspect, while a small number of papers dealt other pressures such as air pollutant emissions and waste [57,58]. This social foundation expedites effective governance and policy by increased clarity of the decision-making scheme and input data, a step towards informed decision through an e-democracy framework.

Via the participatory management interface, residents and professionals are able to gain a better understanding on the processes of collective awareness and behaviors and online networks. Thus, behavioral/business change can be triggered by understanding the dynamics of waste production by e-tools such as those included in Table 1 for pattern analysis and diffusion of information. The interface brings forth possibilities for producers’ empowerment and interaction (Figure 4), e.g., informing municipal or private companies by a smart mobile app for possessing a stock of a specific amount of waste to be collected and processed in the supply chain. This example is essentially an ICT interaction between producers and managers. This promotes newsfeeds and better-informed decision-making processes.

Summarizing the above, effort is required by the scientific community to leverage the collaborative power of social networks and to promote ICT methods and tools for adopting the “socially-oriented” middle pathway approach within communities’ empowerment. However, there are matters that can be put forward as future challenges in the material discussed herein. The main challenge for the scientific community and the political sphere is to maximize the penetration of ICT in the policy-making procedure that will expedite an e-democracy framework on the basis of:

- (i) Equal opportunities,
- (ii) Increased transparency and accountability,
- (iii) Quality assurance of the disseminated data for WtE initiatives.

In addition, assessing societal behavioral shifts that are characterized by an intense dynamical nature can be significantly assisted by tools for societal behavioral modeling of residents and professionals as waste producers. This should also be a crucial future interdisciplinary challenge for science.

## 6. Conclusions

The waste management sector confronts many questions that cannot be answered on their own. Nevertheless, the energy sector is an ideal match, due to its necessity to constantly meet the growing demand in the energy supply chain. WtE technology can simultaneously address two fundamental issues: Processing non-reusable and non-recyclable waste streams and producing significant energy amounts in the corresponding supply chain to satisfy the growing needs in regions over the world. In response to the increasing concern about waste environmental related issues, the waste sector must switch to “intelligent” in its supply chain to consider its effect in terms of environmental deterioration and climate change and adopt initiatives to reduce this effect. A main conclusion of the concept paper is that intelligent WtE strategies require a participatory process. The ICT road path towards implementing the middle pathway approach concept is crucial. ICT forms the basis for residents’ empowerment and professionals’ motivation to affiliate more eco-friendly behavioral patterns in order to maximize resource efficiency.

There is an imperative need to drive scientific community’s and society’s effort towards circular economy, decarbonization, and sustainability. Maximization of the efficiency of waste resources is strongly related to the optimal management of energy resources in order to establish a sustainable energy system for the greatest societal benefit; a vital issue for sustainable development. In the material presented herein, it is clearly depicted that a hybrid and holistic manner is required (i.e., mixing a bottom-up and top-down perspective). It is difficult to make important transitions and transformations, if we will not firstly transform ourselves. This can be realized more effectively when the authority-to-resident modus operandi is collaborating with the bottom-up participatory effort. It is the author’s strong belief that when WtE solutions are implemented through the framework presented, at that time both a rational waste treating strategy and low carbon footprint energy production can be accomplished simultaneously. On this basis, the tale of two challenges may have a parallel happy end, both for energy transition and waste management.

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