Explanatory Note on the Building and Utility Energy Management System Emissions Calculation Model

Project Number: 52230-001
May 2020

PRC: Xiangtan Low-Carbon Transformation Sector Development Program

MEMORANDUM

TO: Asian Development Bank, Xiangtan Program Management Office
FROM: Rachael Jonassen, PhD
DATE: May 24, 2020
RE: Emissions Estimates for Building Energy Management Strategy in Yuhu and Yuetang Districts, Xiangtan County

1. Overview

This memorandum accompanies a report to ADB summarizing projected impacts of Low Carbon City Development in the municipality (county) of Xiangtan, China. The report summarizes each of the project-based and policy-based actions that will be undertaken as a result of the requested loan and indicates the ways in which those actions can be expected to influence the trajectory of GHG emissions over the lifetime of the loan (to 2045). This memo details assumptions and calculations used to estimate the impacts of policies to extend BEMS technology to all public and commercial buildings in Yuhu and Yuetang Districts.

The baseline scenario represents a 'Business as Usual" (BAU) case where the composition of the buildings and all incentives for retrofits or green building construction do not change from today (2020). Under the BAU scenario, all factors that could be influenced by the project-based and policy-based loans are held constant at 2020 values. Only the external factor of population changes in the BAU scenario. The "ADB Scenario" represents the case where each project-based and policy-based action is implemented over time. The ADB Scenario examines the effect of one project-based action and five policy-based actions. These actions are:

Project-based modifications examined:

1. Building Energy Management System expansion and integration in 200 public buildings.

Policy-based modifications examined:

1. Xiangtan implementation plan on piloting a Building Energy Management System
2. Mandatory energy audit on large public and commercial buildings
3. Xiangtan implementation plan on expansion of smart energy and energy/utility management systems
4. Xiangtan implementation plan on Building Energy Performance Database (BEPD) and management rules
5. Xiangtan implementation plan on Energy audit professional training program

Policy-based actions are designed to occur in two tranches with different implementation dates and the effects of policies on human behavior are also phased over time as they reach greater numbers of the relevant population.

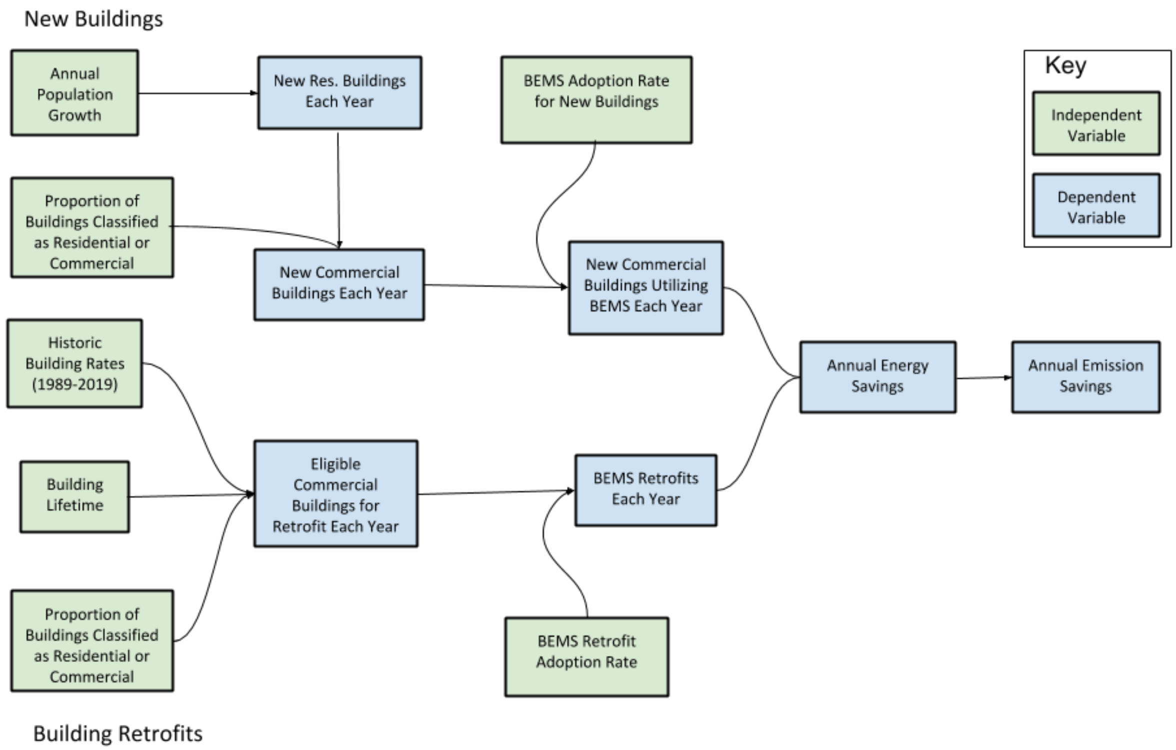
Projected impacts of project-based and policy-based actions related to the building sector are plotted against energy sector emission trajectories for two scenarios, referred to as "Worst Case" and "Best Case" scenarios. Emission trajectories for the BAU and Goal scenarios are derived from two Integrated Assessment Models (IAMs) as reported by the IPCC in the Fifth Assessment. These IAMs provide a global representation of emission trajectories that are used by the international climate change community. At the global scale, these are called Representative Concentration Pathways (RCPs). IAMs create projections of global emissions by socio-economic modeling using a grid-cell discretization of the Earth.

