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Published in:
[Host publication title missing]

2014

[Link to publication](#)

Citation for published version (APA):
Mundaca, L., Na, L., & Smedby, N. (2014). Assessing 'Green Energy Economy' policies for transforming the building stock in Shanghai. In *[Host publication title missing]* International Association for Energy Economics.

Total number of authors:
3

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Assessing ‘Green Energy Economy’ policies for transforming the building stock in Shanghai

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Abstract

The 2008–2009 global financial crisis triggered ‘Green Energy Economy’ (GEE) policy packages to stimulate green growth in many countries. China soon became a leader and, supported by its 11th Five-Year Plan (2006–2010), devoted approximately one-third of its US\$ 647 billion stimulus package to green energy technologies. Since then, numerous policy instruments have been implemented to encourage ‘Green Buildings’. We take the Chinese city of Shanghai as a case study as it has the largest population, urbanization ratio and GDP in China and evaluate the performance of GEE policies targeted at the multi-household building sector. We use a bottom-up modelling tool to quantitatively estimate alternative baselines and assess different policy scenarios for the period 2010–2050. We measure the performance of policies in relation to energy use, efficiency improvements, CO₂ emissions and net direct economic impacts. Our results suggest that current GEE policies are insufficient to stimulate radical change in the building sector. When unambitious policy measures are implemented in isolation, they provide marginal improvements compared to current building codes. The retrofitting of existing buildings is both a significant policy challenge, and offers fertile ground for improvements. Our results show that ambitious, technology-oriented financial incentives for both new and existing buildings, including energy price reform and a CO₂ tax offer the right mix of incentives for green building transformation. When the social costs of climate change are taken into account, an integrated policy mix also delivers the highest net economic benefits. We conclude that policies must be more ambitious and include an integrated mix of instruments in order to drive a low-carbon transformation of both new and existing buildings in Shanghai. Finally, the theoretical impacts and potential benefits of GEE policy instruments must not underestimate the challenges associated with their design, implementation and enforcement.

Keywords: Building stock, Global financial crisis, Green energy economy, Policy evaluation, Shanghai, Economy recovery packages.

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1. Introduction

Following the 2008–2009 global financial crisis, several countries implemented economy recovery packages to stimulate green growth. China (together with South Korea) soon became the leader and invested heavily in environmentally driven projects. The country dedicated nearly 33% of its US\$ 647 billion stimulus package to green measures (e.g. water infrastructure, low-carbon technologies), equivalent to approximately 3% of its Gross Domestic Product (GDP) (Barbier 2010a). Of this amount (approximately US\$ 213 billion), nearly 12% targeted energy-efficient buildings, including support for the deployment of small-scale solar technologies in the construction sector (UNEP and GEI 2009). At the same time, the 11th Chinese Five-Year Plan (2006–2010) had already suggested that the government was prepared for the introduction or continuation of energy-efficiency policies and renewable energy technologies before the financial crisis even began (C. Fan 2006; Price et al. 2011). The Five-Year plan estimated that green energy technology investment (i.e. energy efficiency and renewable energy) would amount around US\$ 285 billion (UNEP and GEI 2009). Later, China also outlined the gradual implementation of a national emission trading scheme in its 12th Five-Year Plan (2011–2015) with the aim to encourage low-carbon technologies and move towards a green economy.

The growing interest in ‘Green Energy Economy’ (GEE) policies stimulated our research in their evaluation, performance and impacts, particularly as there seems to be a policy dichotomy in their implementation. On the one hand, theory-based expectations (e.g. reduced energy use, decline in carbon dioxide [CO₂] emissions, increased job creation) have been used to legitimatise GEE policies, and many aspects of this discourse are consistent, *a priori*, with elements of sustainable development (see e.g. Barbier 2010b; Strand and Toman 2010; UNEP 2012; Allen and Clouth 2012; OECD 2010). On the other hand, while considerable effort has gone into encouraging GEE policies worldwide, there has been no systematic evaluation of their impacts (ex-ante or ex-post). The growing awareness of this situation has resulted in various approaches to GEE policy assessment. Methodologies range from specific issues, such as job creation or the growth of ‘Greentech’ patents (e.g. Pew Charitable Trusts 2009), to broader questions of sustainable development (Green Growth Knowledge Platform (GGKP) 2013; OECD 2011; e.g. UNEP 2012). One over-simplified metric that has been put forward involves a measurement of expenditure on green initiatives as a proportion of GDP (Barbier 2010a).

For the specific case of China, very little is known about the impacts of current or future GEE policies. We found only two explicit policy evaluation attempts in the scientific literature (Price et al. 2011; Zhou, McNeil, and Levine 2012). These studies assessed specific energy-saving policies under the 11th Five-Year Plan. The Plan defined a policy target of reducing energy intensity by 20% by 2010. At the risk of oversimplifying, both studies concluded that existing policy measures must be improved (e.g. through enforcement of building energy standards) if the energy saving target was to be met. In particular, policy measures that targeted the existing building stock needed considerable adjustments. In addition to these specific studies, we also found that despite the rapid development of GEE building policy incentives in China, the total share of the building stock addressed by the policy appeared to be limited. For example, although the number of certified green building projects sharply increased every year, estimates showed that certified ‘green’ floor space represented less than 1% of the new building stock in 2009 (China GreenTech Initiative 2009; China GreenTech Initiative 2011). In fact, although most green building projects are design certified, few have gained approval in the operation stage (Y. Liu 2012). It has also been argued that despite the growing interest in green building policies, Chinese developers favour energy-intensive building designs and short-term profits over long-term energy saving considerations (Ruet et al. 2010). Together, these issues suggest that there is need to improve our knowledge of the performance of GEE policies aimed at the building sector in China.

Using Shanghai as a case study, this paper provides a quantitative evaluation of GEE policies aimed at encouraging low-carbon technologies in the multi-household residential sector. We used a bottom-up model (see methodological details in the next section) to evaluate whether existing and/ or new GEE policies have the potential to transform the multi-household building sector in Shanghai and thus support the transition to a GEE. Using alternative baselines and different policy scenarios, we assess GEE policies in terms of on-site energy use, technology segments, CO₂ emissions, and net direct economic impacts (i.e. policy benefits minus direct policy costs). Policy scenarios were based on current and potential policy instruments (e.g. taxes, building codes, subsidies) to encourage green energy technologies in the multi-household sector. To the best of our knowledge, this paper is the first ex-ante GEE policy evaluation to address the multi-household residential building stock in Shanghai.

