Chapter 8

The Case of Waste to Energy in Bangladesh[*]

Sakib Amin is an associate professor at the School of Business and Economics of North South University in Dhaka, Bangladesh.
Tooraj Jamasb is a professor and director at the Copenhagen School of Energy Infrastructure of the Copenhagen Business School in Denmark.
Manuel Llorca is a postdoctoral fellow at the Copenhagen School of Energy Infrastructure of the Copenhagen Business School in Denmark.
Laura Marsiliani (laura.marsiliani@durham.ac.uk) is an associate professor at the Durham University Business School and a fellow at the Durham Energy Institute in the United Kingdom.
Thomas I. Renström is an associate professor at the Durham University Business School in the United Kingdom.

8.1 Introduction

Policy makers in developing and emerging economies are sensitive to the issue of sustainable development and strive to balance the need for economic growth with protecting the environment for current and future generations. This challenge is acute in the energy sector and in particular in electricity generation, which is at the foundation of economic development.

Waste-to-energy (WTE) power plants can play an important role to foster sustainable development by using waste as a source of energy. A recent study by the Asian Development Bank (ADB) reports that "as of December 2018, there are more than 2,450 WTE plants that are operational worldwide with a total waste input capacity of around 368 million tons per year. It was estimated that more than 2,700 plants will be on-site by 2028" (ADB 2020, p. viii). Significant growth is expected from the People's Republic of China, India, and Southeast Asian countries (Tun et al. 2020).

Electricity generation from waste can help an emerging economy increase its economic competitiveness and industrial output and at the same time reduce the environmental impact of waste. Nevertheless, several issues have been associated with WTE, among them the potential for crowding out reuse and recycling of waste and the release of toxic pollutants and greenhouse gas (GHG) emissions. Because of these problems, to be part of a circular economy model, it is recommended that WTE only employ residual waste and scraps as inputs and deploy environmentally friendly technologies, such as anaerobic digestion (AD) and gasification (Saveyn et al. 2016).

---

[*] Research support from Farhan Khan from North South University, Bangladesh, is gratefully acknowledged. Tooraj Jamasb and Manuel Llorca acknowledge financial support from the Copenhagen School of Energy Infrastructure. We are grateful to Maria Hughes, Stefan Rau, Matti Tervo, and participants at the ADBI virtual conference on Circular Economy in Emerging Markets, 2 June 2021, for valuable comments and feedback that greatly improved this manuscript.

However, most of the existing WTE power plants use conventional technology based on incineration of waste with or without carbon capture and storage. At present, incinerators provide higher returns to investments, but their sustainability credentials are limited mostly due to the release of significant GHGs (especially from non-organic waste) and toxic substances harmful to human health and ecosystems, in addition to lower incentives for waste reuse and recycling.

Emerging methods of generating energy from waste include anaerobic digestion and gasification or pyrolysis,[1] which are deemed to be better aligned with circular economy principles as waste has to be carefully sorted before entering the energy recovering process. Anaerobic digestion can be used to manage organic domestic and agricultural waste, and it is especially promising for developing and emerging economies whose waste is mostly organic. Gasification methods can be deployed for extracting energy, in the form of syngas, mostly but not exclusively from biomass and other organic waste,[2] while pyrolysis can be especially useful to turn plastic waste into fuels and provide feedstock for recycled plastic production. The typically low calorific value of organic waste with respect to non-organic waste and fossil fuels is often advocated as a barrier to the development and implementation of those methods.[3] On the other hand, the potential for GHGs and pollution savings with respect to incineration technology can be significant. For example, Bachmaier, Effenberger, and Gronauer (2010) estimated that GHG emissions from anaerobic digestion electricity generation for 10 agricultural power plants ranged between -85 and 251 g CO_2 e/kWh,[4] with a GHG emissions saving with respect to fossil fuels-based electricity generation between 2.31 and 3.16 kWh_{fossil}/kWh_{el}. The Intergovernmental Panel on Climate Change (IPCC 2012) found that GHG emissions from gasification- and pyrolysis-based electricity generation using biofuel at the plant level ranges between 0 and 360 g CO_2 e/kWh with most estimates being lower than 100 g CO_2 e/kWh.[5] Interestingly, life-cycle GHG emissions from direct incineration of biomass are found to be in the same range as from gasification and even lower than from

---

[1] Anaerobic digestion is the process by which microorganisms break down biodegradable material in the absence of oxygen to generate biogas. Gasification converts waste into syngas and other fuels through a thermochemical reaction using oxygen. Pyrolysis converts waste into syngas, biofuel, and feedstock for plastic, also through a thermochemical reaction but at high temperature and in the absence of oxygen. See Lee at al. (2019) for a review of energy conversion technologies.

[2] There are currently only 26 gasification WTE power plants worldwide due to their higher cost in comparison to incinerators.

[3] Calorific value of fuels can be used to assess energy generation potential with lower values meaning lower generation potential. Results from several studies from a number of case studies suggest that municipal solid waste (MSW) has approximately half the calorific value of natural gas and oil, with even lower value for organic and biomass waste. The composition of waste is crucial to determine its calorific value; composition varies across countries and locations of waste, and time periods. Therefore, to generate 1 kWh of electricity, one would need a higher quantity of waste with respect to fossil fuels and an even higher quantity if waste is organic or biomass.

[4] Estimates of GHG emissions from electricity generation from biogas and biofuels are found from case studies at plant level. In most cases, they include life-cycle assessments. As different plants may use different feedstock or biomass waste compositions, the range of the estimates can be large. The negative estimates for anaerobic digestion may be due to the capability of this process to capture methane.

[5] The 2012 IPCC report presents GHG estimates from a number of bioenergy studies. GHG emissions are distinguished into emissions from incineration, gasification, and pyrolysis-based electricity generation. However, the report does not specify whether the fuels used come from MSW biomass or other feedstock such as agricultural waste, logging residues, aquatic biomass, etc.

pyrolysis.[6] Accordingly, emissions savings with respect to fossil fuel-based electricity generation are significant for most of the case studies. Using the IPCC (2006) calculation methods, CO_2 emission estimates from electricity generation using combustion of undifferentiated municipal solid waste (MSW),[7] natural gas, and oil are, respectively, in the order of 600, 410, and 970 gr CO_2 equivalent/kWh. The IPPC (2012) report also highlights that bioenergy is associated with lower pollutants, such as sulfur dioxide (SO_2) and nitrogen oxides (NO_X), than fossil fuels.

Despite the clear environmental and climate change benefits, nonconventional WTE methods are not widespread, mainly due to their higher cost and lower returns from investments. It is expected that the increasing inclusion of issues of sustainability and circular economy in the regulatory framework for WTE in Europe and other developed countries will spearhead their adoption in the near future.

Indeed, the renewed focus on the idea of a circular economy provides a useful framework for conceptualizing and analyzing the links between environment, economy, and resource use in a unified setting. This integrated system consist of a nexus of food, water, waste, and energy, among other sectors. Lehmann (2018) develops one such framework for case studies of urban areas in Southeast Asia. Kaur, Bharti, and Sharma (2021) find that in developing countries the shortage of waste disposal sites is an increasing problem, and energy recovery is the most common form for waste management.

Siddiqi, Haraguchi, and Narayanamurti (2020) use Monte Carlo simulations to analyze recovery of energy from MSW in Jakarta, Delhi, and Karachi. They show that a one-sided focus on the cost of municipal waste handling without also considering the revenues streams that can be generated from energy recovery, can undermine the benefits of improved waste management practices.

Therefore, while WTE can be part of the circular economy, it requires careful planning, waste analysis and sorting, legislation, choice of technology, environmental impact assessment, and policy commitment. Malav et al. (2020) report a comprehensive survey of the case of India. They then present the main waste management technologies available and review the practices across different regions of India and discuss the various challenges of implementation of WTE projects.

