



# Energy recovery from solid wastes in China and a Green-BRI mechanism for advancing sustainable waste management of the global South

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## Abstract

The only proven alternative for the recovery of value from materials that cannot be recycled is waste to energy (WTE). The first part of the paper provides evidence as to the advantages of WTE over landfilling and examines the role of WTE in the urban environment. The second part of the paper is a holistic analysis of the legislative instruments used in China, that have led to the construction of nearly 400 plants from 2005 to 2019. The Chinese government was instrumental in the development of Public and Private Partnerships (PPPs), in form of Build-Operate-Transfer (BOT), or Build-Own-Operate (BOO) models with a lifetime of 20 years to 30 years. The government accepts most of the investment risk by participating in the equity structure, providing strong tax and policy incentives, and becoming fully engaged in public education and acceptance of new WTE projects. The construction and operation of these plants by the private sector had to comply with the governmental performance standards in order to receive incentives, such as an appreciable credit over the price of electricity received by coal-fired plants. The last part of this paper examines how the elements of the Chinese renewable energy and waste management laws, may be transposed to federal and state legislation for potential application in countries of the Belt and Road Initiative (BRI) region.

**Keywords** Waste to energy · Renewable energy · Belt and Road Initiative · Public and private partnerships

## The role of waste to energy in the urban development

The order of priority and the applicability of sustainable waste management methods can be represented graphically by the Hierarchy of Municipal Solid Waste (MSW) Management (USEPA [1], where sanitary landfilling is given a lower priority than waste to energy (WTE) (European Commission [2], although it is less costly to implement. One reason for this is that sanitary landfilling requires much land and has much higher environmental impacts than WTE. WTE contributes to the energy demand, sustainable waste management, greenhouse gas emissions reduction and land and resource preservation of cities by transforming waste materials into energy and materials [3–5]. WTE recovers two

forms of energy from the combustion of residual MSW: (a) electricity (0.4–0.5 MWh/t of waste), and/or (b) steam (>0.5 MWh/t) that can be used for: (i) district heating/cooling, and/or (ii) the industry, e.g., desalination, wastewater plants, paper mills, etc. Also, WTE allows the recovery of metals and minerals from the WTE bottom ash residue [6].

Although research and development in this area has existed for about one century, combustion based WTE is the only proven and dominant method for the thermal treatment of wastes. The other thermal treatment technologies available, pyrolysis and gasification, are currently under development and not proven for mixed waste materials. However, we should differentiate between the highly technical engineering process of combustion of wastes from the incineration of wastes that occurs in thousands of sites that do not recover energy, often process only hazardous materials, and operate without advanced state-of-the-art Air Pollution Control (APC) systems. Therefore, conventional incineration differs significantly from the high-end process of combustion based WTE plants that operate with advanced APC systems, and comply with stringent air quality standards, and

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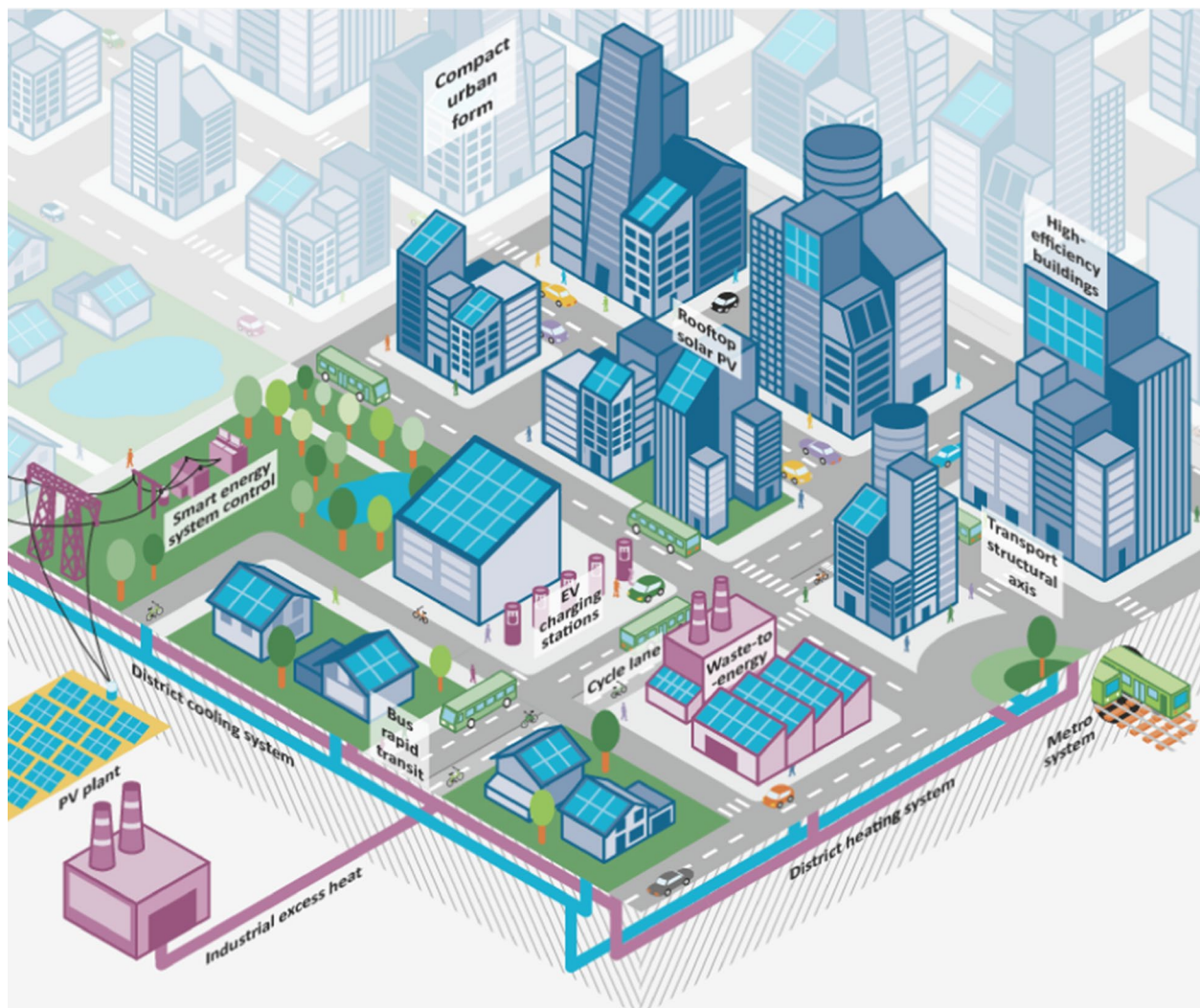
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the main feedstock to the plants is non-hazardous urban and industrial residues [7]. Additionally, considering that these plants operate at high temperatures, about 850–1000 °C, the process significantly destroys the pathogens contained in the wastes. It produces an inert material, the bottom ash, at about 20%–25% (in weight) of the initial feedstock that is processed for metal recovery and the remaining mineral fraction is often used for civil engineering applications, and the fly ash or APC residues, at about 1%–3% (in weight) of the initial feedstock, which is a hazardous material and is stabilized with cement and disposed of in landfills. Both materials used or processed and disposed of in landfills must comply with stringent leaching and civil engineering standards [8]. On average, WTE reduces the volume of wastes by 90% [3, 5, 7].