Our decision to use the Shanghai residential sector (high-rise building segment) for the case study was motivated by numerous key issues. First, the city of Shanghai has the largest population and GDP in China. It is actually one of the largest cities in the world. Secondly, and consistent with the rapid urbanisation taking place across China (Wang 2014; K. Zhang and Song 2003), Shanghai's urban population has increased from nearly 60% in the mid-1970s to almost 90% in 2012 (SMSB 2013). In fact, Shanghai has the highest urbanization ratio of all Chinese provinces and municipalities (Chinese Society for Urban Studies 2008). Thirdly, Shanghai's energy use has increased remarkably in recent decades (Q. Zhang 2004; Chen et al. 2009; Li et al. 2010), by a factor of 3.5 since the 1990s (SMSB 2013), and its per capita residential energy use has grown by more than 50% since 2000 (SMSB 2013; Ruet et al. 2010).¹ Shanghai is located in the Yangtze River Delta in eastern China; its climate is characterised by cold winters and hot summers (Q. Zhang 2004), which drives high demand for heating and cooling energy services. Fourthly, since the mid-1990s Shanghai has had the highest level of CO₂ emissions per capita in China, overtaking other large cities such as Beijing, Tianjin and Chongqing (Dhakal 2009). However, and because of the 12th Five-Year Plan (2011–2015), Shanghai implemented a pilot emission trading scheme in November 2013. Fifthly, and driven by economic growth and the need to improve living standards among its population, Shanghai has also experienced a very rapid uptake of domestic appliances (Q. Zhang 2004) such as electric fans, television sets, and air conditioners (Chen et al. 2009). Finally, and consistent with the Chinese government's GEE policies, Shanghai has implemented numerous incentives to promote the development of 'Green Buildings'. These incentives, which mostly take the form of technology-oriented subsidies (details in the next section) were introduced under the 'Shanghai City Building Energy Saving Project Special Support Measure' initiative in 2012. Prior to that (in 2003), Shanghai had also issued the 'Shanghai Ecological Community Construction Management Approach' and 'Detailed Rules for the Implementation of Ecological Community Technology' in order to improve the eco-environment quality of new communities and raise the quality of new residential buildings (Chinese Society for Urban Studies 2008; Ruet et al. 2010). It has been argued that Shanghai is the Chinese city that is most likely to profit from green stimulus packages and it is expected to take the lead towards a modern, low-carbon urban economy (Ruet et al. 2010). Table 1 presents some key statistics for Shanghai.

The structure of the paper is as follows. Section 2 elaborates on the principle aspects of our methodology, including the model structure and input data. Section 3 outlines the key findings of our research. The following dimensions are used to group results: (a) energy use and technology segments, (b) emissions, and (c) direct economic costs and/or benefits of policies. In the light of our results, we draw some conclusions in Section 4.

¹ Measured in 'Standard Coal Equivalent' (SCE). 1 SCE = 29.31 GJ (low heat).

2. Model and method

2.1. The EEB_Shanghai model v1.0: An overview

We used the generic EEB_model developed under the ‘World Business Council for Sustainable Development and Energy Efficiency in Buildings’ (WBCSD-EEB) Project (see WBCSD 2009) as the basis for the EEB_Shanghai model. The WBCSD-EEB project developed a building energy use simulation tool (see Figure 1) to understand how to encourage building stakeholders to use energy efficiently and reduce carbon emissions (WBCSD 2009). The EEB_model is a bottom-up simulation tool and in its generic form is based on the following main assumptions²:

- Building sector segments (i.e. single- and two-household dwellings; multi-household dwellings) behave independently and decisions are guided mostly – but not entirely – by financial criteria. Although other factors (e.g. transaction costs, information asymmetries) play a critical role in the adoption of energy-efficiency technologies (Mundaca et al. 2013; Jaffe and Stavins 1994), this assumption is necessary to simplify the model of the construction market and household behaviour. However, it should be noted that the model includes a set of non-financial determinants, which are based on qualitative factors and attempt to simulate the bounded rationality of decision makers.
- The unit of analysis is a building (dwelling). The model can take into account on-site energy generation and supply-side emission factors. Technology choices are under the control of building stakeholders. Technology packages are price- and policy-dependent.
- Although the energy and CO₂ performance of the residential sector is based on statistics and technical parameters, there is an assumption of uniform levels of energy services. This assumption is necessary to reduce the complexity of energy use patterns. Moreover (as in the case of Shanghai) data at the energy service level is not always available.
- The model assumes that resources (e.g. construction materials, fuel) are unlimited until the end of 2050. Demand for materials is infinite; however, exogenous restrictions can be set that mimic, for instance, constraints on energy resources.

Based on the above, we define the EEB_Shanghai model as a simulation tool that supports the quantitative modelling and analysis of the building sector in Shanghai in order to assess the performance of different policy instruments. We used the generic EEB model and populated it with data (details in next section) related to the Shanghai residential building sector. Figure 1 shows that the generic EEB model is structured into six types of module (Otto, Kornevall, and Sisson 2010; WBCSD 2009).

The *input* module (Figure 1) consists of five sub-modules, which handle all the data and assumptions. These include qualitative aspects relating to technology portfolios and energy use, energy prices, financial and non-financial decision criteria (details below), and the policy environment (e.g. taxes and subsidies). The input module also contains key data for a number of exogenous variables associated with the geographical scope (e.g. population, total energy consumption, see Table 1).

The *energy* module simulates energy use and it quantifies the energy performance of different technology packages associated with the building stock. This module makes possible to model buildings characterised by different technologies. Disaggregated data is available for: space heating and cooling equipment; ventilation equipment; lighting and cooking equipment; water heating systems; and large and small electrical appliances. The model provides a data-rich simulation of building energy use and can represent a very wide portfolio of residential technologies, including

² For a full description of the model see Otto et al (2010; 2010) and WBCSD (2009) and visit <http://www.wbcd.org/transformingthemarketeeb.aspx>

more than 20 energy-related subsystems and more than 10 categories of material technologies (e.g. insulation, fenestration, ventilation).

The *cost* module comprises financial information about technology packages (e.g. first and maintenance costs) and a projection sub-module to calculate costs for (more efficient) building alternatives.

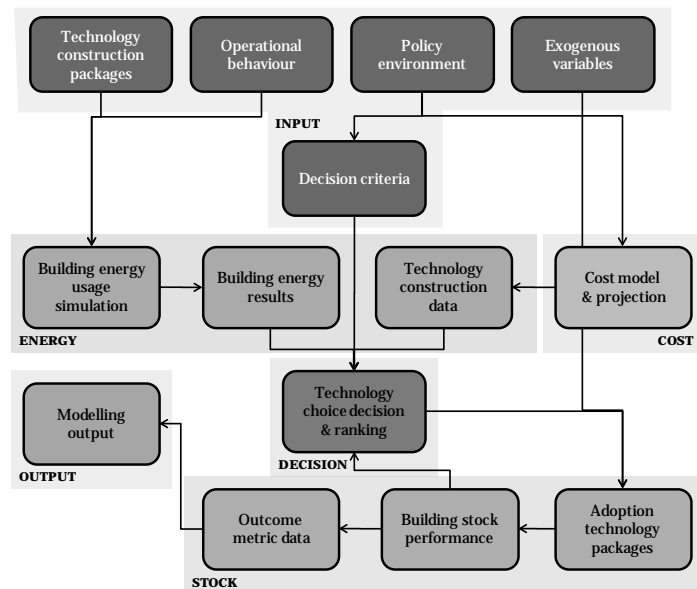


Figure 1: The generic EEB modelling framework process

Source: Adapted from Otto et al (2010) and WBSCD (2009)

The *decision* module is a decision-making framework that determines the adoption of different technologies. This module includes the following key elements: decision variables, user-defined constraints, the policy environment, and exogenous variables (e.g. energy prices). These elements are briefly described below.

