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Decarbonisation policies and energy price reforms in Bangladesh

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ABSTRACT

Bangladesh electricity sector suffers from heavy subsidization of fossil fuels and regulated electricity prices. These interventions distort the fuel mix in electricity production, promote overconsumption of fossil fuels and slow down the low-carbon transition. As a signatory of the 2015 UNFCCC Paris Agreement, Bangladesh has pledged to reduce GHG emissions by 15% (of which 5% is unconditional) with respect to Business as Usual by 2030, yet its overall CO_2 emissions are increasing. Urgent actions are needed for Bangladesh to fulfil its climate pledge. We use a fit-for-purpose Dynamic Stochastic General Equilibrium (DSGE) model to evaluate the effects of several decarbonisation policies, namely the implementation of carbon taxes and the removal of fossil fuel subsidies and intra-sectoral electricity price distortions. We find that all policies can deliver a win-win situation in terms of macroeconomic variables and CO_2 emissions with respect to a benchmark scenario that includes existing price distortions and no carbon taxes. The reduction of 4.6% in CO_2 emissions achieved in the price reform policy experiment indicates that liberalised energy markets can help achieve its Paris Agreement target. Thus, we recommend that the government considers reforming electricity and fossil fuel price structure to foster economic development and environmental sustainability.

1. Introduction

In developing and emerging countries energy policies primarily focus on the issue of energy security and accessibility, while it is also accepted that energy policy should be embedded within the framework of sustainable development (Komendantova et al., 2019; Pandey, 2002). These objectives often appear to be in contrast with each other, with dire consequences for the state of our environment and climate (Jean-Baptiste and Ducroux, 2003; Clift, 2007). In order to achieve their objectives of energy security and access to power, in many developing and emerging economies, governments distort markets by energy price controls. This is often achieved by keeping electricity prices below full economic cost to low-income consumer groups and often by subsidizing fuel costs to support energy production (Amin et al., 2018). In turn, energy market distortions lead to higher Greenhouse Gas (GHG) emissions, jeopardising sustainable development goals and commitment to the Paris Agreement on climate change.

Bangladesh is no exception, and the government provides oil at a subsidised price to the privately-owned oil-fired Quick Rental (QR) power producers to protect them from price volatility in the oil market. The government allowed the QR power producers to enter the energy market in 2009 as an emergency plan to resolve the then sizeable gap between demand and supply of electricity (Amin, 2015). Since then, the QR power plants have contributed to improving overall electricity generation in Bangladesh, but at the cost of an increase in the use of petroleum products (mainly, the High-Speed Diesel and Furnace Oil) in the electricity generation mix. Between 2009 and 2019, the average share of oil in the electricity generation mix in Bangladesh was 24.3% and it reached a peak of 32.4% in 2019 (Fig. 1).

The average electricity generation cost also increased to 6.25 Taka/kWh in 2018 from 2.62 Taka/kWh in 2009. Accordingly, the government feels compelled to provide subsidies to marginalised electricity consumers. As a result, energy subsidies in Bangladesh amounts to nearly 5% of the country's total GDP in 2018, with petroleum products and electricity accounting for nearly 90% of total subsidies (Amin, 2015; Ichord, 2020).[1]

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[1] Before 2009, energy subsidies in Bangladesh were only 0.1% of total GDP, see Amin (2015).

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Energy subsidies are costly and often ineffective in reaching the intended users and send a false price signal that encourages over-consumption (Jamasb and Nepal, 2011). They also crowd out growth-enhancing public spending on physical infrastructure, education, health, and social protection and may hurt the economy. For instance, Amin et al. (2018) find that a 10% reduction of the fuel subsidy would increase household welfare by 0.36%, and GDP by 0.09%.

Moreover, energy consumption is closely related to the state of the environment as it is responsible for manmade CO_2 and other GHG emissions (Mukhopadhyay and Chakraborty, 2002). GHG emissions from fossil fuel combustion are the single most significant cause of global warming and climate change. By distorting markets and discouraging energy saving and the production and use of clean energies, energy subsidies not only cause economic inefficiencies but also hamper a transition towards sustainable development (Schwanitz et al., 2014).[2]

The increased share of oil in the electricity generation mix has led to higher CO_2 emissions in Bangladesh. Around 94.3 million tonnes of CO_2 were emitted in 2019, of which 23.1 million tonnes (i.e., nearly 24.5%) are from oil combustion (Table 1). Natural gas accounts for nearly 66.4% of total CO_2 emissions in Bangladesh and coal for 9.1%. Due to the recent expansion of the share of oil in electricity generation, oil-based CO_2, on average, increased by 12.1% since 2016, which is well above the average growth rate (8.4%) of the last 11 years (2009–2019). This trend, and the plans to step up the use of coal in electricity generation, presents a threat to Bangladesh sustainability credentials.

A country-wise comparison of oil-fired CO_2 emissions for selected South-Asian countries is reported in Table 2. India, Pakistan, and Bangladesh top the table for oil-based CO_2 emissions from electricity generation. In 2018, India emitted 0.48 tonnes per capita of CO_2, while Pakistan and Bangladesh emitted 0.41 and 0.13 tonnes per capita of CO_2, respectively. Although India and Pakistan were until recently well ahead of Bangladesh in terms of CO_2 emissions, the emission growth rates of the former countries show steeper declines in the last three years than Bangladesh. The average per capita CO_2 emission growth rates of India and Pakistan between 2016 and 2018 were 4.6% and 5.3%, respectively, whereas Bangladesh's growth rate was 13.2% in that period. This undermines any climate protection actions.

Table 1
CO_2 emissions (Million Tonnes) from oil and natural gas in Bangladesh.

Year	CO_2 from Oil	CO_2 from Gas	Annual CO_2	Share (Oil)	Share (Gas)
2009	9.99	35.44	49.15	20.33	72.11
2010	10.84	39.40	53.99	20.08	72.97
2011	13.40	39.63	56.56	23.69	70.06
2012	14.88	41.71	60.69	24.52	68.73
2013	13.96	43.33	61.78	22.59	70.14
2014	15.79	45.93	65.98	23.92	69.62
2015	14.69	48.74	72.83	20.17	66.92
2016	15.44	53.55	76.00	20.31	70.46
2017	17.16	53.97	78.88	21.75	68.41
2018	19.67	57.43	85.69	22.96	67.01
2019	23.11	62.59	94.26	24.52	66.40

Source: Global Carbon Project (GCP) (2019).