The contribution of WTE to the global renewable energy supply from the combustion of the biogenic fraction of the waste is about 1%. The global WTE market was valued

at about US\$9 billion and is expected to increase to over US\$25 billion by 2025, an increase of about 5.5%–6% per year, according to conservative estimates [9] that is mainly driven by China, which indicates >6%–7% increase in WTE capacity per year, and nations of SE Asia, Africa, and SE Europe, similar to the Belt and Road Initiative (BRI) boundaries [10]. For the EU, this is also supported by the recent peer reviewed calculations that showed that 142 million tonnes of residual waste treatment capacity will be needed by 2035 in order to fulfil the currently set EU targets on municipal waste, assuming that the current ambitious recycling targets will be achieved for commercial and industrial waste. Current EU WTE capacity is 90 million tonnes and the capacity for co-incineration is around 11 million tonnes. This leaves a gap of around 40 million tonnes [11, 12].

The potential of WTE for urban development has been recognized by the International Energy Association (IEA) (Fig. 1; [7]), the United Nations Framework Convention



**Fig. 1** Urban development according to the International Energy Agency [4]. Adopted by IEA

on Climate Change [5], the Intergovernmental Panel on Climate Change report [13], and others. According to the IEA, the technical potential electricity and heating supplies from MSW, wastewater and sewage gas, are estimated to be 830 TWh of electricity and 2400 TWh of district heat by 2050, or <4% of urban electricity needs in 2050 in the ‘2 °C increase scenario’ (2DS). If the heat is entirely used for district cooling and by assuming a coefficient of performance of 1.6, the cooling energy will be 3860 TWh. MSW and wastewater are associated with significant public health and economic costs, and WTE can provide additional revenue to urban development plans that include energy and material recovery from urban and industrial residues. Smaller cities and towns can collaboratively develop strategies and jointly operate a WTE plant [3, 7].

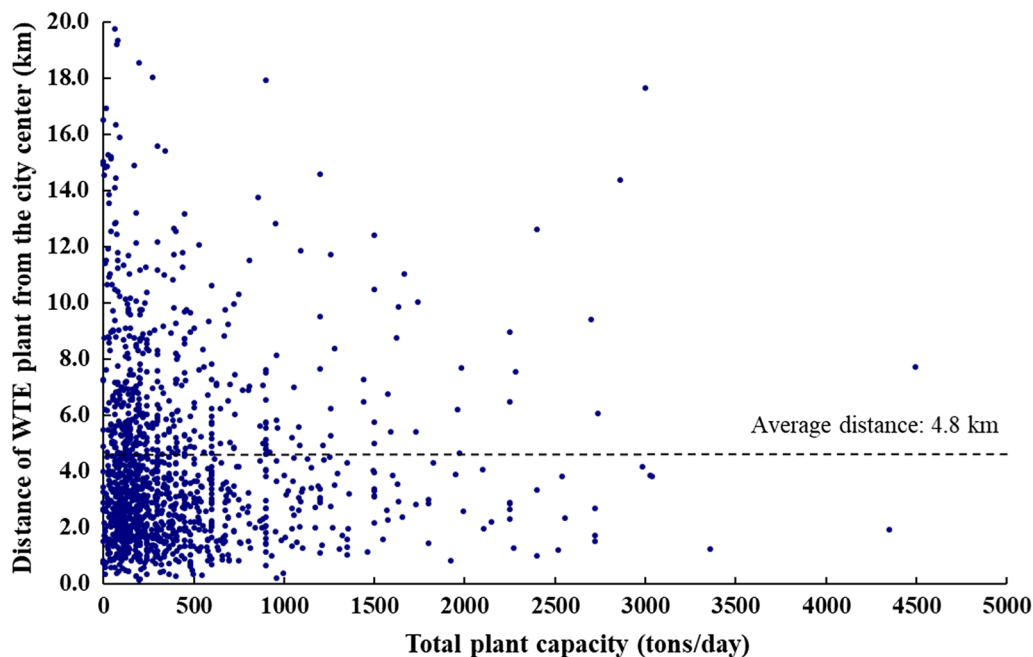
The perception that WTE facilities are undesirable neighbors from an esthetic viewpoint has also been an obstacle to the development of WTE. However, modern WTE facilities operating in the US, Europe, Japan, and China are designed with this concern in mind. WTE plants located in the center of architecturally sensitive cities, such as Vienna, Osaka, and Paris, have shown that such plant designs are compatible with local esthetic requirements. An analysis of primary data by the Earth Engineering Center of Columbia University (EEC) showed that the average distance of WTE plants from the city center is about five kilometers, as shown in Fig. 2 [14], and the capacity of these plants is between 50 t/d and 5500 t/d. Most of the plants in Japan and the EU are located close to city centers. Most of the outliers in Fig. 2