- **Decision variables:** The generic EEB model is based on two sets of decision criteria. These include *financial factors* that allow the simulation of (alternative) building technology configurations using various financial criteria (e.g. net present value [NPV], internal rate of return [IRR]). This makes it possible to take into account purchase/ investment, installation costs, energy saving costs, and operating and maintenance costs among others. The EEB model also includes *non-financial factors* for technology choice, such as appearance, indoor environmental quality, reliability, etc. However, we only used financial factors in our modelling exercise (the use of non-financial factors will be the subject of further research)³.
- **Exogenous variables:** Energy prices, carbon emission factors, etc. act as technology choice determinants and filters. They affect the financial and technical performance of technologies and thus the ranking of the building technology package(s). Therefore, these variables also affect the adoption of construction technology packages.
- **Policy environment:** This is user-defined (e.g. subsidies, taxes) and aims to simulate (or replicate) current and future policies targeted at the residential building sector. Policy conditions can also operate as a technology choice filter. In this way, the adoption of a technology package is subject to the policy environment set by the modeller, i.e. whether single technologies or technology packages meet building codes, are (or not) subject to subsidies or regulatory bans, etc.

³ Note that the generic EEB model also includes other factors, so-called 'value enhancement' technology choice determinants. These include building value, rent, productivity, health, sales margins (retail), and inventory (retail). However, we did not use them in our model as they are based on empirical data that was not available for Shanghai.

- *Other user-defined constraints:* Financial and non-financial criteria are used both separately and in combination on a weighted sum basis to determine the technologies that are finally adopted. Financial constraints are represented, for instance, by a minimum NPV and IRR, or a given break-even time (BET). In our case all implemented technologies must have a positive NPV and life cycle costs (i.e. first and operational costs) must be within the 25% of the lowest cost alternative. A discount rate of 5% was used in all calculations

The *stock* module is composed of three sub-modules, namely: (a) outcome metric data that calculates financial figures (e.g. NPV), (b) a building stock sub-module that establishes the energy performance of different building stock levels (initialised by reference cases), and (c) a technology adoption component that estimates the market share of construction technology packages. In the model, a percentage of the building stock is refurbished annually and new technologies are introduced as old technologies become obsolete. In addition, a part of the building stock is destroyed and removed from the stock model, and new construction brings new technologies and building alternatives into the stock.

Finally, the *Output* module provides the following results: total and net energy consumption (primary and on-site); CO₂ emissions (per-building and total for the building segment under analysis); investments and operating costs (per-household and total for the building segment) and; estimated total cost of policies associated with subsidies, taxes, etc. The model provides averages over five year increments.

2.2. Key input data

Most of the data used to develop and calibrate the model was taken from the Shanghai Statistical Yearbook (SMSB 2013). In addition, we collected information from journal articles, and reports and statistics published by the National Bureau of Statistics of China. Other sources, such as the China Green Building Council and Landsea, China Greentech Initiative, Chinese Society for Urban Studies, China's 11th and 12th Five-Year Plan for Energy Development, and the International Energy Agency (IEA) filled in any remaining gaps (see Table 1 – Table 6). These resources were used to support the inevitable assumptions that we had to make in cases where there was a lack of information.

As previously mentioned, the availability of data meant that we focused our policy analysis on the high-rise (8+ stories) multi-household residential building segment in Shanghai. Key input data related to: basic facts (e.g. the number of buildings); architectural features (e.g. number of floors per building, materials, surface area); mechanical parameters (e.g. heating and cooling systems); electrical features (lighting equipment); internal loads (peak occupancy, lighting and equipment, water usage); energy prices; and CO₂ emissions. It should be noted that although energy use statistics reflect energy losses, they are only applicable to the building itself. Losses related to generation and distribution were not taken into account.

Table 1: Key statistics for Shanghai used to develop and calibrate the EEB_Shanghai model v1.0

	2000	2005	2010
Total population (million)	16.08	18.90	23.02
Urban population (%)	74.6	84.5	88.9
Density (inhabitants per km ²)	2 537	2 981	3 632
Total number of households (10 000 households)	475.73	496.69	519.27
Average household size (person)	2.8	2.7	2.7
New residential building construction – floor space (10 000 m ²)	4 804.12	8 267.24	7 344.07
Total energy consumption (10 000 tonnes SCE)	5 226.79	7 895.17	10 842.33
Residential energy consumption (10 000 tonnes SCE)	461.24	644.37	1 007.02
Share of residential energy consumption (%)	8.82	8.16	9.29
Residential energy consumption per capita (Kg of SCE)	290.49	345.95	446.28
Residential electricity consumption (100 million kWh)	53.20	109.20	168.95
Electricity consumption per capita (kWh)	335.05	586.27	748.74
CO ₂ emissions per capita (registered population) (Mt)	10.2	13.9	n/a
GDP (100 million yuan)	4 771.17	9 247.66	17 165.98
Energy intensity of GDP (ton SCE per 10 000 yuan)	1.15	0.88	0.71
Electricity intensity of GDP (kWh per 10 000 yuan)	1 172.5	996.98	823.18

(n/a): non-available

SCE: Standard Coal Equivalent. 1 SCE = 29.31 GJ (low heat)

Data sources: SMSB (2013), Dhakal (2009) and Li et al. (2010)

Table 2: Key statistics for the high-rise multi-household residential building segment in Shanghai

8+ stories buildings in Shanghai	Value (2010)
Number of buildings*	16 463
Floor space (million m ²)*	131.70
Average area per building (m ²) *	7 999.75
Floor space per flat (m ²)*	75 ~ 110
Number of flats per building*	48 ~ 180
Energy intensity (kWh/ m ²) *	155.74 ~ 179.96
New building growth rate (%) **	11
Demolition rate (%) *	2

(*) Value derived from SMSB (2013)

(**) Value for 2011 compared to 2010, and applicable to the entire residential building stock

Data source: SMSB (2013)

Table 3: Building envelope parameters for multi-household residential building stock in Shanghai

Envelope	U-value (W/m ² K)	Average
Wall	1.00 – 2.04	1.51
Windows	2.80 – 5.04	3.37
Roof	0.50 – 1.01	0.61

Data source: Yang et al. (2008)

Table 4: Annual residential energy use per capita in Shanghai (2010)

Fuel	Use
Electricity (kWh)	748.74
Natural gas (m ³)	34.52
Gas (m ³)	27.88
Liquefied petroleum gas (LPG) (kg)	14.65
Coal (kg)	20.67

Data source: SMSB (2013)

Table 5: CO₂ emission factors

Fuel	Emission factor (kg/kWh)
Electricity	0.82
Natural gas/LPG*	0.22
Gas	0.43
Fuel oil	0.25
Coal	0.90

(*) Assumed value

Data sources: IKE IT & Knowledge for Environment (2014) and World Resource Institute (2014)

Table 6: Residential energy prices (2010)

Fuel	Price (US\$/kWh)
Electricity	0.08
Natural gas /LPG	0.05
Fuel oil/kerosene	0.06
Biomass (wood chips) *	0.02
Coal	0.04

(*) Assumed value

Data sources: derived from IEA (2012) and SMSB (2013)

Exchange rate in December 2010: 1 US\$ = 6.59 Chinese Yuan (CNY) approximately.

2.3. Baselines and scenarios

We developed and used two counterfactuals as standards (benchmarks) against which we measured and analysed all subsequent scenarios. *Baseline 1* simulated ‘business-as-usual’ (BAU) under current building regulations but with no further policy interventions (see Table 7 – Regulations). Equipment prices and energy performance increase marginally and linearly over time. New buildings meet current regulatory standards and energy prices remain unchanged. *Baseline 2 (Scenario 1)* simulated the current portfolio of ‘Green Building’ policies applicable to the multi-household building sector in Shanghai (mostly new buildings) in addition to current regulatory instruments (as in Baseline 1). As mentioned above, all of these policies were introduced after the global financial crisis (see Table 7 – Economic Incentives). We assumed that the entire set of Green Building policies remained in place until 2050. Whether baselines or counterfactuals reflect (or not) the current mix of policy instruments can seriously affect the interpretation of the potential impact of the policy instrument being evaluated.