Bangladesh has recently emphasized the importance of energy pricing policy for environmental protection, as reflected in the Perspective Plan 2041 (PP 2041) (GED, 2020). The PP 2041 states that all fossil fuels should be priced as to eliminate the subsidy. The plan also includes the recommendation to adopt carbon taxes to reduce carbon emissions from fossil fuels and promote clean investment with the overarching goal to ensure consistency between the country's power and energy development strategy and environmental protection. Furthermore, In September 2016, Bangladesh ratified the 2015 UNFCCC Paris Agreement, pledging a "GHG emission decrease of 15% from a Business as Usual (BAU) level by 2030. Of these, 5% reduction would be achieved unconditionally, while the remaining 10% would be conditional on receiving technical and financial support from the global community" (NDC of Bangladesh, 2020, p.2).[3] Therefore, being highly vulnerable to climate change risk and despite contributing less than 0.35% of global GHG emissions, Bangladesh, has ambitious targets to reduce its emissions.

In this paper we use a Dynamic Stochastic General Equilibrium (DSGE) model, augmented with an electricity generating sector and calibrated to the Bangladesh economy to investigate the long-run economic effects of carbon taxes and energy price reforms. To our knowledge, this is the first study doing so. We show, due to the Bangladesh

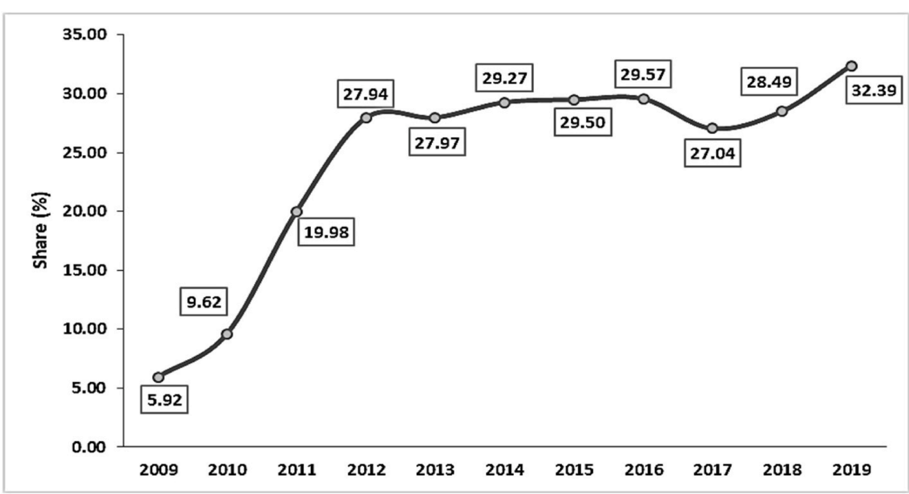

Fig. 1. Share of oil in Bangladesh electricity Generation
Source: Of Bangladesh power development board (BPDB) (2019).

[2] It is argued that facilitating the production and consumption of fossil fuels through subsidies is irreconcilable with the Paris Agreement on climate change.

[3] See NDC of Bangladesh 2020).https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Bangladesh%20First/Updated_NDC_of_Bangladesh.pdf.

Table 2
Oil-fired CO_2 emission (tonnes per capita) in selected South Asian countries.

Year	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
2009	0.07	0.36	0.35	2.50	0.11	0.33	0.60
2010	0.07	0.45	0.35	2.55	0.12	0.35	0.60
2011	0.09	0.53	0.37	2.59	0.12	0.33	0.64
2012	0.10	0.62	0.39	2.79	0.13	0.34	0.64
2013	0.09	0.62	0.39	2.63	0.15	0.32	0.58
2014	0.10	0.60	0.39	3.02	0.17	0.31	0.63
2015	0.09	0.62	0.42	2.86	0.12	0.37	0.66
2016	0.10	0.65	0.46	3.04	0.20	0.48	0.78
2017	0.12	0.69	0.47	3.02	0.23	0.50	0.77
2018	0.13	0.72	0.48	3.03	0.23	0.41	0.76

Source: Global Carbon Project (GCP) (2019).

government-controlled electricity price schedule, the possibility of unexpected long run effects of carbon taxes, such as an increase in GDP. We also find that a removal of fossil fuel subsidies in Bangladesh gives a larger quantitative effect in terms of a GDP increase and a carbon emissions reduction, and that a price reform (where electricity producers face the same selling price) results in even larger quantitative effects. Finally, a combination of all reforms suggests an increase in GDP of 0.65% and a reduction in CO_2 of 4.72%. The policy implication is that, if the government cannot do all the reforms at once, it should focus on the price reform.

There are several advantages in using a DSGE model. First, since the model is dynamic, we are able to model any consequences on savings and investment, which is important in this context. For example, if a carbon tax lowers the rate of return on capital, there would be a reduction in investment and in the long run a lower capital stock. This later effect would be absent in a static model, and so the static model would underestimate the impact of a carbon tax. Second, a DSGE model can handle well multiple providers and multiple fuel usage in the electricity generating sector, as well as the fixed price schedule in Bangladesh. Third, as the DSGE model allows for a careful calibration to actual data, we are able to obtain numerical estimates of the consequences of carbon taxes and price reforms.

In this paper we focus on introducing and evaluating the consequences of a carbon tax, levied on fuel use in electricity generation. There are other carbon control instruments that could have been considered. In the spirit of Coase (1960), an allocation of property rights is a possibility. This may work well for local externalities, but will be more problematic for atmospheric externalities, such as CO_2. We could also have implemented our equilibrium of the model with a tax-credit scheme (setting a target for fuel use, and rebate taxes for less use of fuel). Further efficiency gains may be obtained by monitoring emissions and imposing an emissions levy. This would incentivise firms to adopt cleaner technologies. The first difficulty here, particularly for Bangladesh, is to monitor these emissions, therefore a first step is to focus on fuel use. If emissions can be monitored, we could have considered a cap-and-trade system. Another aspect to reflect upon is the political economy dimension of several control instruments. Ahmed and Khondker (2018) report that there is no institutional framework for a successful implementation of a Bangladesh Emission Trading System (cap and trade). They furthermore argue that, as at present time the political acceptability of a full-fledged carbon tax is low in the country, an immediate alternative could be a transportation fuel tax, following the experience of carbon taxes in India.[4]

We simulate four policy reforms: i) introduction of carbon taxes[5]; ii) removal of all fossil fuel subsidies given to the electricity producers; (iii) implementation of a price reform, where all electricity producers face the same electricity prices in combination of removal of fossil fuel subsidies, and (iv) offers policy package (iii) coupled with carbon taxes. The above policies in Bangladesh can create a win-win scenario if they increase macroeconomic variables such as GDP and employment, among others, and at the same time decrease carbon emissions. To our knowledge, no other study has applied DSGE modelling to provide such an evaluation for Bangladesh. In this paper we augment Amin (2015)'s DSGE model of the Bangladesh economy by embedding CO_2 emissions as a function of fossil fuels (natural gas and oil) used in electricity generation. The underlying assumptions of the model, and 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).