MSW can be a key component of a circular economy and WTE. However, the composition of the waste is important for both the level of energy recovery as well as the environmental impact, which can vary across countries (see, e.g., Li et al. 2021). Appropriate regulatory policies and technologies to manage food waste, including energy recovery, are urgently required in Asia (Joshi and Visvanathan 2019). Despite its relatively low calorific value, energy production from food waste can, due to its volume,

---

[6] For electricity generation, the fuel derived from anaerobic digestion, gasification, or pyrolysis WTE methods needs to be combusted. Therefore, power plants using those emerging techniques can be considered as combustion plants of some sort. Hence, GHG emission ranges are similar to those from direct combustion (incineration WTE) of biomass. In pyrolysis-based power generation, the syngas also needs to be cleaned, causing further GHG emissions from the cleaning process.

[7] Undifferentiated MSW includes not only biomass but also other organic waste such as plastic and non-organic waste.

be efficient and indeed constitute a significant share of total WTE production in Asia (see Laohalidanond, Chaiyawong, and Kerdsuwan 2015; Joshi and Visvanathan, 2019). In general, MSW in Asian cities tends to have a lower calorific value than those in developed economies due to their relative high share of organic waste and the lack of separation.

8.2 Opportunities and Challenges of Waste to Energy for Bangladesh

Bangladesh is the eighth-most populated country in the world and ranks twelfth according to population density. In 2019, the population of Bangladesh was 163.05 million, with an urban population of 60.99 million (37.4% of the total population) (World Bank 2021). Total waste generation in the urban areas of Bangladesh amounts to 25,000 tons per day, which is equivalent to 170 kilograms (kg) per capita per year. Total urban waste generation is expected to reach 47,000 tons per day by 2025 with per capita generation of 0.60 kg per person per day. Dhaka, the capital city, generates about a quarter of the total waste in the country (Ahmed 2019), and, according to the Waste Report 2018–2019 of the Dhaka North City Corporation (2019), average per capita waste generation is already 0.60 kg per person per day. Waste collection varies from 36% to 77% with an average of 55% (Bahauddin and Uddin 2012).[8] Islam (2016) calculated on the basis of waste generation trend that in Dhaka and Chittagong cities of Bangladesh, 1,444 and 1,394 gigawatt-hours of electricity, respectively, can be produced via incineration by 2050. Even though the potential of generating electricity from waste is promising, Bangladesh has so far not been successful in establishing waste-based power plants. Recently, the government is focusing on waste-based electricity generation with a view to accelerate the transition toward renewable energy as pledged in the 8th Five-Year Plan. Bangladesh aims to generate 17% of electricity from renewable sources by 2041 from current 1.53% (on-grid generation).[9] The Sustainable and Renewable Energy Development Authority of Bangladesh (2020) has argued that one of the main source of renewable energy is WTE, as more than 70% of waste is biomass. Therefore, developing a WTE base in the country is becoming of strategic importance for the country.

In Bangladesh, major sources of MSW are households, restaurants, hospitals, vegetable and fish markets, and local factories. Households waste contribute about 90% of the MSW, of which 80%–90% is organic solid waste. According to Alam and Qiao (2020), the average share of food and vegetable waste in the overall collected waste is 74.50%. Some other sources are paper and paper products (9.1%), polythene and plastic (3.5%), textile and woods (1.9%), and dust and mud products (5.1%). On average, the calorific value of waste in Bangladesh is 717 kilocalories per kilogram (Hossain et al. 2014), which is the lowest in Asia and a third of the calorific value in developed countries, such as the United Kingdom (Kumar and Samadder 2017). As Bangladesh is fast developing, the country's waste calorific value is expected to increase rapidly. Overall, given the characteristics of the collected waste in Bangladesh, it has the potential to be used as an alternative source in the electricity generation mix.

---

[8] This is also consistent with the 8th Five-Year Plan (Government of Bangladesh 2020).

[9] For details, see the National Database of Renewable Energy (http://www.renewableenergy.gov.bd/index.php?id=7).

The Government of Bangladesh of recent has sourced substantial investment to facilitate the installation of one major WTE power plant in Dhaka city to generate around 40 megawatts of electricity. According to a recent report by Byron and Alam (2020), China Machinery Engineering Corporation (CMEC) has shown interest in developing the first large-scale WTE project for the Dhaka North City Corporation area in 2021, contributing a daily power generation of 42.5 megawatts for the next 25 years and selling electricity to the government at Tk18.295 per kilowatt-hour in the initial stage. The plan is to use 3,000 metric tons of organic waste out of the 6,000 metric tons of waste that the capital city generates every day (Byron and Alam 2020). The power plant will use incineration WTE technology (Mamun 2020).

This project could be expanded to the entire country and also include animal waste with the aim to establish a self-sustaining, cost-effective, and sustainable WTE technology in Bangladesh. For the way forward, the government has already conducted a feasibility study on WTE conversion in six municipalities: Mymensingh, Cox's Bazar, Sirajganj, Dinajpur, Habiganj, and Jessore (UNDP 2018). It is recommended that for the future WTE generation, gasification and anaerobic digestion be considered as the two most promising technologies for Bangladesh, with the first one being recommended for large cities where land acquisition is more difficult.[10] Gasification and anaerobic digestion technologies are considered more environmentally friendly than incineration as their CO_2 intensity is lower.[11] The challenge for Bangladesh is to source substantial investments for those projects, bearing in mind the higher cost of gasification-based WTE power plants.

8.3 Aims of This Paper

In this chapter, we propose an economic analysis of the policy of introducing WTE power plants in Bangladesh. The introduction of WTE power plants has the potential to create a win–win scenario if it boosts the macroeconomy and has a lower overall environmental impact in comparison to fossil fuels. Previous literature on the economic impact of WTE in developing and emerging economies focus primarily on plant-based case studies (for a compendium, see ADB 2020). To our knowledge, there are no attempts at quantifying the consequences in term of macroeconomic variables such as gross domestic product (GDP), production and consumption, and carbon emissions of implementing WTE technology in Bangladesh.

The model we use is based on Amin (2015), who developed an electricity sector-augmented dynamic stochastic general equilibrium (DSGE) model for the Bangladesh economy. We focus on CO_2 generation to assess the impact of the WTE technology in Bangladesh on the sustainability of the electricity sector. According to the Annual Report of Bangladesh Power Development Board (2020), the shares of natural gas, imported oil,

---

[10] For more details, see UNDP (2018).

[11] We focus on the CO_2 intensity of different fuels, including waste. Therefore, we limit the environmental impact of WTE technology on CO_2 emissions.

and renewable energies (only grid) in the total net electricity generation are 53.25%, 34.05%, and 1.53%, respectively, with the remaining made up of coal.[12] Following the IPCC (2006) calculation methods for CO_2 emissions, typically WTE has been found to have a lower CO_2 intensity than oil, but higher than natural gas. If WTE can be used as a substitute for oil, it can be effective in mitigating the impact of electricity generation on climate change. We therefore model CO_2 as a function of fossil fuels (natural gas and oil) and waste used in electricity generation and assess the impact of introducing WTE in Bangladesh on the macroeconomy and overall CO_2 emissions. The underlying assumptions, in particular, the functional forms of household preferences and technology, follow the seminal work by Kim and Loungani (1992), Dhawan and Jeske (2008), and Amin and Marsiliani (2015). Consistent with the planned economy system of Bangladesh, the government regulates all energy prices. This feature creates market distortions in the economy as prices are often kept below full cost and implicit subsidies emerge (Amin 2015).[13] For illustration purpose, we simulate the introduction in the electricity market of a large-scale WTE, incineration-based power plant for Bangladesh consistent with the proposed CMEC plant.[14] As Bangladesh has just started to consider WTE technology, our policy analysis has the potential to guide future developments in the WTE power sector in the country.