are plants located in the US. Additionally, the EU Directives, one of the most comprehensive and stringent pieces of legislation on waste management, in the period 1995–2017, have resulted in the reduction of landfilling by approximately half. This was achieved by increasing the recycling/composting rates and by increasing the WTE rates, as shown in Fig. 3 [15].

## Policy and fiscal tools for WTE deployment

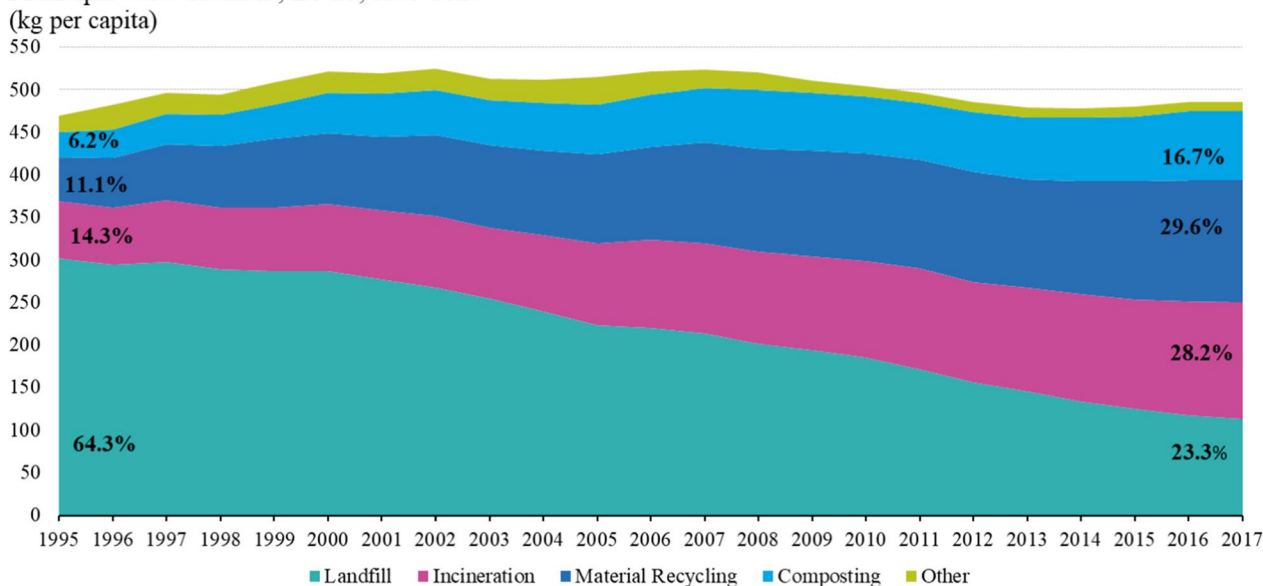
Policy and economic incentives are required to support the deployment of waste management infrastructure, along with standards for renewable energy production, e.g. the R1 efficiency formula of the EU, and pollution control, e.g., the Waste Incineration Directive [17] or later the Industrial Emissions Directive [18] of the EU, and the US Maximum Available Control Technology (MACT) standards of the US EPA [19]. Among the success factors in supporting WTE in communities are sustained national subsidies, technical assistance and capacity-building for implementing this technology and attractive credits for operation.

Incentives are often associated with regulations at the national and municipal level that advocate the diversion of wastes from landfill disposal, e.g., the EU approach of imposing a landfill tax [20]. The main challenge of the landfill ban for low-income communities is the consideration that low charges may not provide sufficient incentives against landfilling, while high charges may lead to illegal disposal.



**Fig. 2** WTE capacity (x-axis) vs. distance of WTE from city center (y-axis). The analysis represents all the about 1000 WTE plants of the world (analysis based on data obtained from [16]). WTE waste to energy

Municipal waste treatment, EU-28, 1995–2017



**Fig. 3** Changes in EU generation and disposition of MSW 1995–2017 (EEC graph based on Eurostat data). MSW municipal solid waste, EEC Earth Engineering Center of Columbia University

Other incentives relate to the credit that the WTE receives for renewable energy production. For example, feed in tariffs or the issuance of tradable green certificates with a guaranteed minimum market value for capacity installed. The European Renewable Energy Directive has been a successful way to encourage waste-to-energy technologies in Europe [21], amended as [22].

Subsidies are often in the form of partial-grant financing or another type of favorable financing instrument, such as soft loans or guarantees provided by international financing institutions and national governments. Efficient investment promotion can be provided through a tax-exempt/renewable energy credit and/or through land permits and subsidized land.