The paper is organised as follows. In section 2 we offer a brief literature review of relevant studies for Asia. In section 3 we outline the DSGE model and in section 4 we describe the calibrated parameters. Section 5 presents the results from our policy experiments. Section 6 concludes, discusses policy implications, and suggests ways forward for future energy modelling research in Bangladesh.

2. Review of the literature on decarbonisation policies in Asia

In recent years, several countries in Asia have adopted decarbonisation policies in order to achieve their Paris Agreement carbon targets. Among these policies, carbon taxes and fossil fuel subsidies removal are generally viewed as effective tools for achieving decarbonisation objectives.[6] Different regions and countries around the world have either implemented, scheduled, or are considering those policies to reduce their CO_2 emissions. In addition, there is a growing literature that analyses the impact of carbon taxes and/or fossil fuel subsidies phase out on macroeconomic indicators and carbon emissions.

In the case of Bangladesh, Ahmed and Khondker (2018) analyse the effects of imposing carbon taxes on petrol for the period 2019–2041. They use a supply and demand model and an input-out model to simulate two policy scenarios, one in which the tax is levied on petrol and another where the tax is additionally imposed on furnace oil and kerosene. They find that the reductions of CO_2 emissions in the two scenarios are 58.1 ml. MT and 67.9 ml. MT as of 2041 respectively. They also estimate an annual loss of 0.01% and 0.02% from 2019 to 2021 with

[4] India started imposing a carbon tax on domestic coal in 2010, followed by a tax on petrol and diesel over a 5 year period.

[5] In this policy experiment we consider i) a carbon tax of $5 per tonne of CO_2 emission, and ii) a carbon tax of $30 per tonne of CO_2 emission. According to the World Bank (2018), "*The price of carbon emissions [worldwide] varies considerably from $1 to $130* per *tonne, with the vast majority set between $5 and $30*".

[6] Coady et al. (2017) and GSI (2019) review the conceptual and quantitative literature on the environmental and economic benefits of energy policies and market reforms in different countries.

respect to the projected GDP. This difference is reduced to 0 after 2021. Moreover, they calculate an annual loss in employment over the entire period of analysis ranging between −0.008% and −0.013% if no substitution effect from fossil fuels to cleaner energy sources is assumed. After 2021, the results depend on the policy scenario and assumptions on the substitution effect.

Kuehl et al. (2021) study fossil fuel subsidy reforms for a set of 33 countries including Bangladesh, China, India, Indonesia, Myanmar, Pakistan, Sri Lanka, and Vietnam. Their analysis highlights the potential for subsidy reforms and other actions pertaining to emissions reductions and adaptation to climate change impacts set in the Nationally Determined Contributions (NDC) of the countries. They find that a removal of subsidies between 2021 and 2025 would imply a 6.7% CO_2 emissions reduction in Bangladesh in 2030. They also estimate that if 20% of subsidy savings were reinvested in energy efficiency improvements and 10% in renewable energy sources between 2021 and 2030, this would result in an additional reduction of 3.3% CO_2 emissions for Bangladesh in 2030.

Some studies examine the impact of carbon taxes and fossil fuel subsidies removal on Asian countries. Anand et al. (2013) use an input-output model based on household survey data to assess the fiscal and welfare implications of the elimination of fuel fossil subsidies in India. They find a net fiscal gain equivalent to 1.7% GDP in 2012. Delpiazzo et al. (2015) analyse the phase out of fossil fuel subsidies in India and China using an Intertemporal Computable Equilibrium System (ICES) model expanded with a realistic depiction of the public sector. They find that this phase out would result in an increase of the Indian GDP by 0.30% and 0.52% for the Chinese GDP relative to a baseline scenario for the period 2007–2030. With respect to the level of emissions, the effect would be a reduction of 1.58% for India but an increase of 0.29% for China. Dong et al. (2017) focus on the introduction of different carbon tax levels in China from 2010 to 2030 using a multi-region Computable General Equilibrium (CGE) model. They find a 6.4% average GDP growth rate in 2030 when a $120 carbon tax is levied, while 6.7% is the GDP growth rate under business as usual. In terms of CO_2 emissions, they calculate a 15.2% reduction on business as usual with $20 tax, and a 43.2% reduction with a $120 tax.

Yusuf and Resosudarmo (2015) analyse the introduction of a $30 USD carbon tax in Indonesia. They use a CGE model and three different simulations that assume i) no revenue is recycled, ii) a reduction in commodity sales tax, and iii) a universal lump sum transfer. They find reductions in GDP that range between 0.02 and 0.04% and cutbacks in CO_2 emissions between 6.39 and 6.55%. Mahmood and Marpaung (2014) examine the introduction of a carbon tax at multiple levels in Pakistan by 2050 using a tax efficient CGE model. They obtain a GDP reduction of 0.44% when a $10 CO_2 tax is levied and a 3.59% declined when the tax is $80. The reduction in emissions is respectively 6.69% and 28.67% for the $10 and $80 taxes.

Wattanakuljarus (2019) evaluate the effects of a carbon tax in Thailand to achieve a 20% CO_2 emission reduction in a 2030 business-as-usual scenario. The study uses a CGE model to analyse fixed/flexible labour/capital scenarios with and without transfers. For a flexible labour and capital scenario with no transfers, the impact is a reduction of the real GDP growth rate of 0.16% and a fall in employment of 0.12%.

Finally, Cabalu et al. (2015) 's CGE model appraises the introduction of $5 USD carbon tax, while analysing the effect of improved energy efficiency and energy mix changes for the case of Philippines in 2020. The simulations show a reduction of 0.6% in real GDP growth when only a carbon tax is levied, but an increase of 2% when there is an improvement in efficiency and the energy mix shifts. The impacts on CO_2 emissions are a reduction of 9.8% and 11% respectively. The effects on unemployment are a reduction of 0.6% with the carbon tax and an increase of 0.9% when the additional changes are considered.

An et al. (2022) explore the effects of an increasing block carbon tax (IBCT) on manufacturing industries in a set of small Asian economies. The recently proposed IBCT is inspired by the increasing block tariffs (IBT) often used in pricing of utility services due to their resource saving and equity properties. In manufacturing industries, they can encourage low-carbon expansion of production capacity and reduce carbon leakage. The information requirement for effective implementation of IBTs is however non-trivial and requires further research.