8.4 The Benchmark Model

We use a DSGE model, explicitly modelling electricity generation. Electricity is produced by using imported oil as well as by using domestically sourced natural gas and, for the purpose of our policy analysis, WTE incineration, as mentioned earlier. We have four main sectors: the industrial sector and the service production sector (in turn using electricity as input), the electricity-producing sector, and the government sector. We also specify an equation for CO_2 emissions.

8.4.1 Production of Industrial Output and Services

Final industry output and services are produced under constant elasticity of substitution (CES) technologies, featuring decreasing returns to scale (DRS),[15] using capital (*k*), labor (*l*) and electricity (*j*):

$$F_i(l_{i,t}, k_{i,t}, j_{i,t}) = A^i l_{i,t}^{\alpha_i}[(1-\Psi_i)k_{i,t}^{-\nu^j} + \Psi_i j_{i,t}^{-\nu^j}]^{-\frac{(1-\alpha_i)}{\acute{\upsilon}^{jj}}} \tag{1}$$

where, A^i is total factor productivity with index *i* denoting the respective sectors (*Y* that is the industrial sector or *X* that is the service sector). α_i and Ψ_i are the labor and electricity shares in production, respectively. The elasticity of substitution (EOS) between capital

---

[12] For more details, see BPDP (2020).

[13] Delpiazzo, Parrado, and Standardi (2015) assess the possible benefits of phasing out fossil fuel subsidies around the world. Coady, Parry, and Shang (2017), and GSI (2019) review the literature on the environmental and economic benefits of fossil fuel subsidies removal in different countries.

[14] For more details, see Byron and Alam (2020).

[15] CES production with DRS has been used in some of the standard DSGE literature (Rotemberg and Woodford 1996; Jaaskela and Nimrak 2011).

and electricity is given by $\frac{1}{1+\nu^{j}}$. The degree of homogeneity of the production function is given by $\acute{\upsilon}^{jj}$, and in order for DRS to hold, we need:

i. $\frac{\nu^{j}}{\acute{\upsilon}^{jj}}<1$

Denoting g and s the electricity use in industry (Y) and services (S), we have:

$$Y_t=A_t^Y l_{Y,t}^{\alpha_Y}[(1-\Psi_Y)k_{Y,t}^{-\nu^g}+\Psi_Y g_t^{-\nu^g}]^{-\frac{1-\alpha_Y}{\acute{\upsilon}^{gg}}} \tag{2}$$

$$X_t=l_{X,t}^{\alpha_X}[(1-\Psi_X)k_{X,t}^{-\nu^s}+\Psi_X s_t^{-\nu^s}]^{-\frac{1-\alpha_X}{\acute{\upsilon}^{ss}}} \tag{3}$$

All firms, except for the government, are profit-maximizing price takers:

$$\pi_{i,t}=\max P_t^i A^i l_{i,t}^{\alpha_i}[(1-\Psi_i)k_{i,t}^{-\nu^j}+\Psi_i j_{i,t}^{-\nu^j}]^{-\frac{1-\alpha_i}{\acute{\upsilon}^{\mathrm{jj}}}}-r_t k_{i,t}-w_t l_{i,t}-\nu^j j_{i,t} \tag{4}$$

where P_t^i, w_t, r_t, and v_j denote the output price, wage rate, the interest rate, and the electricity price, respectively. Wage and interest rates are assumed to be equalized across all the sectors. The final goods price, P_t^Y, is normalized to 1.

8.4.2 The Electricity Generation Sector

As in Amin (2015), we use a CES production function for electricity generation. Our sectors are (i) the government sector (G), using natural gas to produce electricity; (ii) the private independent power producers (I), using natural gas in electricity production; (iii) the privately owned quick rentals (Q), using oil to produce electricity; and (iv) the WTE power plant (R), employing waste.[16] Each firm uses labor, capital, and energy (natural gas, *m*, oil, *h and waste*, *z*) in electricity generation:

$$G_t=A^G l_{G,t}^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}}+\Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{1-\alpha_G}{\nu^{m,GG}}} \tag{5}$$

$$I_t=A^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{1-\alpha_I}{\nu^{m,II}}} \tag{6}$$

$$Q_t=A^Q l_{Q,t}^{\alpha_Q}[\left(1-\Psi_Q\right)k_{Q,t}^{-\nu^Q}+\Psi_Q h_t^{-\nu^Q}]^{-\frac{1-\alpha_Q}{\nu^{Q,QQ}}} \tag{7}$$

$$R_t=A^R l_{R,t}^{\alpha_R}[(1-\Psi_R)k_{R,t}^{-\nu^R}+\Psi_R z_t^{-\nu^R}]^{-\frac{1-\alpha_R}{\nu^{R,RR}}} \tag{8}$$

The parameter $\nu^{m,G}$ determines the EOS between capital and energy. α_G, and Ψ_G are the shares of labor and energy in production, respectively, where $\Psi \in (0, 1)$. To capture the logistics in collecting waste for electricity generation, we will assume a fixed level of *z* (in our computation set its value at 3,000 tons per day), lower than the total waste generated by the households. As this amount is fixed, consistently with the CMEC plan, there is no feedback effect from household, industrial, and service sectors to waste.

Following Amin and Marsiliani (2015), we model a stochastic oil price v_t^e:

---

[16] These specifications are based on historical data and regulatory legislation, see Annual Reports of the Bangladesh Power Development Board (https://www.bpdb.gov.bd/bpdb_new/index.php/site/annual_reports)

$$\ln v_t^e = {}'\Omega^v + \omega \ln v_{t-1}^e + \eta_t^O \qquad (9)$$

where ω is the degree of persistence of the shocks and $'\Omega^v$ determines the steady-state oil price . We assume that the shocks (η_t^O) are normally distributed with zero mean.

8.4.3 The Household

The household consumes standard consumption goods (c), services (x), electricity (e), and leisure (1-l).

The per-period utility function is:

$$U(c_t^A, l_t) = \varphi \, log \, C_t^A + (1-\varphi) log(1-l_t) \qquad (10)$$

where

$$C_t^A = X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}} \qquad (11)$$

1/(1-ρ) is the EOS between c and e. This formulation allows for a lower-than-unity substitution elasticity between ordinary consumption and electricity consumption, which is the case when we set ρ to -0.11 (as in Amin and Marsiliani 2015).

The household receives (i) income from capital ($r.k_t$), (ii) income from labor ($w.l_t$), (iii) a lump-sum transfer (ъ) from the government, and (iv) dividends (π).[17] The tax rates on capital and labor income denoted $\tau^k and\ \tau^l$, respectively. We denote the price of services and household electricity n and q^e, respectively.

The budget constraint for the household is:

$$k_{t+1} + c_t + n.X_t + q_t^e.e_t = (1-\tau^l).w_t.l_t + \text{ъ} + (1-\tau^k).r_t.k_t + (1-\delta)k_t + \pi \qquad (12)$$

where δ is the capital depreciation rate. Consequently, the Lagrange function is:

$$L = \sum_{t=0}^{\infty} \beta^t [(\varphi \, log \left[X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right]) + (1-\varphi)\, log(1-l_t)] - \lambda_t[k_{t+1} + c_t + n.X_t + q_t^e.e_t - (1-\tau^l).w_t.l_t - \text{ъ} - (1-\tau^k).r_t.k_t - (1-\delta)k_t] \qquad (13)$$

where β denotes the discount factor and λ_t the Lagrange multiplier.