Considering the baselines described above, we explored and evaluated four potential policy scenarios that addressed the building segment under analysis (from 2010 to 2050). These scenarios provide a framework for exploring different futures, and provide guidance regarding the actions that need to be implemented now, in order to reach a desirable position in the future. In the model, the choice of technology must meet policy and financial constraints. The four scenarios are described below:

- *Scenario 1 – Energy Price Reform*: This scenario involved a simulation of an energy price reform that increases fuel prices from current (2010) prices. In order to mimic gradual price reform, there is a phased increase ending in a five-fold rise by 2050. This scenario takes into account the regulatory instruments included in Baseline 1.
- *Scenario 2 – Building System Incentives*: This policy scenario frames buildings as an ‘energy system’. Economic incentives relate to energy intensity and not specific technologies. A subsidy of 50% of capital and labour costs was introduced for the construction of buildings with an energy consumption below or equal to 50 kWh/m²/year. In addition, a 25% subsidy was provided for buildings with an energy consumption below or equal to 90 kWh/m²/year. Furthermore, a mandatory ban was introduced on the construction of buildings with energy consumption ≥ 230 kWh/m²/year. This scenario integrated the internalisation of the social costs of emissions via a

carbon tax of US\$30/tCO₂ for the entire period under analysis. Energy prices (2010) were kept constant.

- *Scenario 3 – GEE+ Policies*: Like Baseline 2, this simulates green building policies but it is far more wide-ranging as policies address both new and existing buildings. Financial incentives are 20% for building envelope technologies, 35% for space heating and cooling, and 40% for solar PV and solar thermal. This scenario also takes into account the regulatory instruments simulated under Baseline 1 and the energy price reform introduced in Scenario 1.
- *Scenario 4 – Integrated GEE Policy Portfolio*: In addition to the set of policy instruments simulated under Scenario 3, this scenario also included the internalisation of the social costs of carbon, equivalent to a tax of US\$40/tCO₂ applicable to on-site energy use.

For the specific case of the social costs of CO₂ emissions, we simulated CO₂ taxes (US\$30-40/tCO₂) under Scenario 2 and 4 based on figures generated by three economic climate change models (DICE, FUND and PAGE) (see Interagency Working Group on Social Cost of Carbon 2013). These models estimate the negative global costs associated with one tonne of CO₂ to be between US\$12 and US\$64 in 2020, with US\$43 as the average (Revesz et al. 2014).

Table 7: Policy instruments simulated under Baselines 1 and 2 and applicable to the multi-household building stock in Shanghai

Type of policy instrument		Observations
Regulations		
	Building code	Adopted in 1998. It also applies to the construction of ‘Green Buildings’
	Energy efficiency regulations	Adopted in 2008 and applicable to residential, government office and commercial/ public buildings. It includes numerous technical aspects related to energy/ resource conservation and wall material renovation.
	Minimum energy saving rates	Originally 30% and only in the North, later applied nationwide. Raised to 50% in 2005 and 65% in 2009 for Beijing and Shanghai
	Minimum performance standards for building envelope	Adopted in 2002 and applicable to the People’s Republic of China
	Mandatory use of water-saving appliances in fully-furnished apartments	Adopted in 2011 and applicable to the People’s Republic of China
Economic incentives		
	‘China Green Building Label’ subsidy	Adopted in 2012 and applicable to Shanghai. Equal to 60 CNY/m ² . ‘Two Star’ rating for residential buildings $\geq 25\,000\text{ m}^2$; ‘Three Star’ rating for residential buildings $\geq 10\,000\text{ m}^2$. Mostly applicable to new buildings.
	Subsidy for new buildings with high energy efficiency performance	Adopted in 2012 and applicable in Shanghai to buildings with a floor area $\geq 50\,000\text{ m}^2$. Energy demand 70% lower than the baseline of the mandatory energy-saving rate. Subsidy is equal to 60 CNY/m ² (max. 6 million CNY)
	Subsidy for existing buildings with high energy efficiency performance	Adopted in 2012 and applicable in Shanghai to buildings with a floor area $\geq 10\,000\text{ m}^2$. Energy-saving retrofitting of an existing building is required and must achieve an energy demand 50% lower than the baseline mandatory energy-saving rate. Subsidy is equal to 60 CNY/m ² (max. 6 million CNY)
	Subsidies for windows or window shading renovation of existing buildings	Adopted in 2012 and applicable in Shanghai to buildings with a floor area $\geq 5\,000\text{ m}^2$. Compliance with applicable design standards (DGJ08-205 and DGJ08-107 or JGJ237) required. Subsidy is equal to 150 CNY/m ² window area.
	On-site renewable energy (RE) subsidy	Adopted in 2012 and applicable in Shanghai to buildings with a floor area $\geq 50\,000\text{ m}^2$ with one on-site RE source; or with two or more RE sources and a floor area $\geq 40\,000\text{ m}^2$. Subsidies equal to 60 CNY/m ² of benefit area in the case of solar heating or ground source heat pump; and 5 CNY/Watt of installed capacity in the case of solar photovoltaics.

Data sources: Liu (2012), Orrling (2013), Cai (2010), Lu-Hill and Chen (2013), Shanghai Government (2010), Shanghai Municipal Development and Reform Commission (2012), Chinese Society for Urban Studies (2008) and Ruet et al. (2010).

3. Results

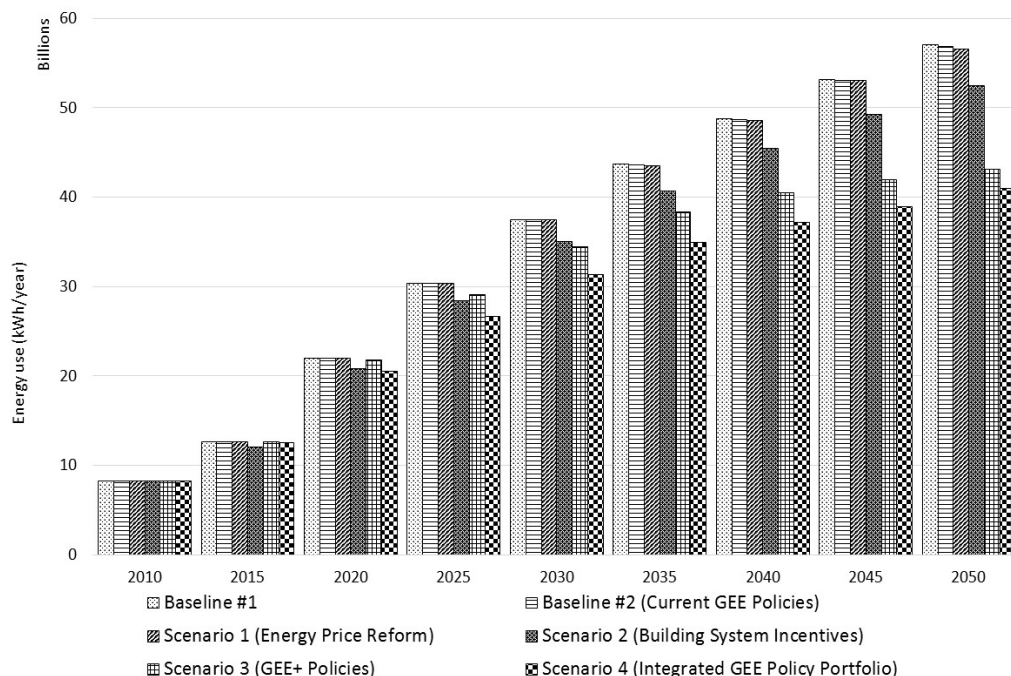
3.1. Energy and technology aspects

Overall, our results correlate well with the ambition of the simulated policy package. That is, the more ambitious the policy design, the more radical, positive changes in Shanghai's multi-household building sector, in particular in the long term. On the other hand, isolated and/ or unambitious policies lead to marginal improvements and impacts follow business-as-usual trends or have selective results. All scenarios, including the two baselines, lead to a decrease in energy use per building (see Figure 2 and Figure 3).