Table 3 summaries the reviewed studies on carbon taxes and energy subsidy removal in Asia and presents the main results in terms of GDP and CO_2 emissions.

3. The model

We specify a DSGE model, including an electricity generating sector where domestically extracted natural gas and imported oil are used. Electricity is both an intermediate input in a final good sector (industry) and a service sector, and as good consumed by households.

3.1. Industry and service production

Production in the finals goods sector (industry) and the service sector are given by a Constant Elasticity of Substitution (CES) production function, allowing for Decreasing Returns to Scale (DRS).[7] The production factors are labour (*l*), capital (*k*) and electricity (*j*).

$$F_i\left(l_{i,t}, k_{i,t}, j_{i,t}\right) = A_t^i . l_{i,t}^{\alpha_i}\left[(1-\Psi_i)k_{i,t}^{-\nu^i} + \Psi_i j_{i,t}^{-\nu^i}\right]^{-\frac{(1-\alpha_i)}{\nu^{ii}}} \quad (1)$$

where, A_t^i is total factor productivity (stochastic). The index $i = \{Y, X\}$ refers to the industrial and service sectors, respectively. The parameters α_i and Ψ_i are the shares of labour and electricity, respectively. The substitution elasticity between electricity and capital equals $\frac{1}{1+\nu^i}$. Finally, the parameter ν^{ii} gives the returns to scale in production.[8] These firms are price takers and maximise profits (see Appendix).

3.2. The energy sector

We model the electricity sector by specifying three firms: *G* (government producer) using natural gas (*m*), *I* (private sector) using natural gas (*m*), and *Q* (private sector) using oil (*h*). Each electricity generating firm uses labour and capital in addition to fossil fuels. We specify the CES technologies as follows[9]

$$j_t = A_t^j l_{j,t}^{\alpha_j}\left[\left(1-\Psi_j\right)k_{j,t}^{-\nu^j} + \Psi_j f_{j,t}^{-\nu^j}\right]^{-\frac{1-\alpha_j}{\nu^{jj}}} \quad (2)$$

where fuel $f_{j,t} = m_{j,t}$ (gas) for $j = \{G, I\}$, and $f_{j,t} = h_{j,t}$ (oil) for $j = Q$. The parameter ν^j gives the substitution elasticity between fossil fuels and capital, while α_j and Ψ_j are the shares of labour and fossil fuels, respectively, for $j = \{G, I, Q\}$.

3.3. The household

We allow for four consumption goods: standard consumption (*c*), leisure (1-*l*), electricity (*e*), and services (*x*). The representative household's per-period utility is:

[7] The DRS property is often used in the standard DSGE models, see Rotemberg and Woodford (1996) and Jaaskela and Nimrak (2011), and also in models with an electricity sector, see Amin (2015).

[8] In particular, DRS holds if $\nu^i/\nu^{ii} < 1$.

[9] See, Amin (2015) and Amin et al. (2019).

Table 3
Selected studies on decarbonisation policies in Asia.

Studies	Country	Policy	Main Features	GDP	CO_2
1) Ahmed and Khondker (2018)	Bangladesh	Carbon Tax – Low policy case 10% increasing to 25%	Tax on gasoline. Supply-Demand model estimates revenue and CO_2 effects; input-output simulation (EIOM) looks at output and prices	Loss of 0.01% on projected for 2019–21. 0% difference after	58.08 ml. MT total reduction as of 2041
ibid	Bangladesh	Carbon Tax – high policy case	Tax on gasoline + furnace oil and kerosene	0.02% loss 2019–21. 0% difference after	67.92 ml. MT total reduction as of 2041
2) Kuehl et al. (2021)	Bangladesh, India, China, Indonesia, Pakistan, Sri Lanka, Vietnam, Myanmar	Fossil fuel subsidy reform, removal over time	Energy demand forecasting model. Only effect on emissions is considered		Bangladesh, −6.73%, India, -2.18%, China, −1.37%, Indonesia, −6.33%, Pakistan, −2.47%, Sri Lanka, −1.34%, Vietnam, −0.56%, Myanmar, 0%
ibid	Bangladesh, India, China, Indonesia, Pakistan, Sri Lanka, Vietnam, Myanmar	Revenue reinvested, 20% in energy efficiency and 10% in renewables	Energy demand forecasting model. Only effect on emissions is considered		Bangladesh, −3.29%, India, −2.86%, China, −1.48%, Indonesia, −10.14%, Pakistan, −2.95%, Sri Lanka, −1.99%, Vietnam, −0.49%, Myanmar, 0%
3) Anand et al. (2013)	India	Elimination of fossil fuel subsidies	Input-output model using household survey data. Only look at fiscal and welfare effect	Net fiscal gain equivalent to 1.7% GDP	
4) Delpiazzo et al. (2015)	India and China	Phasing out fossil fuel subsidies	Recursive dynamic multiregional CGE model	India, 0.3% relative gain to baseline, China 0.52%	India, −1.58%, China, 0.29% increase
5) Dong et al. (2017)	China	Introduction of different carbon tax levels	Multi-region CGE model	6.4% average growth rate with $120 carbon tax in 2030, 6.7% under business as usual	15.2% reduction on business as usual with $20 tax, 39.6% reduction with $120 tax
6) Yusuf and Resosudarmo (2015)	Indonesia	Introduction of $30 USD carbon tax under three simulations: 1) 1. No revenue recycling 2) 2. Reduction in commodity sales tax 3) 3. Universal lump sum transfer	CGE model based on Australian General Equilibrium model	1) −0.04% 2) −0.02% 3)-0.03%	1) −6.55% 2) −6.39% 3) −6.52%
7) Mahmood and Marpaung (2014)	Pakistan	Introduction of carbon tax at multiple levels	Tax-efficient CGE model	$10 tax results in −0.44% $80 tax results in −3.59%	$10 tax gives −6.69% $80 tax gives −28.67%
8) Wattanakuljarus (2019)	Thailand	Carbon tax in order to achieve 20% carbon emission reduction on 2030 BAU scenario	CGE model, looks at fixed/flexible labour/capital scenarios with and without transfers (results here given for flexible labour and capital with no transfers)	−0.16%	−20% (aim of paper)
9) Cabalu et al. (2015)	Philippines	Introduction of $5 USD carbon tax, also look at effect of improved energy efficiency and energy mix changes	CGE based on PHILGEM model	−0.6% just carbon tax, 2.0% increase with efficiency and mix shifts	−9.8% with just tax, −11.0% with other changes
10) An et al. (2022)	Small Asian economies	Carbon tax	Game-theoretical model. Increasing block carbon tax		Expectedly lower

$$U(X_t, c_t, e_t, l_t) = \varphi \log\left(X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right) + (1-\varphi)log(1-l_t) \quad (3)$$

The household receives after-tax income from labour and capital, a government lump-sum transfer, and dividends.[10] The labour and capital income are taxed rates are τ^l and τ^k, respectively. The household savings is the next period's capital stock. All quantities are chosen so as to maximise the discounted sum of per-period utilities (see Appendix for details).