8.4.4 The Government

The sources of government revenue are labor income tax revenue ($\tau^l.w_t.l_t$), capital income tax revenue ($\tau^k.r_t.k_t$), sales of natural gas to other electricity-generating firms ($(v^m - \delta^C)(m_{I,t} + m_{G,t})$), and sales of electricity to the national grid ($P^G.G_t$). Government spending are labor cost ($w_t.l_{G,t}$), capital cost ($r_t.k_{G,t}$), and natural gas expenditure ($v^m.m_{G,t}$) for its own electricity production and a lump-sum transfer to

---

[17] Since the electricity producers operate in decreasing returns to scale, their profit will be handed back to the households.

households (Ъ_t). The price of natural gas in the local market is denoted $v^{\,m}$. Additionally, there is also an extraction cost of natural gas (δ^C). On the electricity generating side, the government seeks to minimize the cost function:

$$c_{G,t} = w_t.\,l_{G,t} + r_t.\,k_{G,t} + v^m.\,m_{G,t} - P^G A^G l_t^{\alpha_G}\left[(1-\Psi_G)k_{G,t}^{-v^{m,G}} + \Psi_G m_{G,t}^{-v^{m,G}}\right]^{-\frac{1-\alpha_G}{v^{m,GG}}} \tag{14}$$

Through the price schedule, there is an implicit government subsidy, as it purchases electricity from the producers at a higher price and sells it at a lower. So, the negative of this subsidy is:[18]

$$b = P^G.\,G_t + P^I.\,I_t + P^Q.\,Q_t - q^e.\,e_t - q^s.\,s_t - q^g.\,g_t \tag{15}$$

The government budget constraint is as follows:

$$\tau^l.\,w_t.\,l_t + \tau^k.\,r_t.\,k_t + (v^m - \delta^C)\big(m_{I,t} + m_{G,t}\big) + (v^h - v^e)h_t P^G.\,G_t - r_t.\,k_{G,t} - w_t.\,l_{G,t} - v^m.\,m_{G,t} - \text{Ъ}_t = b_t \tag{16}$$

Finally, the economy-wide resource constraint is obtaining by combining the household budget constraint, the government budget constraint, and the subsidy equation:

$$k_{t+1} = Y_t - c_t - v^e.\,h_t + (1-\delta)k_t - \delta^C\big(m_{I,t} + m_{G,t}\big) \tag{17}$$

8.4.5 The Equilibrium Conditions

The equilibrium conditions for the labor, capital, and electricity markets are:

$$l = l_Q + l_I + l_G + l_R + l_Y + l_X \tag{18}$$

$$k = k_Q + k_I + k_G + k_R + k_Y + k_X \tag{19}$$

$$e_t + s_t + g_t = (Q_t + I_t + G_t + R_t) \tag{20}$$

8.4.6 CO2 Emissions

Our model assumes that to generate electricity, the government power producers (*G*) and the independent power producers (*I*) use natural gas, the quick rental companies (*Q*) oil, and the WTE company (R) solid municipal waste (SMW). Using data from the United States Energy Information Administration and calculations from IPCC (2006) for MSW, we model natural gas as releasing 0.41 kilograms of CO_2 to generate 1 kilowatt-hour of electricity, oil 0.97 kilograms of CO_2, and SMW 0.60 kilograms of CO_2 to generate 1 kilowatt-hour of electricity (see section 8.5 for further information on those parameters);[19] we therefore specify the CO_2 equation as follows:

$$CO_2 = 0.41(G_t + I_t) + 0.97Q_t + 0.60\,R_t \tag{21}$$

---

[18] q^S and q^g are the electricity prices for the service and industrial sector, whereas P^G is the selling price of electricity by the government.

[19] The IPPC (2006) calculations for MSW include organic and non-organic waste. We could not source a corresponding parameter for organic waste only. Estimates for biomass are available from IPCC (2012), but those do not include plastic, which is a component of organic waste. The important feature for our analysis is that emissions from combustion of natural gas are lower than from MSW. This is supported by available data and existing literature on WTE incineration studies.

8.5 Parameter Specification and Electricity Price Schedule

For the non-waste sectors, we take the parameter values, calibrated on Bangladesh data, from Amin et al. (2019). All calibrated parameters (annual frequency) used in this chapter are presented below in Table 8.1. As in Amin et al. (2021), we set the capital and labor income tax rates τ^k and τ^l to 0.15 and 0.10, respectively.

The prices (treated as parameters) are shown in Table 8.2. All prices, apart from those related to waste, are taken from Amin et al. (2021).

Table 8.1: Parameters

Parameter	Description	Values
θ	Utility: non-electricity consumption share	0.91
γ	Utility: service share	0.81
ϕ	Utility: consumption versus leisure share	0.60
α_Y	Production: industry labor share	0.2
α_X	Production: service labor share	0.313
α_G	Production: government electricity labor share	0.042
α_I	Production: IPP electricity labor share	0.036
α_H	Production: QR electricity labor share	0.004
α_R	Production: WTE electricity labor share	0.15
Ψ_Y	Production: industry electricity share	0.073
Ψ_X	Production: service electricity share	0.079
Ψ_G	Production: government electricity gas share	0.302
Ψ_I	Production: IPP electricity gas share	0.309
Ψ_H	Production: QR electricity oil share	0.596
Ψ_R	Production: WTE electricity waste share	0.432
ν^g	Production: industry EOS between capital and electricity	0.1
ν^s	Production: service EOS between capital and electricity	0.1
$\nu^{m,G}$	Production: govt. electricity EOS between capital and gas	0.1
$\nu^{m,I}$	Production: IPP EOS between capital and gas used in IPP	0.1
ν^Q	Production: QR EOS between capital and oil	0.1
$\nu^{m,R}$	Production: WTE EOS between capital and waste	0.197
$\acute{\upsilon}^{gg}$	Production: industry degree of homogeneity	0.229
$\acute{\upsilon}^{ss}$	Production: service degree of homogeneity	0.234
$\nu^{m,GG}$	Production: govt. electricity degree of homogeneity	0.223
$\nu^{m,II}$	Production: IPP degree of homogeneity	0.223
$\nu^{Q,QQ}$	Production: QR degree of homogeneity	0.222
$\nu^{R,RR}$	Production: WTE degree of homogeneity	0.208
A^Y	Production: industry TFP	0.988
A^X	Production: service TFP	1
A^G	Production: government electricity TFP	0.870

A^I	Production: IPP TFP	0.823
A^H	Production: QR TFP	0.817
A^R	Production: WTE TFP	0.814
ω	Oil price shock persistence	0.95
$\acute{\Omega}^{v}$	Oil price level parameter	0.105
$\zeta,$	Standard deviations of oil price shock	0.002

EOS = elasticity of substitution, IPP = independent power producer, QR = quick rental company, TFP = total factor productivity, WTE = waste to energy.
Source: Amin et al. 2019 and 2021 and authors.

Table 8.2: Electricity and Fuel Prices
(Tk/kWh)

Price	Description	Values
q^e	Household's electricity buying price	4.93
q^g	Industry's electricity buying price	6.95
q^s	Service sector's electricity buying price	9.00
P^I	IPP's electricity selling price	3.20
P^H	QR's electricity selling price	7.79
P^G	Government's electricity selling price	2.3
P^R	WTE plant's electricity selling price	18.295
v^e	International oil price (long run value)	8.19
v^h	QR's oil purchase price	5.72
v^m	Natural gas selling price	0.77

IPP = independent power producer, kWh = kilowatt-hour, QR = quick rental company, WTE = waste to energy.
Source: Amin et al. 2021 and authors.

