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Waste-Energy-Climate Nexus Perspective Towards Circular Economy: A Mini-Review

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ABSTRACT

Population growth requires high demand for vast resources, which includes energy and the consumption of goods. With this strangling situation, many developing countries – including Malaysia; need to face other associated issues such as waste generation as well as climate change. To survive this daunting scenario, a smart alternative known as Waste-to-Energy (WtE) technology emerges as a viable solution to overcome these contemporary challenges. By implementing this technology, waste can be transformed into new energy sources that can be used to meet the needs of the standard energy requirement, whilst, solving mass pollution problems. Though it may sound like a promising solution as of this moment, the availability of these resources and the longevity of this technology is relatively unknown. A mini-review of the modern nexus of waste and energy with the value-added of climate change may enhance the understanding of this linkage and forecast its long-term sustainability. Additionally, this review features an innovation compares with the mainstream reviews by evaluating the nexus of these three in line with the Circular Economy framework (CER). This review encompasses a body of grey-literatures and peer-reviewed literature from multi-disciplinary perspectives including government, researcher, and public. Information obtained in this study exhibits a significant linkage between waste utilization, climate change, and energy security. Identified implications and effects of each provide vital insight towards the establishment of national and global CER. Apart from that, WtE technology turns out to be the best effort as part of the waste minimization strategy and serves as a key factor that can attenuate the environmental impacts concurrently meeting the growing demand of national and global energy.

Keywords:
Energy; Climate Change; Circular Economy Framework

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1. Introduction

The world's urban population is projected to rise up to 9.7 billion in 2050, where the highest growth rate is estimated to strike majorly in Asian countries [1]. As the population number increasing, they are several things that require specific attention from the global community. World Economic Forum website reported that the number of waste produced will potentially grow up to 70 % by 2050 [2]. Our poorly limited landfills are having constant stress due to the unstoppable amount of municipal waste being generate abundantly every single day [3]. Inefficient waste management process creates massive additional waste being led to the landfills, including the one that has

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recycling potential [4-5]. This improper management also creates many detrimental effects on the environment such as biodiversity degradation, air and water pollution, and resource depletion [6-8]. Aside from that, this rising population trend only exacerbated the situation, even more, when the world is having the insufficient replacement of non-renewable sources for energy production [9]. The conventional fuels that we are currently used are the main culprit that causes the greenhouse effect which eventually leads to global warming and climate change issues [10]. As a consequence, non-renewable resources, such as fossil fuels, made up of natural gas, coal, and oil, are higher in demand and have recorded being dwindles gradually [11]. Waste to Energy (WtE) has emerged as a relevant technological soluation to tackle these problems. This technology combines waste and energy nexus to create a new natural energy that is believed can be a cure to the climate nexus problem. However, the longevity and availability of the resources used for this technology are unpredictable, thus the success of this technology still becomes questionable. Many researchers have highlighted certain nexus related to this topic such as energy and climate nexus [12-13], waste, and energy nexus [14-16], and intercorrelation between them, but none of these researchers have combined these three nexus simultaneously. Recent papers discuss another important aspect which is the circular economy [17]. It is considered as a key point that will ensure the availability and sustainability of the resources used in this technology in the long run. Different authors have agreed that the circular economy is an important aspect that should be highlighted through nexus studies [18-19]. This study will be focusing on three nexus which are waste, energy, and climate. Apart from that, the nexus among them will be discussed and their context with the circular economy in Waste-to-Energy (WTE) perspective will be elaborated. In particular, practical and research concerns relating to the assessment of the relation between these three nexus will be addressed: waste, energy and climate change, and the sustainability of WtE technology as a tool that can help keep the sustainability of these three nexus through CER framework