3.4. The government

Tax revenue is collected from labour and capital income. Potentially the government also gets revenue by selling natural gas to electricity generating firms at a price different from its extraction cost. Finally, the government sells electricity to the national grid. The government uses tax revenue to pay for labour, capital, and natural gas in its own electricity production, as well as paying an implicit electricity subsidy and a household lump-sum transfer, the latter being the residual clearing the government's budget.

The government, as a producer of electricity. is not a profit maximiser. This is because with the fixed electricity pricing schedule, market clearing can only happen if the government supplies the electricity demanded. Consequently, the government producer faces a cost minimisation problem (see Appendix).

Given the fixed price schedule for the electricity market, the implicit government electricity subsidy depends on the quantities of electricity demanded in equilibrium, and can be computed (see Appendix).

3.5. CO_2 emissions

For calculating CO_2 emissions, we use the conversion 410gr and 970gr CO_2 per kWh electricity generated using gas and oil respectively

[10] Since the producing firms face decreasing returns-to-scale technologies there will be rents ('profits') in equilibrium, which will be distributed to the households.

Table 4
Preference parameters.

β, discount factor	0.96
φ, consumption vs. leisure share in household utility	0.608
θ, consumption vs. electricity share in household utility	0.911
ρ, CES parameter in household utility	−0.11
γ, service share in household utility	0.811

Source: Amin and Marsiliani (2015) and Amin et al. (2019).

as from the US Energy Information Administration.[11]

$$CO_2 = 0.41(G_t + I_t) + 0.97Q_t \quad (4)$$

4. Parameter specification

In this section we present the numerical values of the parameters used in the computations. Those parameter values are taken from Amin and Marsiliani (2015) and Amin et al. (2019), who calibrate a DSGE model on data from Bangladesh.

Table 4 lists the preference parameters. The discount factor β is set following the standard DSGE literature (see, e.g., Heer and Mausser, 2009). The elasticity of substitution between electricity and general consumption is set at 0.9 (reflecting complementarity), implying $\rho = -0.11$. As for the calibrated parameters, θ is calibrated to match the electricity-general consumption ratio, γ is calibrated to match the service-general consumption ratio, and, finally, φ is calibrated to match $l = 0.33$ (people working about one-third of their time endowment).

Table 5 presents the production parameters. For both industrial production ($i = Y$) and service production ($i = X$), we set the elasticity of substitution parameter $\nu^i = 0.1$ and the returns to scale parameter $\nu^{ii} = 0.2$, giving slight decreasing returns to scale. As in Roberts and Fagernas (2004) and Amin et al. (2019), we set the labour shares in the industrial sectors, α_Y to 0.2. The labour shares in the service sector, α_X, is calibrated to match service employment as a fraction of total employment. The parameters Ψ_Y and Ψ_X are calibrated to match the electricity cost share in industrial and service production, respectively.

As for industrial production, for the electricity generating sectors we set $\nu^Q = \nu^I = \nu^G = 0.1$, and $\nu^{QQ} = \nu^{II} = \nu^{GG} = 0.2$. The labour shares of the three different electricity generating sectors, $\alpha_Q, \alpha_I, \alpha_G$, are calibrated to match the labour cost as a fraction of revenue in the respective sector. The parameters Ψ_Q, Ψ_I and Ψ_G are calibrated to match respective gas and oil use in electricity generation in each of the sectors. As in Amin et al. (2019) we set the extraction cost of domestic gas to 1.1, and we allow for a system loss in electricity production of 10%.

Finally, the depreciation rate (δ) has been set at 0.025 implying that the overall depreciation rate in Bangladesh is 2.5% annually. This rate is consistent with studies on developing economies by Tanzi and Zee (2000) and Yisheng (2006).

The government imposed electricity prices (both on producer and consumer side) are treated as parameters, and are reported in Table 6 below. They are from the actual Bangladesh Power Development Board (BPDB) price schedule, (see Amin et al., 2021).

Finally, as in Amin et al. (2019), the tax rates on labour and capital are set at 0.10 and 0.15, respectively.

5. Policy experiments and results

In order to evaluate the effects of electricity and fossil fuel price reforms on the environmental indicator, the CO_2 emission in the Bangladesh economy, we run four policy experiments in this paper. When introducing the carbon tax, we levy the tax on the electricity producers' use of fuel (increasing the price of oil, v^h, and gas, v^m, in Table 6 according to the respective carbon content). Consequently, only the use of oil and gas needs to be monitored. Alternatively, we could have charged the electricity producers on the basis of emissions, therefore incentivising technological change. The problem with the latest policy is that the government would then need to monitor emissions, which may be difficult in practice. Finally, if we instead we had levied a tax on electricity consumption, it would not have been possible to target the fuels' carbon content.

Table 5
Production parameters.

α_Q, labour share, QR	0.0041
α_I, labour share, IPP	0.0361
α_G, labour share, BPDB	0.0421
α_Y, labour share, industrial production	0.200
α_X, labour share, service production	0.3135
Ψ_Q, capital share, QR	0.596
Ψ_I, gas share, IPP	0.309
Ψ_G, gas share, BPDB	0.302
Ψ_Y, electricity share, industrial production	0.073
Ψ_X, electricity share, service production	0.079
δ^c, gas extraction cost	1.1
κ, system loss fraction	0.10
δ, depreciation rate, capital	0.025
ν^G, EOS parameter, gas and capital, BPDB	0.1
ν^I, EOS parameter, gas and capital, IPP	0.1
ν^g, EOS parameter, electricity and capital, industrial production	0.1
ν^s, EOS parameter, electricity and capital, service production	0.1
ν^Q, EOS parameter, oil and capital, QR	0.1
ν^{GG}, returns-to-scale parameter, PDB	0.2
ν^{II}, returns-to-scale parameter, IPP	0.2
ν^{gg}, returns-to-scale parameter, industrial production	0.2
ν^{ss}, returns-to-scale parameter, service production	0.2
ν^{QQ}, returns-to-scale parameter, QR	0.2

Source: Amin and Marsiliani (2015) and Amin et al. (2019).