We set the price for selling electricity from the incineration plant to Tk18.295/kWh, which is the planned price for selling electricity from WTE at the initial stage of production (Byron and Alam 2020). Reflecting the lower labor intensity of incineration plants, we set α_R=0.15. We set returns to scale in capital and waste to 0.955 (i.e. close to 1, so doubling capital and doubling waste nearly double electricity output). To find Ψ_R, ν^R, and $\acute{\upsilon}^{RR}$, we calibrate the model so that the output per waste, when labor and capital are chosen optimally, the electricity-to-waste ratio matches the Baku WTE Project in Azerbaijan (ADB 2020).[20] One main reason to calibrate the model to the Baku WTE Project is its association with the Balakhani landfill (where 90% of total waste generated in Baku City is disposed), which exhibits similar features to the Aminbazaar landfill in the Dhaka North City Corporation area (where the first Dhaka WTE power plant is planned to be built). The waste z is set, so it corresponds to 3,000 metric tons per day, on an annual basis as for the Dhaka WTE proposal by the CMEC.[21] Finally, we calibrate total factor productivity A^R to fit with the Baku plant.

---

[20] For more details about the Baku WTE Project, see ADB (2020).
[21] For more details, see Mamun (2020).

For calculating CO_2 emissions, we use the conversion 410 gr and 970 gr CO_2 per kWh electricity generated using gas and oil, respectively, per the United States Energy Information Administration (2021). For the carbon emissions from the waste incineration plant, we take the value of 600 gr CO_2/kWh, which is consistent with the IPCC (2006) calculation method and widely used in the literature on WTE.

8.6 Policy Experiment and Results

We compute the model and then compare the steady state values of relevant economic and environmental variables for the scenarios with no WTE power plants (benchmark model)[22] and with WTE technology (WTE-connected model). The steady-state values of the relevant variables are listed in Table 8.3.

Table 8.3: Steady-State Values

Variables	Benchmark Model	WTE-Connected Model
GDP, Aggregate Economic Output	2.10424	2.10487
Y, Aggregate Industrial Output	0.411961	0.412128
c, General Consumption	0.255495	0.255586
e, Electricity Consumption	0.00745989	0.00746255
I, IPP Electricity Generation	0.00231843	0.00231837
Q, QR Electricity Generation	0.00119735	0.00119735
G, Government Electricity Generation	0.0142124	0.0142051
R, WTE Energy Plant Generation	-	0.000001396
Env, CO_2 Emissions	0.00793907	0.00795281
X, Service Production	0.789976	0.790046
l, Aggregate Labor	0.300876	0.300894
K, Aggregate Capital	5.79942	5.80273
g_t, Government Transfer	0.187411	0.18753
g_s, Energy Subsidies	-0.0581488	-0.0582014

GDP = gross domestic product, IPP = independent power producer, QR = quick rental company, WTE = waste to energy.
Source: Authors.

The steady-state comparison reveals that opening up one waste burning power plant in Bangladesh consistent with the CMEC plan has a small effect on the steady-state variables as the plant will constitute a small fraction of GDP (the WTE electricity production in value terms is 0.01% of GDP). The government electricity production falls by 0.05%, while generation from the private sector does not change (this is due to the fixed electricity price schedule in Bangladesh). Essentially, the waste burning plant

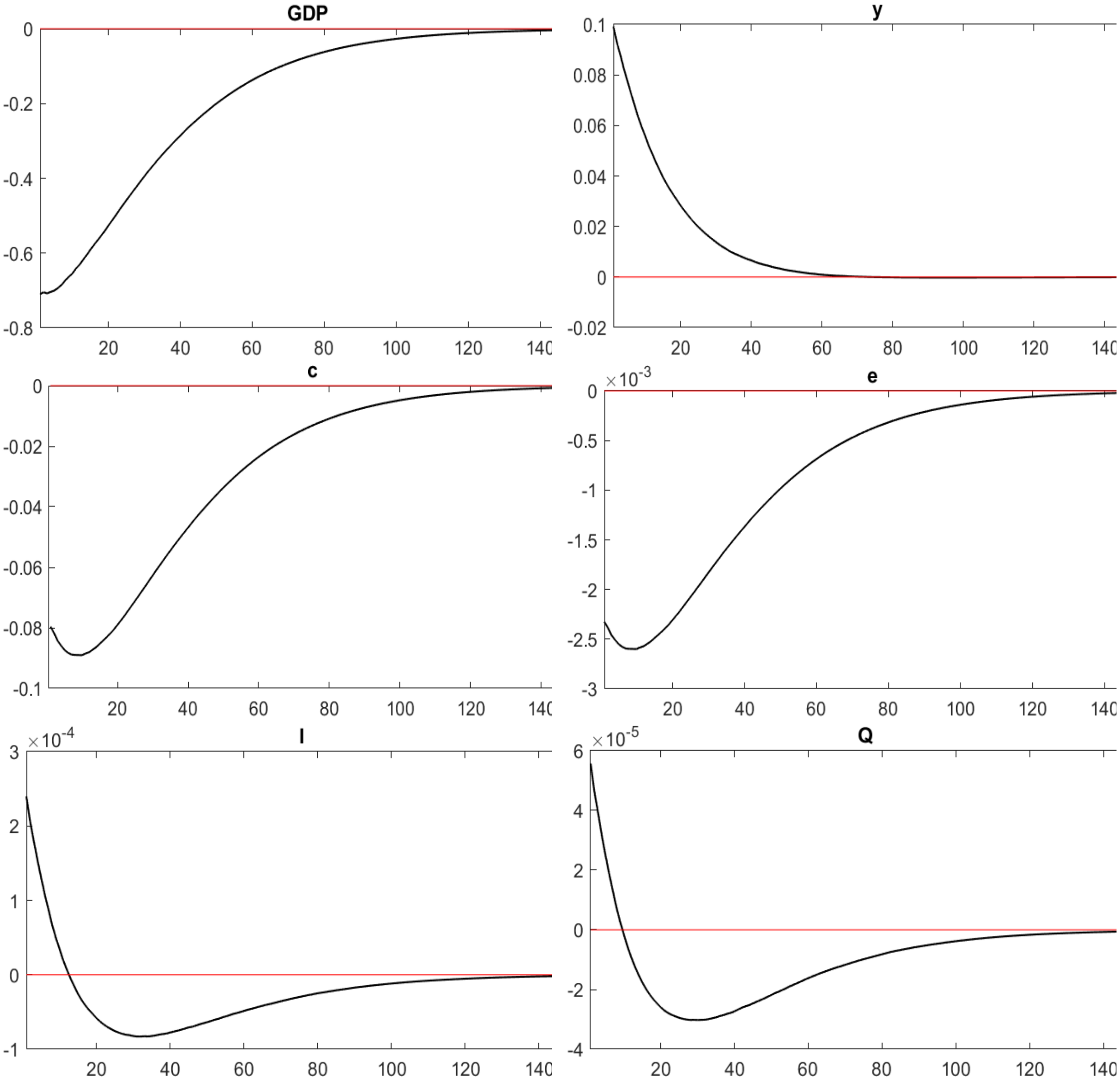
---

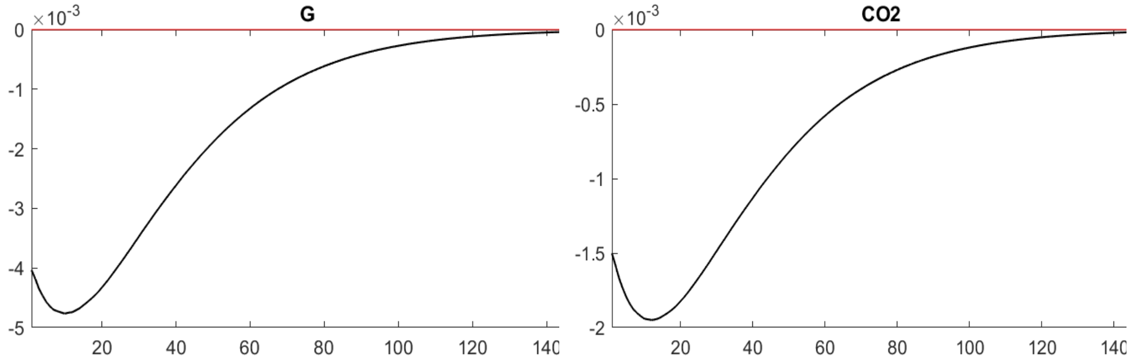
[22] In terms of waste management, the benchmark model for Bangladesh represents a situation with landfill disposal only, while the WTE-connected model also includes WTE disposal.

crowds out government production only, with a net result of a 0.03% increase in total electricity generation. Industrial output increases by 0.04%; GDP and standard consumption also both increase by 0.03%. However, as a result of moving away from natural gas (which is used in government electricity generation), CO_2 emissions increase by 0.17%, hampering the opportunity for a win–win situation for the economy and the environment.