2. Methodology

A systematic review is one of the key components in research. Through summarizing literature from the previous study, a certain gap is established and the information generated by certain areas of research is improved [20- 21]. According to Rowley and Slack [20], search engines and online databases are among the popular method to do the literature search. In this research, we use many search engines to access the peer-review literature, including *Science Direct (Elsevier), Scopus, Springer Link, Emerald Insight, and Wiley Online Library (Wiley)*. Other than peer-review literature, we also collected some sources from grey literature. Grey literature is a non-peer-reviewed publication that is organization or discipline-specific. This entails studies and other publications by federal departments such as the United States Environmental Protection Agency (USEPA), international institutions such as the United Nations, and non-governmental groups such as the World Wildlife Fund (WWF) [22]. This review comprises of an extensive body of grey-literatures and peer-reviewed literature from a multi-disciplinary viewpoint which includes the government, policymakers, industries, researchers, and the public. Some specific keyword has been used to acquire the desired result such as Circular Economy (CE), the definition of CE, principles of CE, CE and waste, waste utilization, CE and climate, greenhouse gas emission, CE and energy, energy recovery, energy security, renewable energy, Waste to Energy Technology and Sustainable Development Goals. After going through all the sources, we have selected 50 sources to be included in the citation manager. We also have using the specific criteria for the literature selection. The flow of literature search was conducted based on Figure 1. Initially, we present an overview of each issue individually. We will define the concept used in this paper and present some of the most recent literature and ideas in each of the related selected nexus for this issue. Various use cases and analyses at various levels provide insights and exemplars into the relationships in later sections. We will create a theoretical framework that comes out with a solution. From there, we will go specifically based on the current situation happening in Malaysia, and the potential of WtE implementation in Malaysia based on the nexus relationship that has been discussed in the earlier section.

3.Results

3.1 Understanding the Concept of Nexus

Nexus can be simply defined as a connection or link [23]. Despite the fact that it has just been discovered in recent decades, the global attention received from multi-disciplinary researchers on this topic is extraordinary. Recently, the Nexus approach is being used progressively at the project level and supported by some governments, civil society, international development partners, the private sector, and researchers [24]. According to Endo *et al.,* [25], there is no clear definition of the term "Nexus". While, Brouwer *et al.,* [11] has defined "Nexus" as a linkage between resource to the other such as energy, food, land, and climate. Through this concept, it is believed that by putting pressure on one part of Nexus, another pressure will be created on another part as well. In managing resources, including waste, the application of the Nexus concept seems particularly relevant. Hettiarachchi [26] emphasized the importance of nexus thinking in the management sector, as it can take place across established disciplines to improve resource efficiency. It is noted that since 2015, the term "Nexus" mostly being used in Human Society studies, which discussed the Nexus between energy and its associates, such as Energy-Water or Energy-Climate Nexus [27]. The development of the Nexus application indeed showed the significance of this concept as it can enhance the understanding of any subject being studied. For example, in de Bercegol and Gowda [15], they refer a waste-to-energy plants as a 'modern nexus' of waste and energy, and 'alternative nexus' as the existing traditional recycling sector. It is turn out that by grouping within more specific Nexus, the more efficient outcome is obtained. Figure 1 illustrates the flow of for literature review.