Table 6
Value of Electricity and Fuel prices (Taka/kWh).

Parameters	Description	Values
q^e	Electricity purchase price, households	4.93
q^g	Electricity purchase price, industry	6.95
q^s	Electricity purchase price, service	9.00
p^I	Electricity selling price, IPP	3.20
p^Q	Electricity selling price, QR	7.79
p^G	Electricity selling price, government	2.3
v^e	Oil (international) price	8.19
v^h	Oil purchase price, QR	5.72
v^m	Gas (domestic) price	0.77

Source: Amin et al. (2021).

Experiment 1: A model economy where the government introduces carbon taxes and return all revenues to households lump sum. We model carbon taxes of $5 and $30 USD per ton of CO_2, the minimum and maximum value suggested for Bangladesh by the UN (World Bank, 2018).[12]

Experiment 2: A model economy where the government removes all fossil fuel subsidies to the electricity producers. For this experiment we set the oil price to be equal to the world price and the natural gas price to be equal to the extraction cost.

Experiment 3: A model economy where all generators and consumers face the same electricity price (set at 3.20 takas/kWh) in addition to fossil fuel subsidy removals, as discussed in Experiment 2. This price is a weighted average of the electricity prices facing the consumers and producers.

Experiment 4: A combination of experiments 3 and 1 where the

[11] https://www.eia.gov/tools/faqs/faq.php?id=74&t=11.

[12] See: http://documents1.worldbank.org/curated/en/721381535709573696/pdf/Carbon-Taxation-in-Bangladesh.pdf.

Table 7
Steady-state values of relevant variables.

	Experiment 1		Experiment 2	Experiment 3	Experiment 4	
Variables	With Carbon Tax (\$5/ton of CO_2)	With Carbon Tax (\$30/ton of CO_2)	Fossil Fuel Subsidies Removal	Price Reforms in Electricity Market	Price Reforms with Carbon Tax (\$5/ton of CO_2)	Price Reforms with Carbon Tax (\$30/ton of CO_2)
GDP, Aggregate Economic Output	0.06%	0.315%	0.38%	0.60%	0.6125%	0.6496%
Y, Aggregate Industrial Output	−0.03%	−0.16%	−0.24%	−0.35%	−0.3498%	−0.3430%
c, General Consumption	0.077%	0.39%	0.56%	0.82%	0.8293%	0.81%
e, Electricity Consumption	0.077%	0.39%	0.56%	0.82%	0.829%	0.81%
I, IPP Electricity Generation	−4.69%	−28.68%	−10.35%	−10.37%	−14.57%	−36.06%
Q, QR Electricity Generation	−4.36%	−31.55%	−18.13%	−60.70%	−62.43%	−75.66%
G, Government Electricity Generation	1.32%	8.42%	4.02%	7.95%	8.88%	12.86%
Env, CO_2 Emissions	−0.31%	−2.40%	−1.14%	−4.57%	−4.708%	−4.721%
X, Service Production	0.024%	0.12%	0.17%	0.25%	0.2542%	0.2473%
l, Aggregate Labour	−0.01%	−0.05%	−0.058%	−0.08%	−0.086%	−0.077%
K, Aggregate Capital	0.024%	0.17%	0.63%	0.78%	0.7888%	0.8037%
g_t, Government Transfer	0.78%	4.19%	2.23%	4.91%	5.18%	5.95%
g_s, Energy Subsidies	0.93%	0.46%	−11.60%	−11.43%	−11.42%	−11.44%

electricity producers and consumers face the same prices in addition to the carbon taxes (\$5 and \$30 USD per ton of CO_2) and fossil fuel subsidies have been removed.

We initially compute our benchmark model for Bangladesh where electricity is traded at government regulated prices, and the government provides subsidies for fossil fuels. We then compare the long-run steady-state values of key economic variables under the three scenarios to examine the consequences of energy price reforms and carbon taxes on the environmental and macroeconomic indicators. The steady state values of the model variables are listed in Table 7.[13]

In Experiment 1, a carbon tax of \$5 (\$30) causes a reduction in electricity generation by the firms using oil of 4.4% (31.6%), and by the private firms using gas of 4.7% (28.7%). Since electricity prices are fixed, the government increases electricity production by 1.3% (8.4%), to clear the market, so total electricity production increases by 0.06% (0.29%). A reduction in oil imports improves the trade balance, so less of the industrial good needs to be exported. Industrial production falls by 0.03% (0.32%), still allowing for a general consumption increase of 0.08% (0.39%). The carbon tax generates tax revenue, transferred to the households, so both service consumption and electricity consumption increase by 0.02% (0.12%) and 0.08% (0.39%), respectively. Due to the expansion of the service sector, GDP increases by 0.06% (0.32%). As the economy shifts from oil to gas, CO_2 emissions fall by 0.32% (2.4%).

Removing the fossil fuel subsidies in Bangladesh (Experiment 2) energy market increases GDP by 0.38%, general goods consumption by 0.56%, and total electricity production by 0.42% at the steady-state. The sector using oil for electricity generation shrinks by 18.13%, and the private sector using natural gas shrinks by 10.35%. As a result, CO_2 emissions fall by 1.15%. Thus, in terms of CO_2 emissions, removing the fossil fuel subsidy is more effective than a \$5 carbon tax. The reason is that oil is subsidised relatively more than natural gas, so removing this price distortion will reduce the use of oil (which is the fuel contributing more to CO_2 emissions).

When the phasing out of fossil fuel subsidies is combined with a price reform on the producer side that is producers facing the same electricity price (Experiment 3), further efficiency gains are obtained as the economy moves towards an unregulated electricity market. We find an increase in household goods consumption by 0.82%, an increase in electricity production by 0.62%, and a GDP increase by 0.61% at the steady-state. Due to the price reform, electricity price for producers using oil is lowered and results in a substantial reduction in electricity generation by those producers (a reduction of 60.71%) to natural gas (an increase of 4.84%).,[14][15] This makes CO_2 emissions fall by 4.57%, nearly double the effect of introducing a \$30 carbon tax.[16]

In Experiment 4, a carbon tax of \$5 (\$30) coupled with price reform, including fossil fuel subsidies removal, induces GDP to rise by 0.61% (0.65%) and CO_2 emissions to fall by 4.70% (4.72%).

The reason why GDP increases in all experiments is as follows. A carbon tax, and alternatively a fuel price reform, disproportionately increases the oil price for electricity producers, causing a reduction in QR electricity production and oil use. The reduction in imported oil use, reduces the export sector (industrial production), to maintain trade balance. Consequently, industrial production falls and factors of production move into the service sector and government electricity generation. The expansion of the latter sectors offsets the reduction in industrial production, so the overall effect is an increase in GDP. This result is due to the fixed price schedule in Bangladesh. Had there been flexible prices, the impact may be different.