In general, the strategies for supporting WTE deployment should (1) establish policy and government responsibility, (2) internalize externalities, social acceptance, stakeholder engagement, and investor mobilization, (3) provide economic incentives and price support, and (4) set up comprehensive performance evaluation program [23].

An excellent summary on the policy direction of WTE deployment can be found in [24].

### Environmental impacts related to the management of post-recycled wastes

Several studies have been conducted on the environmental benefits of WTE plants, such as country-level assessments on dioxins/furans [25–29] and greenhouse gases, over the

only proven alternative for the management of post-recycled wastes, landfilling [2–4, 13, 30–37].

One of the main advantages of WTE over landfilling is the reduction in methane emitted during the landfilling of waste materials. A recent study on US landfills [38] concluded that methane emissions from landfills are on average 0.05 t CH<sub>4</sub>/t of waste landfilled. Assuming that the potency of methane is 84–86 that of CO<sub>2</sub>, in a 20-year horizon (IPCC), US landfills potentially emit up to 4.3 t CO<sub>2-eq</sub>/t of waste landfilled. According to current GHG inventories, landfills are the 3rd largest source of anthropogenic methane globally and in the United States [39]. However, new data suggest that landfill emissions, and the opportunity to reduce them, are much greater. A series of recent studies employing direct measurement of methane plumes via aircraft downwind of landfills have shown that measured emissions average about 2.3 times the modeled emissions reported in current GHG inventories [40–44]. Based on this growing set of data, the total 2019 US landfill methane emissions, as reported in US EPA [39] were 4.58 MMT CH<sub>4</sub>, and by adjusting US inventory with the 2.3 factor, yields total landfill emissions of 10.5 MMT CH<sub>4</sub>. Total agricultural sector emissions, including enteric fermentation, manure management, rice cultivation, and field burning of agricultural residues, were 10.26 MMT CH<sub>4</sub> [39]. Thus, landfill methane emissions are comparable to the methane emissions from the entire agricultural sector.

The emission of CO<sub>2</sub> from 1 tonne of MSW combusted in WTE is significantly lower, considering that 28% of C combusted to CO<sub>2</sub>, and there is not methane production [2, 12, 45–50]. Also, further reductions of CO<sub>2</sub> emissions



are attenuated for the WTE industry, provided a few recent developments that enable carbon capture and storage (CCS). Aker Solutions, the Netherlands and Norway, has developed a technology that is called ‘Just Catch’ and can capture 10,000–100,000 ton/year of CO<sub>2</sub> with a standardized design that can be used in fossil fuel plants, cement factories, and WTE facilities [51, 52]. The Norwegian Government has initiated a full-scale CCS project in the Fortum Oslo Varme waste-to-energy plant, which in conjunction with the Heidelberg Norcem cement factory in Telemark will capture around 400,000 tons of CO<sub>2</sub>. The total cost of the project (investment and operating costs for five years) is estimated at 13.1 billion NOK (about US\$1.4 billion) [53]. Finally, recent developments in the UK, are using Accelerated Carbon Technology (ACT for the production of lightweight aggregates from WTE fly ash residues, which indicates significant potential in further off-setting WTE CO<sub>2-eq</sub> emissions [54].

## The growth of WTE in China

In China, a phenomenal growth is observed with the deployment of WTE plants with exponential growth since the beginning of the century, as shown in Fig. 4. The number of plants increased by about 400 WTE plants from 2000 to 2019 [55, 56], and the installed power capacity was >8 GW [57]. In 2019, the combined capacity of the plants in China, about 130 million t/a year or 402,000 t/d [57], was higher than the combined capacity of the EU and US plants, about 127 million tons [58, 59].

A comparison of the capital investment required in several countries of the world is provided in Fig. 5 [56]. China has demonstrated that it is possible to reduce the capital cost of WTE plants by means of industrial and academic Research and Development (R&D), and mass production, instead of one plant at the time. In addition, the government was accepting most of the risk of the investment by participating in the equity structure, by providing strong tax and policy incentives, e.g., land permits, disposition of residues, energy credit, etc., and becoming fully engaged in public education and acceptance of new WTE projects. All these actions were associated with significant reductions in the capital required for WTE. For instance, the WTE plant in Dublin, Ireland, was commissioned in the late 1990s but opened in 2018, mainly associated with the public opposition of the project. The capital investment required was about US\$1200/t, compared to about US\$672/t of the West Palm Beach plant in the US, and about US\$190/t of the plant in Nanjing, China [56].

## Policy structure that encourages WTE

Despite higher capital and operating costs than sanitary landfills, a growing number of cities in China have built or are planning to build WTE facilities. The success of the Chinese developments was associated with the very strong support that the sector received from the national and local governments, including tax incentives, such as corporate income tax exemption for the first five years of