Under Baseline 2 (current GEE policies), energy efficiency improvements are marginal: 0% per year for the period 2010–2030, and in the range of 0.1% and 0.4% per year for the period 2035–2050. This means that the subsidies on offer are insufficient to make efficient technologies more attractive than conventional ones. Average estimated energy use per building remains nearly the same throughout the period under analysis (see Figure 3) compared to Baseline 1. This means that existing building codes alone (Baseline 1) may be sufficient to maintain 'autonomous' efficiency improvements on a per-building energy use basis. Not only does the policy mix under Baseline 2 lack ambition, but we also found that current GEE policies focus on incentives for new buildings – and not the current building stock (c.f. Price et al. 2011; Zhou, McNeil, and Levine 2012).

Similarly, Scenario 1 (energy price reform) generated minimal impacts if implemented gradually (c.f. Zhou, McNeil, and Levine 2012; Y. Fan, Liao, and Wei 2007) and in isolation. Our results show that it offers relatively better incentives when the price increase is fully implemented (in 2050): energy savings are around 0% before 2030 but reach 0.5 and 1% in 2050 compared to Baselines 2 and 1, respectively.

Figure 2: Estimated on-site energy use for Shanghai's multi-household building stock (8+ stories) (2010-2050)

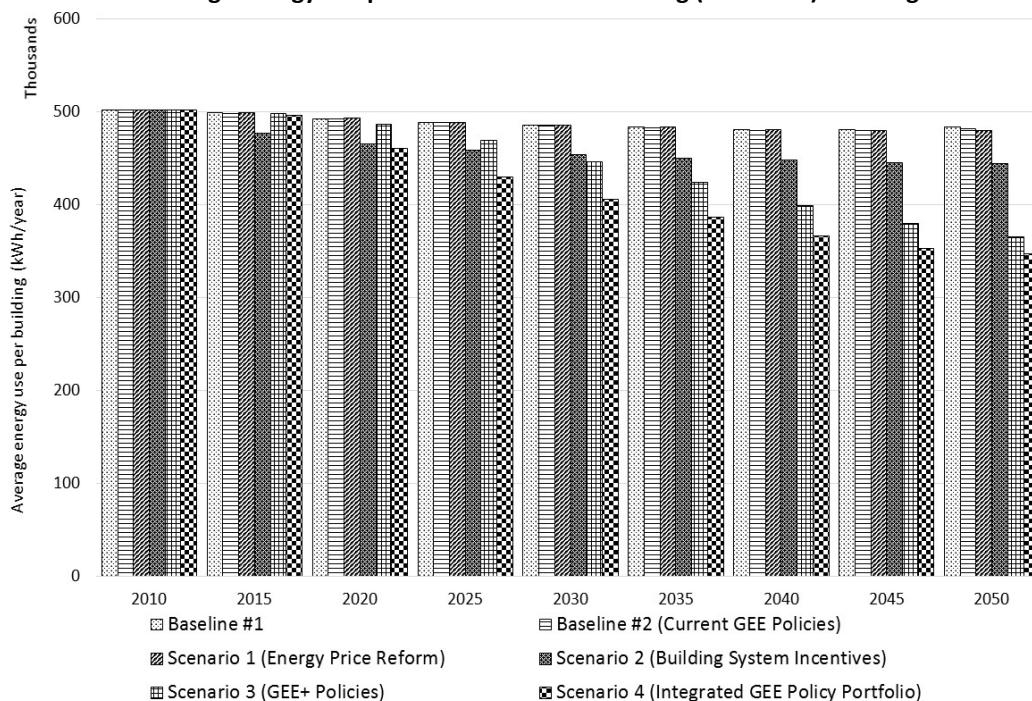


Scenario 2 (building system incentives) generated more efficiency improvements than the scenarios and baselines described above. Compared to current GEE policies (Baseline 2), energy savings were estimated to be around 4% in 2015 and 8% in 2050 (see Figure 2 and Figure 3). Until 2025, Scenario 2 delivers more energy efficiency improvements than Scenario 3. This is explained by the strong

incentives given to new buildings, with energy intensity levels equal or lower than 50 to 90 kWh/m² per year, combined with a tax of US\$30/tCO₂, and a ban on the construction of high-energy intensity buildings (≥ 230 kWh/m²/year). However, in the long run, this scenario fails to send incentives for the renovation of the existing building stock.

Scenario 3 (GEE+ policies) is less effective in generating energy efficiency improvements prior to 2030, but leads to more energy savings than Scenario 2 after that year. This is because the effects of the energy price reform become more apparent in the long term and, when combined with more aggressive subsidies, send better price signals not only for the construction of new buildings, but also for the retrofitting of existing premises. Energy savings total 24% in 2050, compared to Baseline 2. However, prior to 2030, policy incentives have most impact on new building stock. Consequently, Scenario 3 delivers lower energy savings (e.g. approximately 1.5% in 2020) compared to Scenario 2 (e.g. approximately 5% in 2020) for the period 2010–2025. This can be attributed to the fact that Scenario 3 is far less aggressive than Scenario 2 regarding maximum energy intensity levels for new building.

Figure 3: Estimated average energy use per multi-household building (8+ stories) in Shanghai 2010–2050