Finally, we presented a model where there is no long-run growth in equilibrium. Had we used an endogenous-growth model (say an AK model), it is likely that long-run growth would be negatively impacted by the carbon tax. With the industry sector shrinking in size, the marginal product of capital would be lowered, in turn resulting in a lower

[13] Due to the relatively smaller size of the QR generators, this vast reduction (around 60%) in the QR generations would not affect the total electricity supply as it is compensated by an increase of 7.9% in public generation. For more details of the power generation in Bangladesh, see: https://bd.bpdb.gov.bd/bpdb_new/d3pbs_uploads/files/Generation%20Capacity%2012_11_2020.pdf.

[14] Since the prices in all experiments are fixed, there is no issue of the reforms impacting the market structure so as to give raise to oligopoly or monopoly behaviour.

[15] As the relative prices of the other productive factors increase due to the market reforms, private generators are forced to reduce their production. Therefore, the government has to intervene in the market by increasing its production to maintain the equilibrium in the electricity market. The role of the government producers is to clear the electricity market at the fixed prices.

[16] See Yusuf and Resosudarmo (2015) on the impact of recycling carbon tax revenue by reducing commodity sales taxes in Indonesia.

steady-state growth rate.

6. Conclusion and policy implications

Policymakers and energy experts firmly believe that the energy sector has played a crucial role in the sustained economic growth experienced by Bangladesh since the mid-1990s (GED, 2020). However, the energy sector does not operate efficiently as the Bangladesh government regulates energy prices. It keeps electricity prices below economic cost to benefit the poorest electricity consumers and supports electricity production through subsidizing fuel. There are growing concerns regarding the use of energy subsidies because of the high cost of providing them, their failure to reach the intended groups and their consequences for the environment.

Amin (2015) argues that the absence of cost-reflective pricing causes overconsumption of fossil fuel in Bangladesh and delays the transition towards a sustainable energy mix. Moreover, fossil fuel consumption is closely linked with CO_2 emissions, a significant cause of global climate change. As Bangladesh has steadily increased its use of oil in energy production and plans to rely more on coal, there is an urgent need in the country for decarbonisation policies. Carbon taxes, removal of fossil fuel subsidies and phase-out of intra-sectoral electricity price distortions are all policies that can help Bangladesh on the path towards sustainable development. Since June 2020, Bangladesh has been chairing the Climate Vulnerable Forum (CVF), a group of 48 countries facing high disaster risk from climate change. Bangladesh is urging those countries to ramp up their actions to limit the rise in global average temperatures to 1.5 °C above pre-industrial times, consistently with the target of the 2015 Paris Agreement.

In this paper we present a fit-for-purpose Dynamic Stochastic General Equilibrium framework to assess the implications for the macro economy and carbon emissions of several decarbonisation policies in Bangladesh. Our analysis can guide Bangladesh and other developing and emerging economics in fulfilling their climate pledges.

We find that the introduction of a carbon tax $5 ($30) increases GDP by 0.06% (0.32%), and general consumption increase of 0.08% (0.39%). The carbon tax generates tax revenue, directed to the households, and accordingly, both service consumption and electricity consumption increase by 0.02% (0.12%) and 0.08% (0.39%), respectively. Since electricity prices are regulated and constant, the government electricity generation increases by 1.3% (8.4%), to clear the market, so total electricity production increases by 0.06% (0.29%). Since the government uses more natural gas, the economy shifts from oil to gas and CO_2 emissions fall by 0.32% (2.4%).

Our results also reveal that removing the fossil fuel subsidies in the Bangladesh energy market can increase GDP by 0.38%, household goods consumption by 0.56%, and total electricity production by 0.42% at the steady-state. The sector using oil for electricity generation shrinks by 18.13%, and the private sector using gas shrinks by 10.35%. As a result, CO_2 emissions fall by 1.15%.

Furthermore, when the removal of fuel subsidies is combined with an electricity price reform on the producer side (different producers now facing the same electricity price), further efficiency gains are obtained. We find an increase in household goods consumption of 0.82%, a total electricity production increase of 0.62% and a GDP increase of 0.61% at the steady-state. Due to the electricity price reform, the cost of oil-based electricity production increases and results in a more substantial shift from oil (with a reduction of 60.716%) to gas (an increase of 4.84%). This makes CO_2 emissions to fall by 4.57%.

When combining the carbon taxes with the subsidy free environment where the electricity producers and consumers face same prices, our results reveal that further gains can be achieved in terms of GDP increase and CO_2 reductions. For a carbon tax of $5 ($30), GDP rises by 0.61% (0.65%) and CO_2 emissions falls by 4.70% (4.72%).

Our paper suggests that although all proposed policies can benefit the economy and the environment, the policy of removing fossil fuel subsidies and intra-sectoral electricity price distortions coupled with carbon taxes provides the highest benefits. Nevertheless, one should notice that adding a carbon tax of $5 ($30) per ton of CO_2 only provides a marginal benefit, as CO_2 emission reduction increase from 4.57% to 4.71% (4.72%) and GDP rises from 0.6% to 0.61% (0.65%), signifying that most of decarbonisation and GDP increases are due to the electricity price reform. Therefore, the most important policy recommendation emerging from this paper is for the government to enable an electricity market with fewer price distortions. Only when these distortions are removed, the government may consider the implementation of a carbon tax to achieve further reduction of CO_2 emissions. This paper reveals that the highest reduction in CO_2 emissions of 4.57%, achieved under a regime with lower electricity price distortions, would already position Bangladesh towards fulfilling its Paris Agreement pledge of an unconditional 5% reduction in GHG with respect to Business as Usual by 2030. With the further help of a carbon tax imposed on an efficient energy market, it is expected that the CO_2 reduction would be even higher. In this paper we have focused on moderate reforms as we believe that those are more easily implementable in Bangladesh. We could consider a major reform involving liberalising all electricity prices; however, as this policy would require a substantial political will, we leave it for future work.

Furthermore, a carbon tax has the additional benefit of generating revenues. In our paper we return all revenues to household in a lump-sum fashion, although different ways of recycling revenues could be modelled. One example would be the implementation of 'Double Dividend' policies (see Bovenberg and Goulder, 1996 and Marsiliani and Renström, 2000) where tax revenues are used to decrease existing rates of distortionary taxation such as labour or consumption taxes and to generate a win-win situation between the economy and the environment.[17] Revenues could also be used to incentivise the adoption of cleaner, often more expensive, production technologies that would further reduce CO_2 emissions,[18] and provide public services such as public education and health care for the benefit of disadvantaged groups in the population (e.g., poor and rural households). Analysis of double dividend and redistribution potential of a carbon tax in Bangladesh is for future work.