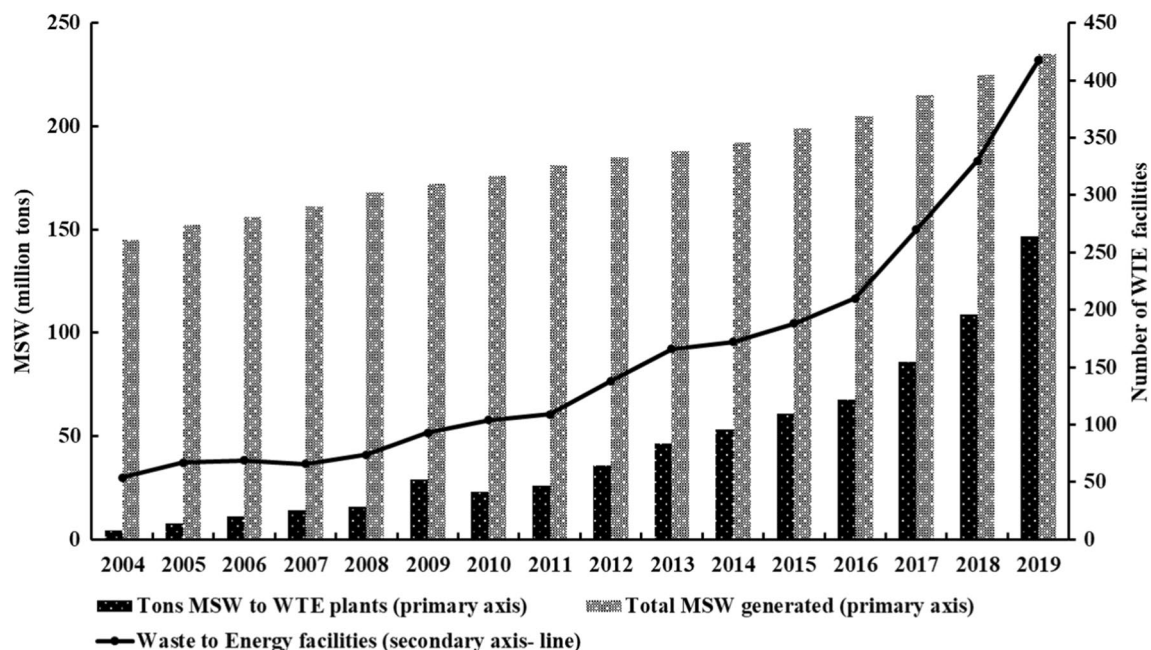
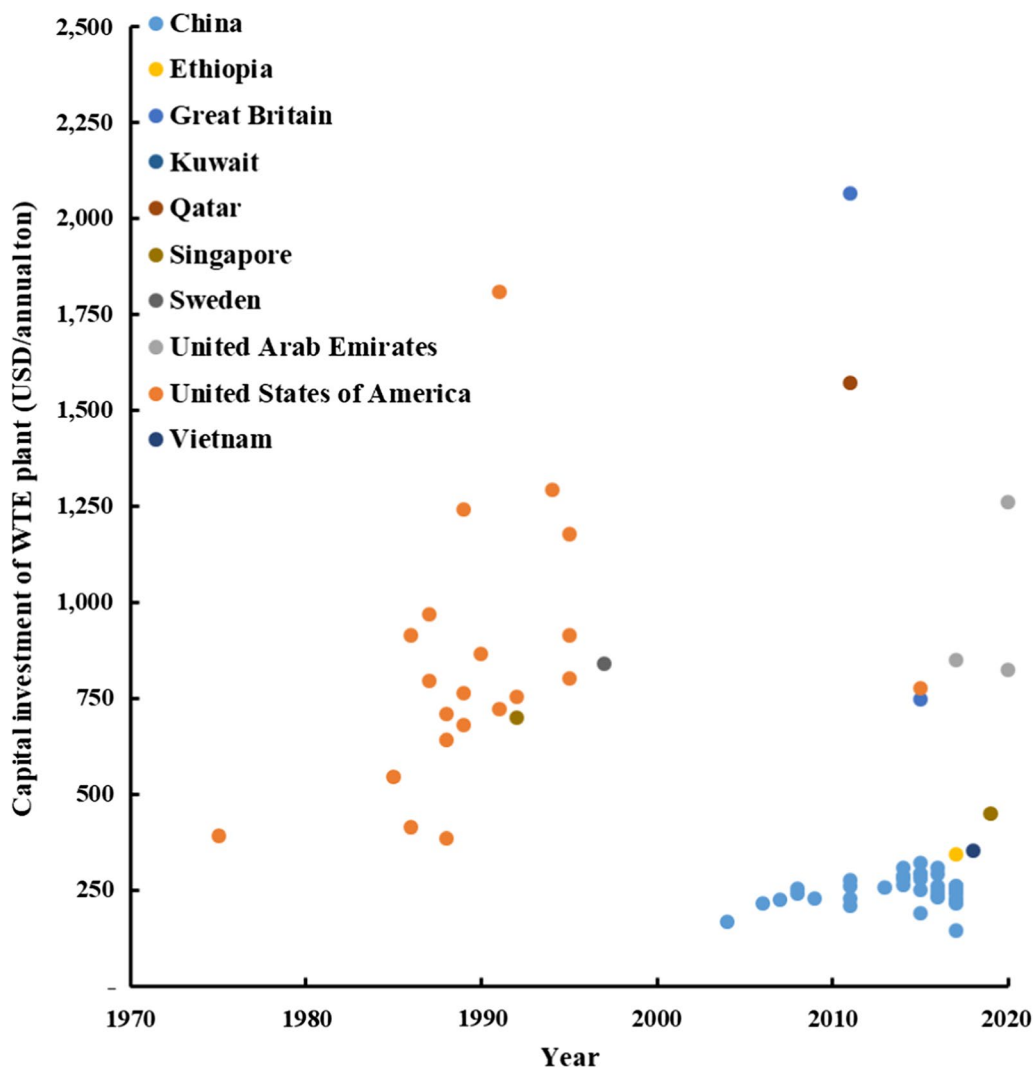