We also analyze the impact of an oil price shock on the economy. The impulse response functions (IRFs) show little difference across the two scenarios (Figures 8.1 and 8.2). The reason is that the waste burning sector is relatively small.

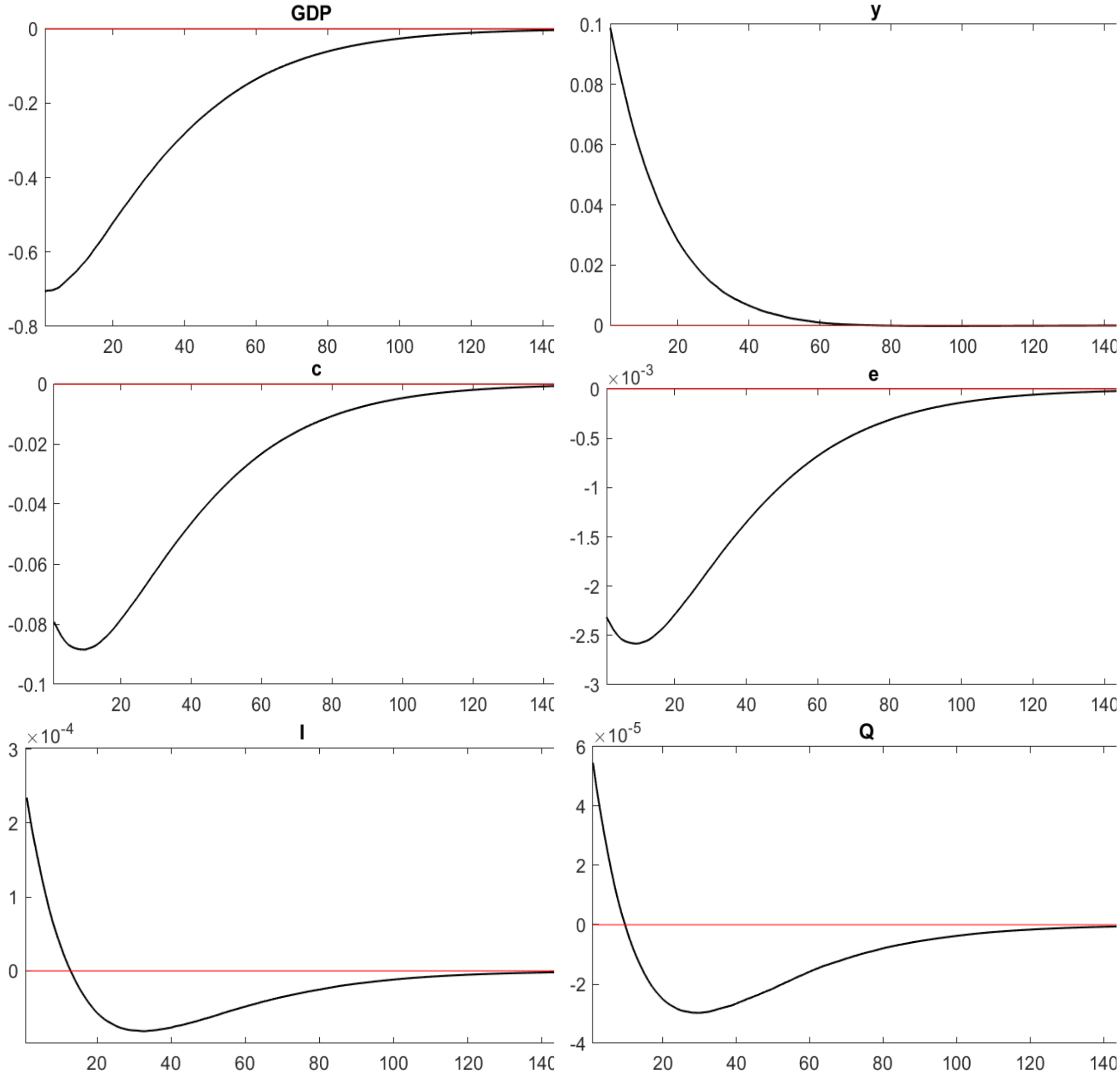
Figure 8.1: Impulse Responses to an Oil Price Shock in the Benchmark Model

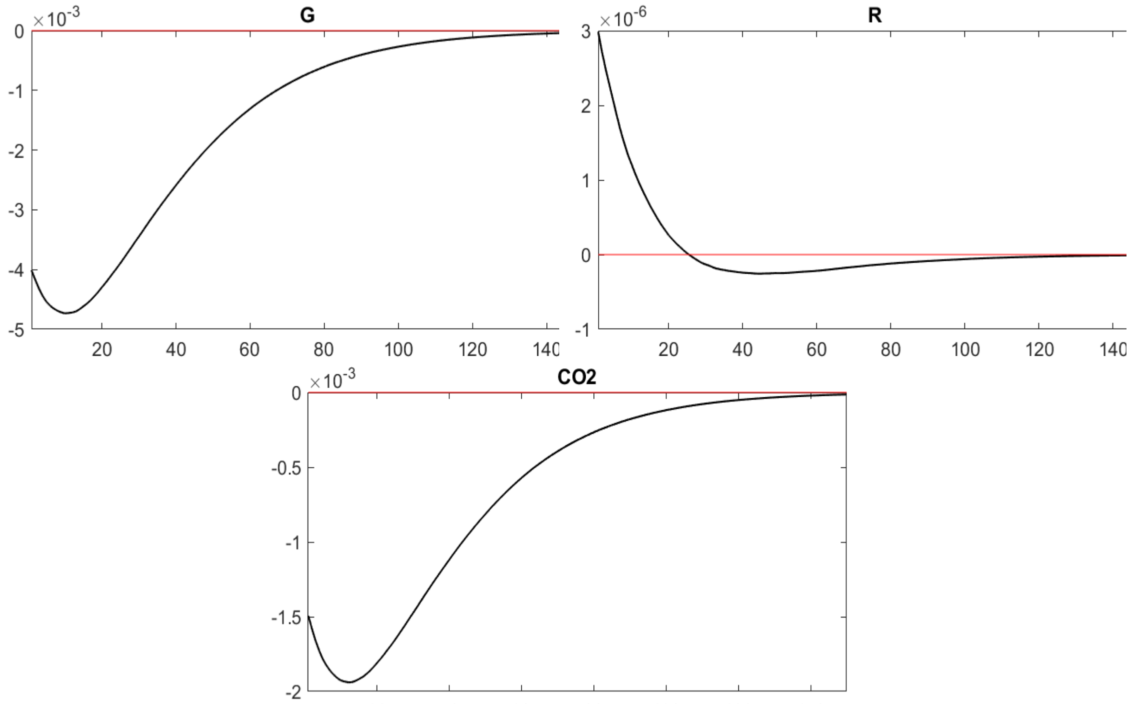




CO$_2$ = carbon dioxide, GDP = gross domestic product.
Source: Authors.