Moreover, Cross-Border Electricity Trading (CBET) could also be another mechanism through which price distortions in the energy market in Bangladesh can be mitigated with resulting decrease in CO_2 emissions. With a harmonized policy framework and creating regional solid energy cooperation, Bangladesh can access international energy sources. It is worth noting that the government already imports 1160 MW of electricity from India daily since 2013. Furthermore, Nepal and Bangladesh have recently agreed to hydropower import of 700 MW through transmission lines in India. Including the regional power trade in our model is also left for future research. [19]

Finally, there are important sectoral differences across the economy, knowledge of which can help in designing more effective policies. Our model primarily focuses on the electricity generation sector, while in many countries other sectors in the economy are also substantially contributing to carbon emissions. Future modelling developments could focus on introducing other emission intensive sectors such as transportation.[20]

[17] Using an energy demand forecasting model, Kuehl et al. (2021) find a 3.29% reduction in carbon emission for Bangladesh after recycling carbon tax revenue in energy efficient and renewable investments. See also Cabalu et al. (2015) on revenue reinvestment in energy efficiency in the Philippines.

[18] Dou et al. (2020) explore the effect of trade openness on carbon emissions using a balanced panel data of 76 countries. They point to technology spill overs as an effective measure of achieving carbon reductions. They find an inverted U shape between trade openness and carbon emissions. The study suggests that trade openness could be an alternative instrument in decarbonisation.

[19] See Yu et al. (2021) for an input-output model of the transport sector in China.

[20] As firms face decreasing returns-to-scale technologies there will be rents ('profits') in equilibrium, which will be distributed to the households.

CRediT authorship contribution statement

Sakib Amin: Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Tooraj Jamasb:** Supervision, Resources, Investigation, Conceptualization, Writing – original draft, Writing – review & editing. **Manuel Llorca:** Supervision, Resources, Investigation, Conceptualization, Writing – original draft, Writing – review & editing. **Laura Marsiliani:** Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – original draft, Writing – review & editing. **Thomas I. Renström:** Resources, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

A.1 Industry and Service Production

The production factors are labour (*l*), capital (*k*) and electricity (*j*). Industrial ($i = Y$) and service ($i = X$) producers are price takers and solve:

$$\pi_{i,t} = \max p_t^i\, A_t^i\, l_{i,t}^{\alpha_i} \left[(1-\Psi_i) k_{i,t}^{-\nu^i} + \Psi_i j_{i,t}^{-\nu^i} \right]^{-\frac{1-\alpha_i}{\nu^{ii}}} - r_t k_{i,t} - w_t l_{i,t} - q^j j_{i,t} \tag{A.1}$$

where w, r, and q are the wage rate, interest rate, and electricity price, respectively. p^Y is normalised to unity, and we will denote the price of services as n ($=p^X$).

A.2 The Household Budget and Choice Problem

The household receives income from labour (wl_t) and capital (rk_t), a government lump-sum transfer (ƅ), and dividends (π).[21] The labour and capital income are taxed rates are τ^l and τ^k, respectively. The price electricity faced by the household is denoted by q^e. The household's budget constraint is as follows:

$$k_{t+1} + c_t + nX_t + q_t^e e_t = \left(1-\tau^l\right) w_t l_t + \text{ƅ} + \left(1-\tau^k\right) r_t k_t + (1-\delta) k_t + \pi \tag{A.2}$$

where δ denotes capital's depreciation rate. We write the Lagrange function to the household's problem as follows:

$$L = \sum_{t=0}^{\infty} \beta^t \left[\left(\varphi \log \left[X_t^{\gamma} \left(\theta c_t^{\rho} + (1-\theta) e_t^{\rho} \right)^{\frac{1-\gamma}{\rho}} \right] \right) + (1-\varphi) \log(1-l_t) \right] - \lambda_t \left[k_{t+1} + c_t + n.X_t + q_t^e e_t - \left(1-\tau^l\right) w_t l_t - \text{ƅ} - \left(1-\tau^k\right) r_t k_t - (1-\delta) k_t \right] \tag{A.3}$$

with β being the discount factor.

A.3 The Government

The government gets revenue by selling natural gas to electricity generating firms at a price (v^m) different from its extraction cost (δ^C). The government revenue from selling electricity to the national grid is ($P^G G_t$). Because of the fixed electricity pricing schedule market clearing can only happen if the government supplies the electricity demanded. Consequently, the government producer faces a cost minimisation problem, seeking to minimise:

$$c_{G,t} = w_t l_{G,t} + r_t k_{G,t} + v^m m_{G,t} - P^G A_t^G l_t^{\alpha_G} \left[(1-\Psi_G) k_{G,t}^{-\nu^G} + \Psi_G m_{G,t}^{-\nu^G} \right]^{-\frac{1-\alpha_G}{\nu^{GG}}} \tag{A.4}$$

Given the fixed price schedule for the electricity market, the government implicitly subsidises electricity. This implicit subsidy is given by:[22]

$$b = P^G G_t + P^I I_t + P^Q Q_t - q^e e_t - q^s s_t - q^g g_t \tag{A.5}$$

Taking into account the tax revenue, the government's budget constraint is given by:

$$\tau^l w_t l_t + \tau^k r_t k_t + \left(v^m - \delta^C\right) \left(m_{I,t} + m_{G,t}\right) + \left(v^h - v^e\right) h_t P^G G_t - r_t k_{G,t} - w_t l_{G,t} - v^m m_{G,t} - \text{ƅ}_t = b_t \tag{A.6}$$

[21] q^S and q^g denote the electricity prices for the service and industrial sector, respectively.

where the household lump-sum transfer (τ_t) is the residual clearing the budget in each time period.
A.4 Equilibrium Conditions

Market clearing require:

$$l = l_Q + l_I + l_G + l_Y + l_X \quad (A.7)$$

$$k = k_Q + k_I + k_G + k_Y + k_X \quad (A.8)$$

$$e_t + s_t + g_t = (Q_t + I_t + G_t) \quad (A.9)$$

The aggregate resource constraint is derived by combining the household's and the government's budget constraints with the subsidy equation and using the definition of profits. It reads as:

$$k_{t+1} = Y_t - c_t - v^e h_t + (1-\delta)k_t - \delta^C (m_{I,t} + m_{G,t}) \quad (A.10)$$

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