Fig. 4 Growth of WTE in China



**Fig. 5** Capital investment in WTE plants (in US\$/annual ton capacity) by country (adjusted for Exchange Rates and Inflation) [56]

operation, electricity subsidies, and municipal subsidies through waste disposal fees [60–64]. In addition, governmental authorities have taken an active role in alleviating public opposition to WTE developments [61, 65]. For example, the construction of the Nanjing WTE plant faced significant public opposition, which was mitigated by the application of actions, ranging from a visit of Nanjing’s waste management stakeholders to the Suzhou WTE facility, public and media engagement, and advocacy of the positive effect of the proposed WTE in alleviating local poverty. Between 1990 and 2015, the annual governmental expenditures in equipment and infrastructure for MSW management increased by 60 times. The national government of China invested US\$12.3 billion in the WTE sector, in the period from 2011 to 2015, resulting in a dramatic reduction in improper landfilling and the conservation of land resources [66–69]. In addition, the 13th Five Year

Plan (FYP) allocates more than US\$40 billion of funding to new facilities [70, 71].

A summary of the national policies that advocated WTE development is presented in Supplementary materials S1. National policies included WTE as a form of renewable energy, with the first augmentation seen in the renewable energy law of 2005, where the national government accepted most of the risk of the investments, by advocating effective Public and Private Partnerships (PPPs) [60, 61, 72]. The laws and the following amendments enforced energy purchase obligation by the national grid, and the creation of a renewable energy development fund, which is financed by budgetary allocations from the Central government, is associated with significant deployments in the sector [69].

One of the most important policies was the increase in the feed-in tariff for MSW combustion up to US\$ 0.11/kWh of electricity [60, 69]. WTE plants can sell their excess

electricity to the grid at a price of US\$0.09/kWh, whereas coal-fired plants receive a price of US\$0.06–US\$0.07/kWh of excess electricity [60]. The price of electricity produced by WTE plants ranges between US\$ 0.08–0.13/kWh; in comparison, the price of electricity from coal fired power plants ranges from US \$0.03–0.05/MWh [56]. In addition, WTE facilities receive an \$10–40 per ton of waste subsidy from the local government that also provides low-cost loans and fiscal support to the project [73].

In most of the WTE developments, the local or national government will provide a significant part of the initial capital investment and will seek private investors that are able to provide 30% of the initial capital [68] and meet the financial, technical and environmental performance requirements asked by the national government. The Central government often provides tax exemptions on 5% earned revenue [68]. This combination of measures makes WTE development economically attractive and sends strong signals to the WTE industry to identify methods to advance energy production, and to invest in research and development in collaboration with major academic institutions [63, 69, 73].

In terms of PPP efficacy, the Chinese government followed a structured approach by using market tools to eliminate financial risk associated with WTE development by creating strong signals and securing private investors and firms, and by aiding the welfare of the communities. It was able to create strong links and mutual interest during the

deliberation between the several stakeholders engaged in the development. The Chinese government mainly promoted Build-Operate-Transfer (BOT) or Design-Build-Operate-Transfer PPP models, as it allows the financial risk to be shared among the involved entities; however, Build-Operate-Own models are often observed [49, 61–63]. A schematic of a typical PPP financial model of WTE project in China is presented in Fig. 6. The government grants the construction and operation of the facilities to an enterprise, which is then responsible for the investment, financing, design, construction, and operation of the WTE plant. The local government pays waste disposal fees to the WTE plant and ensures that the electricity generated by the plant is sold to the national grid. After a period of operation, usually 20–30 years, the facility is transferred to the public entity [46, 50, 64, 68, 69].

### WTE development in the BRI region

In 2015, the Chinese government introduced the BRI to provide financial support to nations of the defined region (Green BRI; [74]). This is a significant opportunity for the nations of the Green BRI (G-BRI) region to advance sustainable waste management and alleviate the public health problems associated with the current improper management of waste materials.