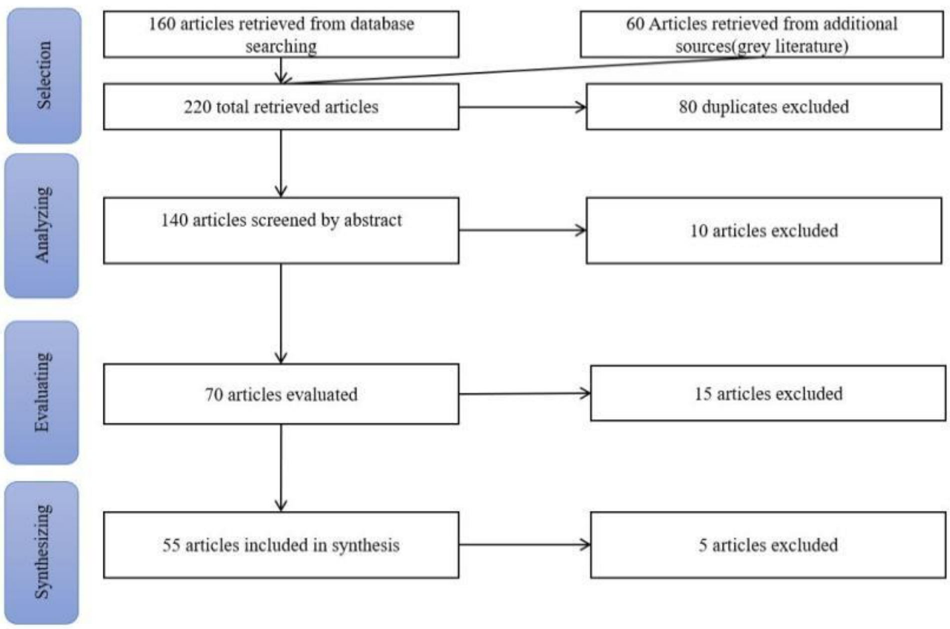

Fig. 1. The flow of literature review

3.1.1 Climate-Energy Nexus

Energy and climate are two factors that are strongly correlated with each other. Different authors have agreed that the synergy between climate and energy should be put in the limelight since they have a big influence on each other [28-29]. Problems that occur within these two Nexus such as climate change and energy depletion are frequently related to human activities. Activities such as open burning, deforestation, and fossil fuel combustion increase the greenhouse gases that lead to global warming and the change of climate [30]. These activities also involved much energy been sacrificed through multiple levels. Most countries are highly dependent on non-renewable sources as the main source of energy. For example, in Malaysia, about 80-90% of the domestic's install generation capacity and output is made up of gas and coal [31]. This high dependency level will become a nightmare for the country's development in the future. If we are keeping counting on this conventional fuel, carbon dioxide emission will be increased and will lead to a more serious problem such as environmental pollution.

According to Othman *et al.,* [32], it is estimated that carbon dioxide emission will rise to 8.6 billion metric tons from 2020 to 2035, and as a fact, half of these polluted gas will be remaining in the atmosphere. This pollution will eventually lead to global warming and greenhouse gas emission that can cause climate change problems [33]. Climate change can universally threaten the economy, environment, and livelihood of people [34]. At this level, cleaner alternatives are required to ensure the sustainability of the planet. In solving this issue, the energy recovery application seems to be the most promising solution. It receives significant attention, where it did not only come in handy in terms of waste minimization approach but also it can help to maintain the sustainability of the energy sources at the global level. Through energy recovery such as Waste-to-Energy (WtE) technology perspective, the nexus between climate and energy will able to be balanced. According to King and Gulledge [35], climate change is a dominating factor that can disrupt the energy system and influence energy security. By implementing this technology, the energy depletion issue will be solved subsequently, while reducing the effect of climate change. Malaysia is considered a lucky country because it has abundant natural resources that can be used as alternative energy such as biomass, solar, wind, and hydropower. At present, biomass accounts for 16% of the country's overall energy distribution, where 51% of it is from palm oil and 22% from wooden waste, followed by solar energy as the second-largest potential as energy replacement in Malaysia. These renewable sources are available throughout the country and can be harnessed abundantly [36]. This current status showed a positive insight on energy security forecast, and we can maintain energy at a secure level if we find a way to utilize these sources efficiently. The government also plays an important role to focus on energy policies that can promote and encourage clean and renewable energies among the industry players and users, for future energy security at a global level, including Malaysia.