Figure 8.2: Impulse Responses to an Oil Price Shock in the Waste-to-Energy Model





CO_2 = carbon dioxide, GDP = gross domestic product.
Source: Authors.

8.7 Conclusion and Policy Recommendations

Bangladesh has made significant progress over the past decade from a socioeconomic standpoint and is now known as the new Asian Tiger for its remarkable development. During this time, the Bangladesh economy has been growing steadily at 7% on average every year, elevating millions of people out of poverty. The energy sector has played a crucial role in achieving this landmark success. However, the sector is characterized by market distortions as the Bangladesh government regulates energy prices and subsidizes energy consumption by keeping prices below costs. Amin (2015) argues that these distortions substantially delay the transition toward a sustainable energy mix.

As a game changer, the government has recently considered opening the first WTE power plant in the country. This chapter has presented a fit-for-purpose DGSE model to assess the implications for the Bangladesh economy of introducing a WTE power plant in the electricity generation sector. We calibrate the Bangladesh economy model and run a policy experiment based on the proposal put forward by the CMEC (Byron and Alam 2020). Our results show that transitioning toward an energy sector in which WTE power plants are present increases key macroeconomic variables. For illustration purposes, based on the one plant policy experiment, we find a 0.03% increase in total electricity generation, a 0.04% increase in industrial output, and a 0.04% boost in GDP and standard consumption. However, as a result of moving away from natural gas (which is used predominately in the government electricity generation), CO_2 emissions increase by 0.17%. This is due to the WTE plants crowding out government power generation that is fueled by natural gas. Given the Bangladesh electricity price system, gas, oil, and electricity prices are fixed. Thus, the private producers will only change their production if the interest rate and the wage rate change. Consequently, increased supply of electricity when the waste plant is connected to the grid will not crowd out the private electricity generation. The government electricity producer acts to clear the market (swing producer) and therefore cuts its production.

According to our IRF analysis, moving toward a more sustainable energy sector via the introduction of WTE technology does not make the Bangladesh economy less sensitive to oil price shocks; in our policy experiment, the economy is still significantly reliant on oil.

Overall, our study shows that transitioning away from fossil fuel toward WTE has the potential to increase Bangladesh overall production, consumption, and GDP. However, we have also found that CO_2 emissions will increase due to natural gas in electricity generation being displaced by waste incineration.

One dimension that we have not explored is the pollution impact of the proposed Dhaka incinerator and its effect on human health and ecosystems, with toxic substances and ash releases being of particular concern. A firm regulatory approach from the government would be needed to ensure that up-front recycling and reuse of waste is pursued and clean technology is deployed to process the residual waste. Besides, the increase in Bangladesh macroeconomic variables such as production, consumption, and GDP from opening the grid to the Dhaka incinerator can in turn increase GHG emissions, pollution levels, and amount of waste. Therefore, it is even more important that regulatory actions are in place and the polluter-pay-principle is effectively adopted (e.g., via carbon or energy taxes). In this respect, the need to align policies with Bangladesh's Paris Agreement pledge to reduce GHG emissions by 15% with respect to business as usual by 2030 can accelerate the transition toward sustainable development in the country.

Based on our results, this study provides the following policy implications. First, it advocates the case for removing energy market distortions as they are the fundamental cause of the increase in CO_2 emissions from opening the grid to the WTE power plant. Furthermore, as reliance on imported oil is increasing in Bangladesh—indeed between 2009 and 2020, the average share of oil in the electricity generation mix increased from 5.92% to 34.05%—there are concerns in policy circles about the country's vulnerability to oil price shocks and energy security. Given this remarkable increase in oil use, fueled by high GDP growth rates, and the evidence that domestically sourced natural gas reserves are being depleted, this study also argues for a more decisive transition toward renewables including WTE of biomass. As the latter typically generates less GHG emissions and less pollutants than fossil fuels, it has the potential to foster sustainable development in the country. All of this, however, can only be achieved once price distortions have been removed.

Another promising extension would be modeling WTE technologies other than waste incineration and alternative waste loads (to account for higher reuse and recycling of materials) and exploring their relative performances in terms of macroeconomic variables and CO_2 emissions. It is expected that, for the same amount of waste utilized, cleaner WTE technologies such as anaerobic digestion will lower CO_2 emissions per kilowatt-hour of electricity generated.[23]

Finally, it would be important to assess which incentives are needed in Bangladesh to foster the adoption of clean WTE technologies. As Bangladesh develops, more financial resources are expected to be available for environmental protection and for opportunities to implement a circular economy system.

The case of the removal of price distortions, coupled with the introduction of WTE technology in Bangladesh, the impact of emerging WTE technologies, and the assessment of the incentives needed for the transition toward cleaner WTE processes are left for future work.

---

[23] It is also expected that electricity generation from given amount waste decreases, as biomass typically has lower calorific values than undifferentiated waste; in our model, this means that WTE will displace natural gas less than in the study in this chapter, but overall emissions will still decrease. See section 8.1 for further information on GHG emissions from anaerobic digestion recovery process and biomass calorific value.

References

Ahmed, N. 2019. When the Garbage Piles Up. *The Daily Star*. 7 October. https://www.thedailystar.net/opinion/environment/news/when-the-garbage-piles-1810375

Alam O., and X. Qiao. 2020. An In-Depth Review on Municipal Solid Waste Management, Treatment and Disposal in Bangladesh. *Sustainable Cities and Society*, 52, 101775.

Amin S. B. 2015. *The Macroeconomics of Energy Price Shocks and Electricity Market Reforms: The Case of Bangladesh*. Ph.D. Thesis., Durham University.

Amin S. B., T. Jamasb, M. Llorca, L. Marsiliani, and T. I. Renström. 2019. Combining Private and Public Resources: Captive Power Plants and Electricity Sector Development in Bangladesh. *Emerging Markets Finance and Trade*. https://doi.org/10.1080/1540496X.2019.1703107

Amin S. B., T. Jamasb, M. Llorca, L. Marsiliani, T. I. Renström, and A. Sarkar. 2021. Captive Power, Market Access and Macroeconomic Performance: Reforming the Bangladesh Electricity Sector. *Energy Economics* 102, article 105468.

Amin S. B., and L. Marsiliani. 2015. Energy Price Shocks in Dynamic Stochastic General Equilibrium: The Case of Bangladesh. *Review of Business and Economics Studies* 30 (3): 12-21. https://rbes.fa.ru/jour/article/view/24/24

Asian Development Bank (ADB). 2020. *Waste to Energy in the Age of the Circular Economy Compendium of Case Studies and Emerging Technologies*; https://www.adb.org/publications/waste-to-energy-age-circular-economy-handbook

Bachmaier J., M. Effenberger, and A. Gronauer. 2010. Greenhouse Gas Balance and Resource Demand of Biogas Plants in Agriculture. *Eng. Life Sci.* 2010, *10*(6), 560–569. DOI:10.1002/elsc.201000073.

Bahauddin K. M., and M.H. Uddin. 2012. Prospect of Solid Waste Situation and an Approach of Environmental Management Measure (EMM) Model for Sustainable Solid Waste Management: Case Study of Dhaka City. *Journal of Environmental Science and Natural Resources*, 5(1), 99-111.