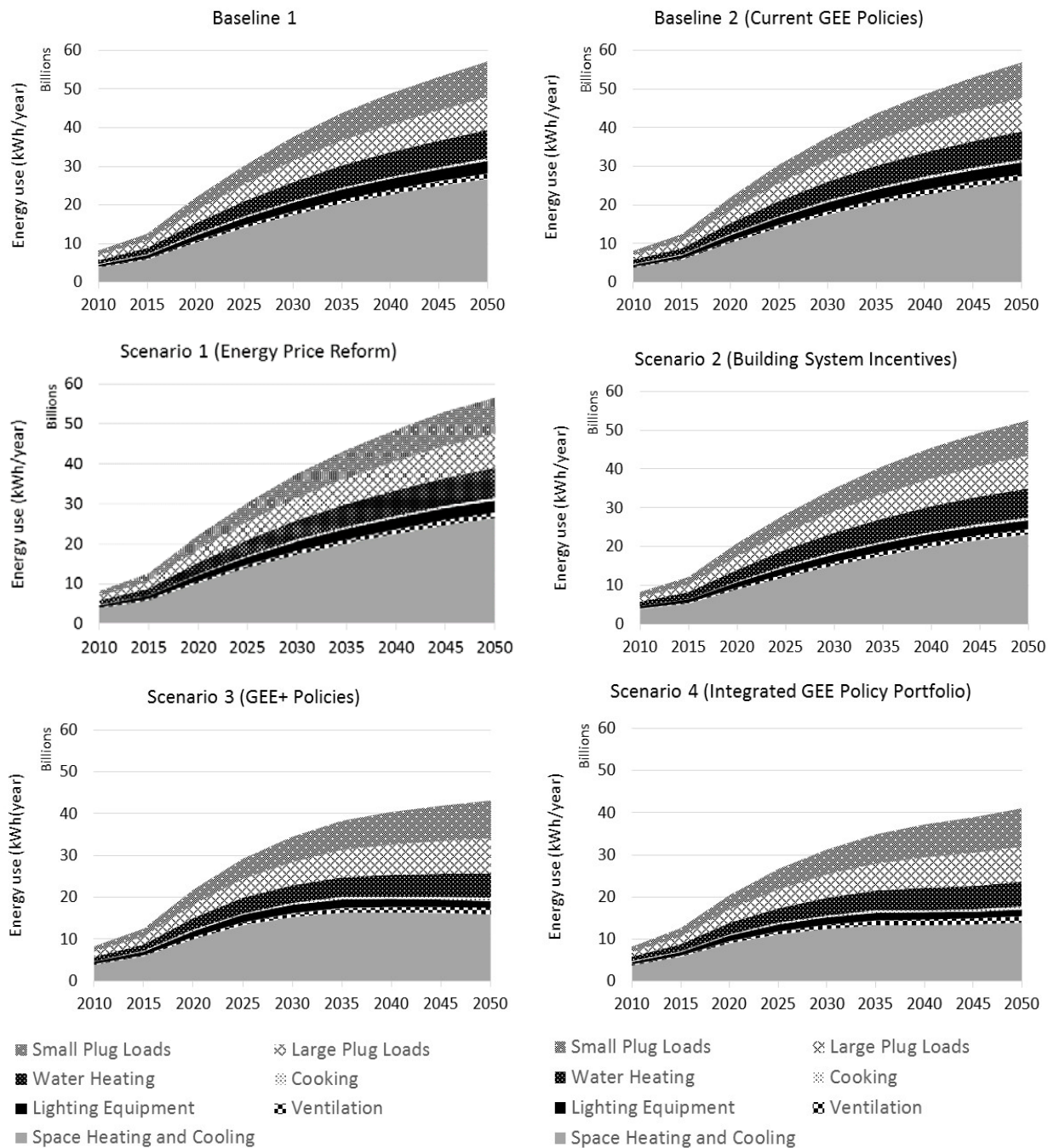
Scenario 4 (integrated GEE policy portfolio) offered the most ambitious and diverse set of policies. It also delivered the most significant efficiency improvements compared to the other policy scenarios (see Figure 2 and Figure 3). Compared to both baselines, Scenario 4 delivered efficiency improvements of around 7% in 2020, 17% in 2030, 24% in 2040 and 28% in 2050. Average per-building energy use reflected the same level of improvement. Scenario 4 combines the strengths of the other scenarios (e.g. building codes, energy price increase and aggressive financial incentives for low-carbon technologies) with a higher carbon price signal (US\$40/tCO₂), which offers strong incentives for the development of both new and current building stock.

Results revealed that heating and cooling technology segments are the principal source of energy efficiency improvements across *all* policy scenarios (see Figure 4). This finding is consistent with previous research, which highlights the importance of the demand for heating and cooling energy services (both in China as a whole and Shanghai in particular) as important sources of savings, in particular in the existing building stock (see e.g. Chen et al. 2009; e.g. Zhou, McNeil, and Levine 2012;

D. Liu et al. 1997; Pan, Huang, and Wu 2007). Under Scenario 2, energy savings from heating and cooling reach approximately 2340 GWh in 2030 and 3524 GWh in 2050 (compared to Baseline 2). Under Scenario 4, estimated savings are much higher: 4995 GWh in 2030 and 12640 GWh in 2050. From a technology point of view, the drivers behind these figures are better building envelopes (e.g. wall insulation, fenestration) combined with solar thermal and high-efficiency heating, ventilation, and air conditioning (HVAC) control systems.

Lighting equipment (e.g. compact fluorescent lamps) and water heating represent other important sources of savings across all scenarios. For instance under Scenario 2, energy savings from efficient illumination appliances reach 342 GWh in 2030 and 793 GWh in 2050. Under Scenario 4, energy savings accounted for 464 GWh in 2030 and 1644 GWh in 2050. This result correlates well with earlier studies on Shanghai (D. Liu et al. 1997; Chen et al. 2009; Pan, Huang, and Wu 2007), which stressed that lighting was one of the most cost-effective energy-saving measures in the building sector. Water heating also represents a relatively major source of energy savings, in particular under Scenario 3 (e.g. 513 GWh in 2030) and Scenario 4 (e.g. 637 GWh in 2030). Under the business-as-usual baseline, gas water heaters are most widely used (see also Chen et al. 2009); however, Scenarios 3 and 4 provide strong incentives for the integration of solar water heating into residential buildings.

Figure 4: Technology segments and energy use under different baselines and scenarios (2010–2050)

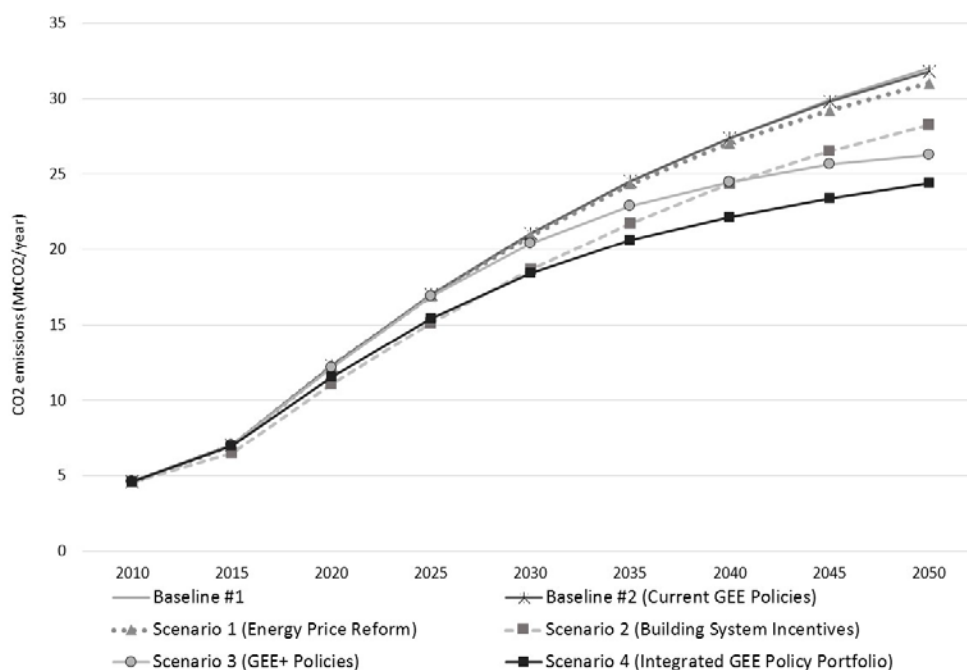


Efficiency improvements from small/ large plug loads (e.g. refrigerators, washing machines) were relatively minor, suggesting that current appliance standards and labelling programmes have reduced energy saving potential in this segment. This finding seems to be consistent with previous research, which argues that labelling programmes and appliance standards in China have proved robust (Price et al. 2011; Pan, Huang, and Wu 2007).