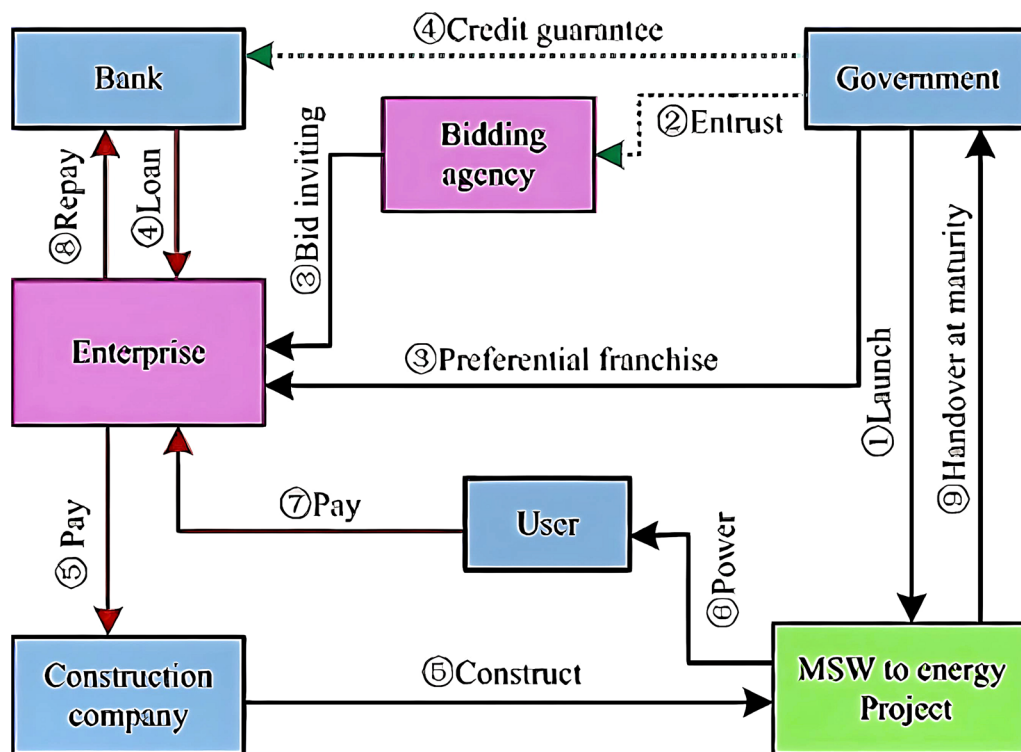


Fig. 6 Typical PPP financial model in WTE deployment in China

In specific cases of the BRI region, energy recovery from wastes (WTE) in India has progressed at a slow pace, with a current capacity of under 300 MW of electricity; however, a national plan in place to advocate source separation of recyclables and use of the post-recycling wastes as fuel in WTE power plants can accelerate the transition from waste dumps and landfills to WTE (IEA [70]). The Swachh Bharat Mission is incorporated within the Smart City Proposal and considers two components: (IV) Solid Waste Management (75% Central contribution), and (V) Public Awareness (75% Central contribution) [75]. The government released the Manual of Sustainable Waste Management [76] and their influential governmental think tank drafted the 3-year action plan [77], which included the construction of up to 100 WTE plants [78]. The plan is aimed at managing some 170,000 t/d of waste generated in about 8000 larger municipalities. It has also suggested the establishment of a new Waste to Energy Corporation of India to aid the development of public–private partnerships for building these plants, and establishing regional field offices to assist and monitor the progress of the projects. Also, in many states, WTE investment is supported by feed-in-tariffs, e.g., Uttar Pradesh [79], through inclusion in the local renewable energy law, e.g., Karnataka [80], or by providing tax exemptions and land, e.g., Gujarat [76]. Conversely, low rates of collecting and treating MSW hinder sector expansion [81].

Thailand is also in the early stages of WTE deployment. Electricity generation from WTE is expected to increase to over 200 MW by 2021 and the government has a long-term target to increase WTE capacity to 550 MW, under the Alternative Energy Development Plan. A regulation is in place that provides \$155–\$190/MWh to WTE plants. In Indonesia, a national plan has been announced for the construction of WTE plants in twelve major cities of the country by providing a WTE electricity price of US\$133/MWh. Similar is the case in Pakistan, where US\$100/MWh is provided to WTE plants, two of which are under construction in Lahore and Islamabad [70, 81].

A PPP of a Chinese public entity outside China was developed in the case of the Reppie WTE facility in Addis Ababa. The project was constructed by China National Electric Engineering Co., Ltd. (CNEEC, Beijing, China), and was fully financed by the Ethiopian government; it is expected to process 1400 tons of solid waste daily and is part of the national plan to become an environmentally-friendly middle-income economy by 2025. At the inaugural event, the President of Ethiopia welcomed the advocacy of Chinese enterprises to participate in green infrastructure projects in Africa [82, 83].

As part of the BRI, in November 2019, Greece signed 16 MoUs with China on trade, infrastructure and culture [84], and many other nations of the BRI region, e.g., Algeria, Italy, and Switzerland, are keen to participate in similar cooperation agreements.

## Challenges and opportunities in cities of the BRI region

A significant challenge is associated with the creditworthiness of the BRI nations, especially the countries that belong to developing/emerging economies, where it is estimated that only 20% of the 500 largest cities are considered creditworthy [70]. Another obstacle is the low Willingness to Pay (WTP) for WTE by the municipality or the government who participate in a PPP, e.g., by means of a waste disposal fee, as has been the case for China, or by means of equity participation (e.g., in the case of the Baku WTE). An aspect of significant importance is the Willingness to Accept (WTA) by citizens/voters of a possible increase in the waste disposal fee, or the municipal tax that includes waste management for WTE development.

In addition, countries of the BRI region often have underdeveloped waste collection services, segregation infrastructure and recycling which significantly affect the quality of the fuel that can be processed in WTE plants, considering that moisture and low calorific value wastes, e.g., food, are not removed upstream [6]. Other challenges observed in the BRI economies are the high expectations the local stakeholders usually have from the private entities that participate in the consortium, the low level of citizen compliance, inadequate public information/education that also results in low public acceptance of the projects, and lack of local expertise in WTE processes. Also, in most cases, obstacles that impede WTE deployment are fiscal and political fluctuations, high financing costs for WTE facilities, and institutional and regulatory hurdles associated with permitting.

These characteristics do not allow the establishment of strong relationships between the several stakeholders and entities interested in WTE deployment, and often the deliberations are concluded unsuccessful. A typical challenge and opportunity for BRI regions is the practice of informal recycling. According to the UN, about 2% of the population in developing/emerging nations derives their income from this activity [81, 85, 86]. The main challenge is that these groups are not keen to be part of the formal system, since they are isolated by the communities and their contribution to waste management is underestimated or neglected. Thus, inclusion of these groups into the formal system will require social adjustments that citizens are often not eager to accommodate. Experiences by authors in India, Indonesia, and Mexico and observations by other researchers indicate that indirect incentives must be provided for the inclusion of informal recycling in the formal sector of the economy. These incentives can be provided through, housing or the provision of health services, etc., but it is still very challenging to bridge the social and



cultural gaps between the groups of informal recyclers and the citizens of urban centers [87]. In China, they included informal recyclers as workers in new WTE plants because of their professionalism and familiarity with waste streams and actors in the market. However, informal recycling is still present mostly in rural areas where these groups contribute to the economy, and they derive an income that otherwise has to be provided by the government [86].