3.1.2 Climate-Waste Nexus

There are multiple series of waste management method that has been introduced from the past few decades. Waste management options have been evolved from linear to the circular method, which includes the traditional landfill approach to the advance option such as incineration and WtE. Despite this evolution, waste management still becomes a controversial issue that is still being discussed openly in the modern world. This is due to the fact that improper waste management still becomes one of the main factors that contribute to the current environmental problem such as pollution and climate change [37-38]. Dutta *et al.,* [8] have verified a significant linkage between waste management and climate change. Their finding showed that the lack of awareness, policy implementation, and supply chain are the factors that contributed to poor waste management. Figure 2(a) shows the waste management hierarchy that is currently practiced globally, which recommends sustainable practice as an important part of waste management [39]. Based on the figure, the most sustainable way of managing waste is by minimizing or reducing waste at the source. Unfortunately, people tend to choose an easier way such as disposal as a favorable practice. Some have agreed that reduction at source is quite difficult to implement [37,40]. In fact, Esa *et al.,* [41] has emphasized that the 3R principle which includes reduce, reuse, and recycling practices is insufficient to mitigate the waste generation. Thus, the implementation of WtE may resolve this issue more properly. It is, in fact, an intelligent approach that allowed human behavior that keeps producing waste, to now become less burdened since this waste can generate positive output such as cleaner energy that will reduce the climate change effect.

3.1.3 Definition and the key concept of circular economy

The circular economy has vast definitions explained by many researchers from different fields [15]. It is usually defined as a system that keeps the life cycle of a product for a little longer by shifting the 'end-of-life' concept with restoration, and preventing toxic contains in product from polluting the environment through repairing, reusing, and redesign the product before the last cycle which is the elimination process [42]. Preston [43] has stated that it is a concept designed based on the regeneration aspect, such as reducing the consumption of raw materials. Figure 2(b) shows the cycle include in the circular economy concept and comparison between the current linear economy practice [44]. The idea started with the materials being in a cycles which includes recycling, remanufacturing, refurbishment, reuse, and reclamation. Circular economy activities will minimise costs by reusing products and reducing waste, thus creating new revenue opportunities for businesses [45]. It is practically in line with the sustainability elements in the social, environmental, and economic aspects. According to Sariatli [46], the linear economic model that consists of disposal as the final method in managing waste is totally impractical when not only did unmanaged waste lose its original purpose, but it was also become wasted, as its potential as a new source of energy is being neglected. This also has contributed to resource exploitation efficiency, resulting in an unacceptable amount of waste production. Thus, a new circular economy model has been introduced to improve the current linear.

Fig. 2(a). Waste management Hierarchy Adapted from Cristóvão [39]

Fig. 2(b). Linear Economy versus Circular Economy. Adapted from Circular Economy and Linear Economy Presentation Graphic [44]

3.1.4 Waste-Energy-Climate Nexus and Circular Economy

Waste-to-energy (WtE) is a modern approach that quite convincing and comes with a sustainable influence that acts as a critical measure to manage waste. According to Nerini *et al.,* [47], renewable energy is in the most central position of the intermediate circle due to its cumulative effect. It virtually links each industry, enabling many inter-sector synergies. Similarly, Chen *et al.,* [48] concluded that WtE is a predominant measure to establish a circular economy system. In waste-energy, waste can serve as raw material where three problems; waste management, energy generation, and greenhouse gas emission can be solved at once. To meet the material demand of society, cost-effective waste management approaches are needed. In this context, the concept of "reuse and recycle" must be promoted. For example, the recovered materials from waste can be used for remanufacturing processes. Waste to Energy in balanced coordination with the recycling of waste at source is considered the most effective, powerful, advanced, and updated technology for solving urban solid waste management and treatment problems [16]. However, it does have a downside. There are still a few implementations needed to obtain the optimum benefit of this technology.