3.2. CO₂ emission levels

Results show that Scenario 4 is capable of delivering more CO₂ emission reductions than any other policy mix. Compared to Baselines 1 and 2, Scenario 4 reduces emissions by nearly 24% in 2050 (see Figure 5). It also yields much higher emission reductions (e.g. nearly 14% on average compared to Baseline 2) than any other scenario. This is basically because Scenario 4 combines a high carbon price signal (US\$40/tCO₂), which affects both new and current building stock, with the strengths of Scenario 1 (energy price increase) and Scenario 3 (aggressive financial incentives for low-carbon technologies).

Figure 5: CO₂ emissions from multi-household buildings (8+ stories) in Shanghai under different baselines and scenarios



Under Baseline 1 (business-as-usual), emission levels increase by 6% per year on average. To some extent, this result is consistent with Dhakal (2009) and Niu et al. (2012), who found that despite progress in carbon intensity reduction, major Chinese cities (including Shanghai), still show distressingly high energy use and CO₂ emission trends⁴. Compared to Baseline 1, current GEE policies (Baseline 2) only deliver marginal reductions: approximately -0.1% (2010–2030) and -0.6% (2035–2050). This suggests that building codes and subsidies alone are insufficient for effective reductions in CO₂ emissions in Shanghai’s high-rise multi-household building stock.

Consistent with the gradual fuel price increase, emission reductions under Scenario 1 are most apparent only after 2040 (-1.2% compared to Baseline 2), leading to reductions in emission levels by 2.5% and 3.1% in 2050 compared to Baselines 1 and 2 respectively. The mix of policies under Scenario 2 (building system incentives) delivers relatively higher emission reductions in the short

⁴ Economic growth is estimated to have made the largest overall contribution to increased CO₂ emissions in Shanghai for the period 1990–2006 (Dhakal 2009).

term (until 2040) compared to Scenario 3, and emission levels are comparable to Scenario 4 until 2030. The policy mix under Scenario 2 provides short-term incentives that heavily address the new building stock, including the promotion of solar technologies (see previous section).

Scenario 3 leads to greater reductions in emissions from 2040 onwards compared to Scenario 2. This is primarily due to the incremental effects of the energy price increase and the long-term effects of renovating the existing building stock. Before 2040, Scenario 3 delivers more emission than Scenario 2. This effect can be largely explain due the fact that Scenario 3 is less determined than Scenario 2 regarding maximum energy intensity levels for new buildings (50-90 kWh/m²/year) and it lacks of a carbon pricing mechanism. After 2035–2040 Scenario 3 reduces emissions at 2% per year compared to Scenario 2, and approximately 12% per year compared to Baselines 1 and 2. Until then, policy incentives primarily have an impact on new building stock. This situation yields average annual emission reductions of around 3% (between 2010 and 2035) compared to Baselines 1 and 2.

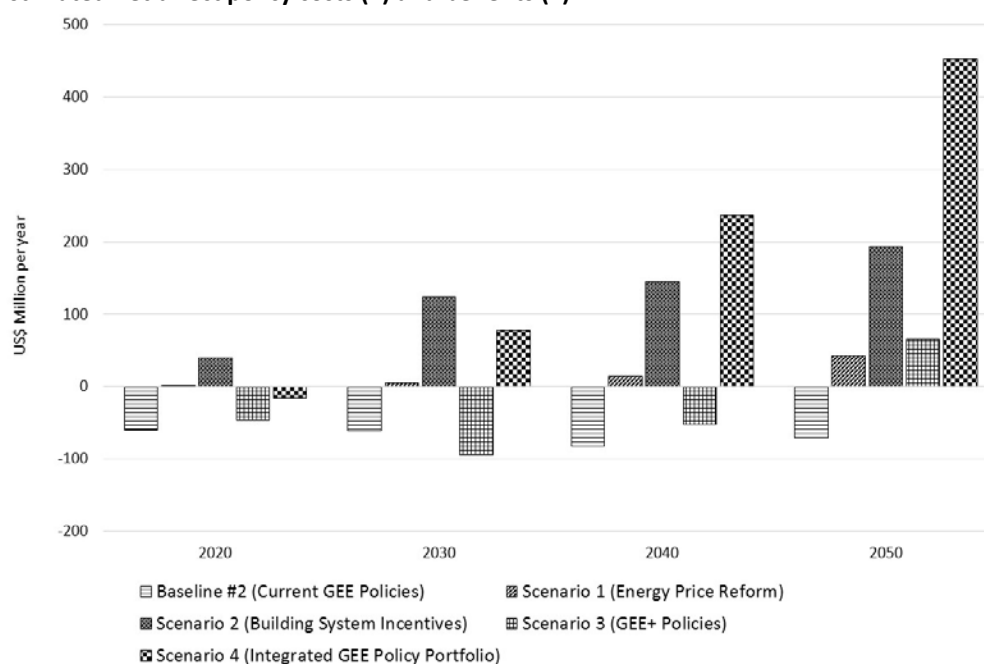
To some extent, our findings are consistent with research by Li et al. (2010), Niu et al. (2012) and Ruet et al. (2010), who argue that large reductions in CO₂ emissions (or carbon intensity) are possible in Shanghai as a whole (i.e. all end-use energy sectors included) if additional policy measures (e.g. beyond the 11th Five-Year Plan) are implemented. In fact, note that China has followed its commitment to implement a carbon market gradually. Back in 2011, the National Development and Reform Commission (NDRC) mandated five cities, including Shanghai, and two provinces (Guangdong and Hubei) to implement pilot emission trading schemes. In Shanghai, the pilot scheme started in November 2013 and covers more than half of the city's emissions. In our case, however, we found that only commercial buildings (and not residential buildings) emitting more than 10,000 tCO₂/year were included in the scheme.⁵

3.3. Economic impacts

In energy and climate policy analysis it is very important to make the components of estimated economic figures explicit. Here, we estimated *net policy costs or benefits* resulting from the simulated policy scenarios, including Baseline 2 (current GEE policies). We define *policy costs* as the sum of all the direct financial incentives provided under a given scenario (i.e. technology- and building-oriented subsidies under Baseline 2 and Scenarios 2, 3 and 4). *Policy benefits* are avoided social costs of CO₂ emission due to reductions resulting from the implementation of green energy technologies (average value of US\$43/tCO₂ - see Revesz et al. 2010). Policy benefits in the form of tax revenues were also estimated from the carbon pricing incentive simulated under Scenario 2 (US\$30/tCO₂) and Scenario 4 (US\$40/tCO₂). We did not take into account potential co-benefits associated with the implementation of green energy technologies (e.g. improved energy supply security). Figure 6 shows the estimated net policy costs and benefits resulting from our modelling exercise.

⁵ Eligible sectors under Shanghai's ETS are industries producing electricity, iron and steel, petrochemicals, non-ferrous metals, chemicals, building materials, textiles, pulp and paper, rubber, and chemical fibers and that emitted more than 20,000 tCO₂/year in 2010-2011. Airlines, ports, airports, railways, commercial, hotel and financial sector buildings that emitted more than 10,000 tCO₂/year in 2010-2011 are also included under the scheme. Industries and other commercial activities that started operation after November 2013 are not covered in the pilot phase. For details see <http://www.ieta.org/worldscarbonmarkets>

Figure 6: Estimated net direct policy costs (–) and benefits (+)



Estimates show that an ambitious policy portfolio (Scenario 4) is also economically feasible as the benefits from CO₂ emission reductions considerably outweighs direct policy costs. Net policy benefits estimated under Scenario 4 suggest that there is also considerable potential for the directional recycling of CO₂ revenues to induce further the deployment of low-carbon technologies and green building construction. Unlike the other simulated scenarios, there do not appear to be any trade-offs in terms of effectiveness (energy savings and emission reductions) and net economic impacts.