Bangladesh Power Development Board (BPDB). 2020. *Annual Report*. https://www.bpdb.gov.bd/bpdb_new/resourcefile/annualreports/annualreport_1605772936_AnnualReport2019-20.pdf

Byron. R.K., and H. Alam. 2020. Waste to Electricity: China to Build Power Plant for

DNCC Area. *The Daily Star*. 13 November. https://www.thedailystar.net/backpage/news/waste-electricity-china-build-power-plant-dncc-area-1994101

Coady D., I. Parry, and B. Shang. 2017. "Energy Price Reform: A Guide for Policymakers", CESifo Working Paper Series 6342, CESifo Group Munich.

Dhaka North City Corporation. 2019. *Waste Report 2018–2019*. https://dncc.portal.gov.bd/sites/default/files/files/dncc.portal.gov.bd/annual_reports/6693c776_0dde_49da_b85b_1928d398a7f4/2020-07-07-15-04-0388efe51e61d331efb81045a0648dd2.pdf

Dhawan R., and K. Jeske. 2008. Energy Price Shocks and the Macroeconomy: The Role of Consumer Durables. *Journal of Money, Credit and Banking* 40 (7): 1357-1377. https://doi.org/10.1111/j.1538-4616.2008.00163.x

Delpiazzo E., R. Parrado, and G. Standardi. 2015. Phase-Out of Fossil Fuel Subsidies: Implications for Emissions, GDP and Public Budget. Research Papers Issue RP0275, ECIP-Economic analysis of Climate Impacts and Policy Division, CMCC Research Paper.

Global Subsidies Initiative (GSI). 2019. *Raising Ambition through Fossil Fuel Subsidy Reform: Greenhouse Gas Emissions Modelling Results from 26 Countries*. Geneva: Global Subsidies Initiative of the International Institute for Sustainable Development.

Government of Bangladesh. 2020. *8th Five-Year Plan (July 2020–June 2025): Promoting Prosperity and Fostering Inclusiveness*. Dhaka. https://oldweb.lged.gov.bd/UploadedDocument/UnitPublication/1/1166/8FYP.pdf

Hossain H.Z., Q.H. Hossain, M.M.U. Monir, and M.T. Ahmed. 2014. Municipal Solid Waste (MSW) as a Source of Renewable Energy in Bangladesh: revisited. *Renew. Sustain. Energy Rev*. 39, 35–4

Intergovernmental Panel on Climate Change (IPCC). 2006. *IPCC Guidelines for National Greenhouse Gas Inventories.* Volume 5-Waste. Japan, IGES.

Intergovernmental Panel on Climate Change (IPCC). 2012. *Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN)*. Cambridge University Press
Islam K. M. N. 2016. Municipal Solid Waste to Energy Generation in Bangladesh: Possible Scenarios to Generate Renewable Electricity 473 in Dhaka and Chittagong City. Journal of Renewable Energy, Article ID 1712370, http://dx.doi.org/10.1155/2016/1712370

Jaaskela J. P., and N. Nimrak. 2011. A Medium-Scale New Keynesian Open Economy

Model of Australia. *The Economic Record* 87(276): 11-36. https://doi.org/10.1111/j.1475-4932.2010.00688.x

Joshi P., and C. Visvanathan. 2019. Sustainable Management Practices of Food Waste in Asia: Technological and Policy Drivers. *Journal of Environmental Management*, Vol. 247, 538-550.

Kaur, A., Bharti, R., and Sharma, R. 2021. Municipal Solid Waste as a Source of Energy, *Materials Today*: Proceedings (forthcoming).

Kim I. M., and P. Loungani. 1992. The Role of Energy in Real Business Cycles. *Journal of Monetary Economics* 29: 173-189. https://doi.org/10.1016/0304-3932(92)90011-P

Kumar A., and S.R. Samadder. 2017. A review on Technological Options of Waste to Energy for Effective Management of Municipal Solid Waste. *Waste Management*, http://dx.doi.org/10.1016/j.wasman.2017.08.046

Laohalidanond K., P. Chaiyawong, and S. Kerdsuwan. 2015. Municipal Solid Waste Characteristics and Green and Clean Energy Recovery in Asian Megacities. *Energy Procedia*, Vol. 79, 391–396

Lee S.Y., R. Sankaran, K.W. Chew, C.H. Tan, R. Krishnamoorthy, D-T. Chu, and P-L. Show. 2019. Waste to Bioenergy: A Review on the Recent Conversion Technologies. *BMC Energy* 1**,** 4. https://doi.org/10.1186/s42500-019-0004-7

Lehmann S. 2018. Conceptualizing the Urban Nexus Framework for a Circular Economy: Linking Energy, Water, Food, and Waste (EWFW) in Southeast-Asian cities, In *Urban Energy Transition* (Second Edition), Ed. Droege, P., Elsevier, Pages 371104949.-398, ISBN 9780081020746. https://doi.org/10.1016/B978-0-08-102074-6.00032-2.

Li C., L. Yang, X. Liu, Y. Yang, L. Qin, D. Li, and G. Liu. 2021. Bridging the Energy Benefit and POPs Emission Risk from Waste Incineration. *Innovation,* Vol. 2, Issue 1, 28 February, 100075.

Malav L.C., K. Kumar, Y. Neha, G. Sandeep, G.K. Sharma, S. Krishnan, S. Rezania, H. Kamyab, Q.B. Pham, Y. Yadav, S. Bhattacharyya, V.K. Yadav, and Q-V Bach. 2020. A Review on Municipal Solid Waste as a Renewable Source for Waste-to-Energy Project in India: Current Practices, Challenges, and Future Opportunities. *Journal of Cleaner Production*, Vol. 277, 123227.

Mamun, S. 2020. 2 Waste-to-Energy Power Plants in Dhaka on the Cards. Dhaka Tribune. 24 September. https://archive.dhakatribune.com/bangladesh/dhaka/2020/09/24/2-waste-to-energy-power-plants-in-dhaka-on-the-cards

Rotemberg J. J., and M. Woodford. 1996. Imperfect Competition and the Effects of Energy Price Increases on Economic Activity. *Journal of Money, Credit and Banking* 28: 549,577.http://links.jstor.org/sici?sici=00222879%28199611%2928%3A4%3C549%3AICATEO%3E2.0.CO%3B2-7

Saveyn H., P. Eder, M. Ramsay, G. Thonier, K. Warren, and M. Hestin. 2016. Towards a Better Exploitation of the Technical Potential of Waste-to-Energy , EUR 28230 EN, Publications Office of the European Union, Luxembourg, 2016, ISBN 978-92-79-63778-0 (online), 978-92-79-74180-7 (ePub), doi:10.2791/870953 (online),10.2791/269648 (ePub), JRC104013.

Siddiqi A., M. Haraguchi, and V. Narayanamurti. 2020. Urban Waste to Energy Recovery Assessment Simulations for Developing Countries. *World Development*, Vol. 131, 104040.

Sustainable and Renewable Energy Development Authority. 2020. Waste to Energy. http://www.sreda.gov.bd/site/page/676cb08b-17b7-490c-b94b-d6b71c3ecb19/-

Tun M. M., P. Palacky, D. Juchelkova, and V. Síťař. 2020. Renewable Waste-to-Energy in Southeast Asia: Status, Challenges, Opportunities, and Selection of Waste-to-Energy Technologies. *Applied Sciences*, 10(20), 7312.

United Nations Development Programme (UNDP). 2018. *Feasibility Study on Waste to Energy Conversion in Six Municipalities in Bangladesh*. Dhaka. https://www.bd.undp.org/content/dam/bangladesh/docs/Projects/srepgen/WASTE%20TO%20ENERGY.pdf

United States Energy Information Administration (EIA). 2021. Frequently Asked Questions: How much carbon dioxide is produced per kilowatthour of U.S. electricity generation? https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

World Bank (2021). World Development Indicators database, World Bank, 1 July 2021, Available at http://data.worldbank.org/data-catalog/world-development-indicators