Generating power or producing chemicals from municipal solid waste (MSW) may be more expensive compared to production from conventional raw materials. However, reducing the landfill area and reducing greenhouse gases from methane emissions make thermal treatment an attractive and feasible option. Other than that, the generating capacity from this technology is also unstable [49]. Waste that we obtained through seasons maybe change in terms of quantity and form. For example during Ramadhan season in Malaysia, there's a significant increase in food waste, thus it causes the high water content and low heat value of MSW being generated for the month [50]. Other than that, some waste emits harmful and dangerous flue gases after incineration at high temperatures. They cannot be eliminated, even though some treatment method has been applied during the process. It will cause several effects on the environment, and if that's happened, the whole thing will be pointless [51]. So, the right policy is needed to control and prevent the decomposition of toxic and hazardous gases to avoid any significant harm to the environment during the decomposition process. Despite those few drawbacks, it is still considered as the best among the other waste management practices that ever exists. Through WtE technology, many technical advantages have been highlighted as compared to the previous waste management technique, such as landfill and composting. Through this method, the waste is reduced efficiently through stabilization, well sanitation, and also useful energy generation and recovery [52]. Thus, it has the potential to preserving balance in the energy cycle and fixes the requirement for sustainability in sustainable development. It also can help to reduce a significant waste volume on a massive scale, which up to 80-90% [53]. Other than that, it also brings less harmful effect to the environment as the incineration process that uses high temperature is effective in decomposing harmful substances in waste by killing the pathogen completely during the process and reducing harmful substances such as viral contaminants, toxic organic compounds, and flammable carcinogens [54]. By converting waste to biomass energy, we also can further leverage the circularity of energy [55]. As a linear economic model is no longer an option, we may prevent the efficiency of resource extraction, which cause an unsustainable amount of waste production [46]. Therefore, it is undeniably competent to be featured in the current circular economy concept. In Malaysia, the circular economy seems like an ambiguous long-term goal as we have a limited legal framework. However, we are moving in the right direction since we are having convulsive practices of cleaner production at firm levels [56]. WtE technology turns out to be the best effort as part of the waste minimization strategy for now and it has a big potential to serve as a key factor that can attenuate the environmental impacts concurrently meeting the growing demand for national and global energy.

3.2 Proposed Prepositions

It is observed that there is both direct and indirect preposition between the circular economy and waste-energy-climate. The primary arguments made thus far have shown some couplet relationships between the four subjects. Multiple associations, including two-way communications and moderating relationships, are involved in the complexities. Therefore, for these subject matters, we initially suggest three general solutions.

3.2.1 Preposition 1: WASTE-CIRCULAR ECONOMY-CLIMATE

Circular economy act as the facilitator that can restrain the interrelationships between waste and climate. Application of circular economy practice that includes part of waste management strategy such as reduce, reuse, and recycle can be applied to extenuate the climate change effect.

3.2.2 Preposition 2: ENERGY-CLIMATE

The regulation of CO_2 emission that affects the climate is interrelated with energy consumption practice. By limiting the energy usage, the emission of CO_2 being regulated will be able to control. The synergy between these two elements also will be able to balance out.

3.2.3 Preposition 3: WASTE-ENERGY-CLIMATE-CIRCULAR ECONOMY

The circular economy concept that has been introduced since the 20th century has provoked the linear economy practice that using sanitary disposal methods to generate waste, by appreciating the recovery process of waste resources. From a circular metabolism perspective, managing waste using a circular economy principle can reduce environmental pressure and seems to be a systematic nexus between waste and energy. Therefore, Waste to Energy Technology has been introduced as an alternative method that can combine these two nexuses thus assist to help the waste management issue, energy depletion, as well as climate change problem.

4. Conclusion

This paper conducted a systematic mini-review of the waste-energy-climate nexus perspective towards the circular economy. By going through much literature on the global level as well as in Malaysia, a series of issues were identified. Clearly, some issues are probably more prevalent and realistic, while others are still relatively conceptual. It is indicated that there is a synergy between WtE technology and the circular economy, which include three important elements: energy, climate change, and waste. Energy can be produced through this technique, but the sustainability of sources used should be taken care of. In order to face current environmental challenges and resource shortages, both the economy and the environment should be preserved as a circular link. Conclusively, the identified implications and the effects of each given conflict (waste utilization, climate change, and energy security) provide a vital insight towards the establishment of national and global circular economy framework. Apart from that, WtE technology turns out to be one of the best efforts as part of the waste minimization strategy and serves as a key factor that can attenuate environmental impacts, while concurrently meeting the growing demand of national and global energy resource.

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