The Green BRI can act as the bridge between the knowledge accumulated by Chinese companies during the construction of hundreds of WTE plants, and the waste management needs of nations in the BRI region. As an indication of the significant contribution China can contribute to the deployment of WTE in other nations, Zhejiang University, sister academic institution of Columbia University in sustainable waste management, has become the National Center on Waste Combustion, with several WTE pilot facilities and a training center for engineers, managers, and policy makers. The Center operates in collaboration with major Chinese WTE companies and other universities in China and abroad. A ‘Green’ Belt and Road Initiative (G-BRI) can aid the deployment of WTE in the participating nations by providing significant capital and security to the required investments. The Green BRI can aid the participating cities of other nations in obtaining similar benefits to those already observed in hundreds of Chinese cities, closing of waste dumps and replacing them with state-of-the-art WtE plants that provide both renewable energy and GHG reductions. However, as noted earlier, these new plants must employ the best available technology and comply fully with EU, US, and recent Chinese standards. In addition to strict environmental standards, performance-based indicators should be used to ensure the sustainability of the projects, and the defined subsidy or award in return. Therefore, it is absolutely necessary for public entities in the BRI region to ensure the sustainability of Green-BRI-supported WTE projects, by providing and monitoring measures and avoiding a particular WTE plant to stigmatize the WTE technology that by now has proven successful in over one thousand plants all over the world.

Creditworthiness, accountability, and service delivery practices are essential in effective urban investment strategies. Technical assistance and capacity building programs are needed to support BRI cities in bringing order to their financing and accounting practices, thus improving credit ratings and becoming creditworthy. Results-based financing can directly address the construction, operation, and counterparty risks in infrastructure investments. For example, environmental impact bonds can be used and/or energy service companies can provide either ‘shared-savings’ or ‘guaranteed savings’ energy performance contracting (EPC) for upfront results-based WTE investments. An excellent

summary of the financing mechanisms can be found in GPRBA [88].

It is important for the public entity in the consortium to secure the stability of the contracts for WTE deployment and ensure effective PPPs, which will result in mutually beneficial benefits. The government and the consortium should be part of the actions for the mitigation of any misconceptions of the project. The establishment of/or coordination with existing regulatory authorities is key to ensuring continuous monitoring of the operations and confidence of the public and investors. The waste should not be seen as an environmental hazard but as a resource of energy and metals of value. In addition, the allocation of federal or local/municipal investment funds between investments in waste management and other sectors, e.g., energy and transport, should be promoted [89]. The consortium should promote the benefits that may contribute to the transition to a green economy, including the potential for the future life-extension of the green infrastructure, by the development of civil engineering projects for the community, e.g., land restoration, open dumps to land, WTE, water treatment (depending on the economics), etc., and the benefits to the community, e.g. cheap energy, lower collection costs, education centers, green areas, etc. Surveys should be conducted to assess citizen compliance and identify the key elements of benefits to the community by the consortium.

The formation of cooperatives and committees that discuss the concerns and promote the benefits of WTE has been observed to be beneficial for the public acceptance of projects. The inclusion of local groups in the design, construction and operation of the plant aids public acceptance and advances the social contribution of the projects. Also, the WTE industry should show continuous commitment to improvement through efficient industry practices. The promotion campaigns should focus on the importance of developing integrated sustainable waste management systems that include WTE and eliminate landfilling, and the benefits on public health, the environment, and the economics of the community.

## Conclusions

The aim of this paper is to provide evidence as to the benefits of WTE for sustainable waste management, and to analyze and make recommendations as to how the elements of the Chinese waste management framework and laws may be transposed to national and regional legislation for potential application in countries of the BRI region.

The benefits of WTE can be summarized below:

- Produces energy from waste that cannot be recycled, instead of landfilling it.

- Successful examples all around the world have proven that recycling goes hand in hand with WTE.
- WTE is the only way to concentrate and remove hazardous materials from the circular economy cycle.
- Allows recovery of metals and minerals from non-recyclable wastes.
- Saves land (estimated at 1 m<sup>2</sup>/15–20 tons of MSW, for sanitary landfilling) and GHG (about 1 ton of CO<sub>2-eq</sub>/t of MSW) over landfilling.
- the “turns” or “cycles” in a circular economy need energy that can be provided by WTE.

Technology is now available at an affordable capital cost in developing nations. For the advancement of sustainable waste management of nations, China’s WTE development model can be used as a baseline for what can be accomplished in the regions of the BRI financial mechanism. China’s successful WTE development can be attributed to the efforts of a strategic nationwide approach that can be broken into two main parts:

1. Structured approach by using market tools to eliminate financial risk associated with WTE development, making the path clear for private investors and firms. The Chinese government has preferred using the BOT structure in regard to financing WTE projects, as it allows financial risk to be shared among parties.
2. Planned approach with targets set by the national government for WTE development and amount allocated to WTE growth. The planned approach is associated with China’s Five-Year Economic Plan. WTE is recognized by the central government as an integral part of growth, both economically and socially. The planned approach was critical to WTE development in China, which is due to a combination of favorable tax policies, tax exemptions, loan guarantees, and pricing on energy production (credit for renewable energy production of \$30/MWh of electricity produced by WTE) and effective PPPs.

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**Data availability statement** The data used to support the findings of this study are included within the article.

## Declarations

**Conflict of interest** The corresponding author states that there is no conflict of interest.

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