Baseline 2 (current GEE policies) revealed net negative policy costs. The marginal level of emission reductions (compared to Baseline 1) means that the order of magnitude of social benefits is much lower than the direct costs of subsidies. This means that even if current GEE policy measures offer marginal positive effects in terms of efficient energy use and emission reductions, the scenario is still prohibitive in terms of direct policy costs.

Scenario 3 shows a relatively similar outcome, except at the very end of the period under analysis. This means that although emission reductions (and thus negative externalities) are much higher, particularly after 2030 (compared to Baselines 1 and 2), the economic benefits do not compensate in net terms for expensive technology and building subsidies (at least not before 2050). From an economic policy point of view, this suggests that ambitious subsidies alone are insufficient and should be accompanied by other policy measures that tap into climate mitigation potentials. It is remarkable that the carbon pricing mechanism (that distinguishes Scenarios 2 and 4 from Scenario 3) results in such a radically different economic performance.

Energy price reform (Scenario 1) shows that, on its own, an increase in energy prices can be economically viable and perform better than current GEE policies. Regardless of the order of magnitude of the estimated net benefits (which are much lower than under Scenario 4), the pace of change in energy pricing is critical. Net policy benefits become apparent when the five-fold increase start being fully materialised. This is consistent with empirical research which stresses that the pace of energy price reform (or the removal of energy subsidies) is one of the critical conditions for energy efficiency improvements in China (Zhou, McNeil, and Levine 2012; Y. Fan, Liao, and Wei 2007; Lin and Jiang 2011).

Scenario 2 (building system incentives) is also economically attractive and delivers net benefits, even much higher than Scenario 4 until 2030. This is because Scenario 2 entails less direct policy costs than Scenario 4 and send better incentives to new buildings (and resulting emission reductions) in the short term. However, Scenario 2 fails to address the existing building stock and after 2030, policies under Scenario 4 delivers larger net benefits than Scenario 2, as policy incentives yields higher emission reductions resulting from both new and refurbished buildings. This situation largely offset direct policy costs of subsidies under Scenario 4 (higher than under Scenario 2).

4. Conclusions

The objective of our paper was to evaluate Green Energy Economy (GEE) policies aimed at the multi-household building sector (8+ stories) in Shanghai, China. We used a bottom-up modelling tool to estimate and analyse different baselines and policy scenarios from an energy, environmental and economic point of view. Overall, we conclude that GEE policies can have a significant positive impact on the multi-household building sector, provided that their design and implementation is both ambitious and integrated. Our results clearly show that there is no single-best policy instrument to drive a GEE and transform the multi-household building sector, and the inclusion of the social costs of climate change play a critical role.

The level of ambition of policy scenarios correlated well with the order of magnitude of impacts. When various market and policy conditions are met (details below), our model strongly suggests that a more integrated policy portfolio (e.g. Scenario 4) that includes ambitious low-carbon technology-oriented financial incentives (for new and existing buildings), energy price reform, and a CO₂ price mechanism is the right mix of incentives for green building transformation. This is a plausible long-term scenario; moreover if co-benefits of low-carbon technology implementation are estimated and taken into account. Additional savings in peak load electricity demand and reductions in the need for new power generation can also be expected.

Whereas the implementation of current GEE policies appear to be a step in the right direction, they seem insufficient to stimulate transformation in the multi-household sector when implemented in isolation and on a small scale. Findings suggest that current policies may deliver marginal improvements in the long term and entail net direct economic costs. From an economic point of view, this suggests that aggressive building codes might be a much more cost-effective way to ensure nearly the same improvements (e.g. decreased per-building energy use). In fact, compared to technology-specific policy subsidies, results strongly suggests that green building transformation is better driven when maximum energy intensity targets for whole new buildings are introduced (Scenario 2).

Consistent with earlier research, findings highlight that the retrofitting of existing buildings represents not only a serious policy challenge, but also it can result in significant environmental and economic gains in the long-term. Assuming the effective enforcement of building codes, our findings show that policy incentives need to give more weight to retrofitting. This is particularly relevant in the heating and cooling technology segments, which were important sources of energy savings across all policy scenarios.

The internalisation of the social costs of CO₂ emissions is central to the calculation of the magnitude of net economic policy impacts. Our results show that more ambitious integrated policies also increase net direct policy benefits. Although we may have used a low value of social benefits associated with CO₂ emission reductions (c.f. Revesz et al. 2014), the economic results provide useful insights for the design of GEE policies. When an explicit carbon price mechanism is included in the policy mix, better price signals are sent for the deployment of low-carbon technologies in both new and existing buildings. Results also suggest that the timing of emission reductions is sensitive to carbon pricing and the composition of the building stock (new and existing buildings). Whereas it

remains to be seen whether the residential building sector will be included in Shanghai's ETS, results show that even the most ambitious policy scenarios may not require the trade-offs that are often claimed in climate policy (e.g. although policies may be environmentally-effective, they are expensive). Even if there are high direct policy costs, potential carbon revenues can have positive tax recycling effects on further energy savings and CO₂ emission reductions.

Finally, the theoretical impacts and potential benefits of GEE policy instruments must not underestimate the challenges associated with their design, implementation and enforcement. Our research highlights key aspects of policy and the critical conditions that should be met for the estimated impacts to become apparent. First, the impact of all simulated policies assumes full compliance with building codes, and their effective enforcement (as mentioned above). Secondly, some of our scenarios assume that there is energy price reform. This means that all the related political, legal and social challenges (whether for Shanghai or China as a whole) can be overcome. Thirdly, it is critical to consider the political feasibility of policy measures (e.g. carbon price mechanisms) and its related design (e.g. inclusion of residential building sector) and level of ambition (e.g. in the form a progressive absolute caps). Fourthly, our results are based on the effective implementation of other economic and informational policy measures. For instance, uncertainties about the performance of low-carbon technologies are reduced for end-users due to information provided by equipment manufacturers, building companies, energy service companies (ESCOs), and/or public authorities. Transaction costs (e.g. due diligence, legal advice) are very low or close to zero for households and key stakeholders (e.g. building companies). End-users are fully aware of policy incentives and the benefits (e.g. financial performance) of implementing low-carbon technologies, due to successful information campaigns launched by public authorities. Building associations/companies or low-income households have access to capital (e.g. via soft loans) to cover incremental costs and undertake retrofitting projects, etc. In all, these economic and informational policy measures are a key part of policy formulation that can lead to the implementation of ambitious and successful GEE policy portfolios.

Acknowledgements

The authors would like to acknowledge the contribution of Kevin Otto (Robust Systems and Strategy LLC), Christian Kornevall (World Business Council for Sustainable Development), Liu Yujun (ESG Research, China) and Mingxing Sun (Shangdon University) who provided key input and critical information. Luis Mundaca would like to acknowledge the financial support of the AES Research Programme of the Swedish Energy Agency, grant N° 33684-1.

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