Emission estimates from project and policy-based actions in Xiangtan are compared to solutions derived from the IAM grid cell containing Xiangtan for the RCP 8.5 scenario, developed by the MESSAGE modeling system, and the RCP 2.6 scenario, developed by the IMAGE modeling system. This grid cell does not contain Changsha or other major Chinese cities; therefore, it is reasonable to believe that the results primarily represent emissions due to activities in Xiangtan. For the energy sector, RCP 8.5 represents the "Worst Case" scenario, in which the global economy follows a pathway of emissions close to that China is now following as it continues to expand the use of coal and oil as energy sources, while RCP 2.6 represents the "Best Case" scenario, exhibiting an early peaking of GHG emissions followed by a rapid decline. These are the two most extreme RCP scenarios; thus, movement from one to the other represents the most ambitious goal.

2. Assumptions

1. "Commercial" and "public/ commercial" buildings include all non-residential buildings.
2. BEMS policies will apply to all new and existing public/ commercial buildings in YH and YT built since 1989 (see Appendix, Figure A1 and A2).
3. Building quantities assume no future change in ratios of residential to commercial/public buildings, numbers of residents per household, number of household units per residential building, and population growth rate into the future. Projected building rates reflect only what is needed to meet this additional housing demand and maintain constant ratios of residential and commercial/ public buildings in the overall building stock. This method may underestimate actual increases in commercial building space evidenced in yearbook data from YH + YT (XT PMO 2020).
4. BEMS adoption models assume initial (2019) adoption rates near 0% based on observation that only one building from the Xiangtan was found within databases of existing green building certifications (LEED, EDGE, 3 Star).
5. Starting the adoption of BEMS technology at 19% for retrofitted construction in 2017 reflects data from Changning District's public building sector. Building retrofit projects completed before 2022 are assumed to occur without influence of XT green building policy, while retrofit projects completed after 2022 are attributed to XT green building policy. This ignores the possibility of retrofit projects that would have occurred without additional incentives provided by XT building energy management policy. As of 2018, institutional, commercial, and industrial building owners surveyed in the *2018 Energy Efficiency Indicators* survey indicated that building controls improvements were the top energy efficiency measure pursued within the past 12 months, and 63% expressed plans to incorporate building energy controls within the next 12 months, which may suggest the number of building owners pursuing retrofit projects in a BAU scenario is greater than zero (Johnson Controls 2018).
6. It is assumed 100% of commercial heating and cooling energy loads are supplied by electricity, with a constant emissions factor equivalent to the emissions factor of the Xiangtan electricity supply in 2019.
7. Each year after 2019, a certain number of existing buildings reach the end of their expected lifetime and become prime candidates for retrofit. The number of eligible buildings is based on historic building rates 1989-2019 and average expected lifetime of urban buildings in China. Of these buildings, a certain percentage each year will be retrofitted based on a logistic growth model for adoption of green building practices and standards. All other existing buildings are assumed to undergo any modifications or upgrades necessary to continue operating at the same energy efficiency level.
8. Buildings built before 1989 are not considered for BEMS retrofit, due to uncertainties in the quality of older building stock and any impediments to sustainability upgrades that may exist. See Paradis (2016) for examples and further discussion of potential barriers to sustainability upgrades in older buildings.
9. Amecke et al. (2013) note that China's building sector is "characterized by rapid new construction and demolition of older buildings" and thus has included little focus on retrofits to date. The proportion of eligible buildings undergoing retrofits should consider policy approaches that address high up-front costs for retrofits and balancing incentives for demolition and new construction with incentives for retrofits.
10. Average annual energy reductions for new and retrofitted commercial/ public buildings assume energy reductions per unit floor area will mirror energy reductions calculated for the project-based component, Building Energy Management System expansion and integration in 200 public buildings (summary data included in Appendix).
11. The national goal of 50% of new buildings certified as "green" in 2020 is presented for context and it is not plausible that the goal will be exceeded. We assume there will be a new national goal in the upcoming 14th 5-year plan.
12. Impacts of policies affecting residential and commercial energy use are assumed to be additive, and any synergistic effects of DH, green building, and/or BEMS policies are not modeled in emission reduction estimates.

3. Logical Flow



4. User-Defined Parameters

Parameter	Chosen Value	Equation(s)	Data Source	Explanation
t_p *(year)*	2022	*Eq. 1*	XT PMO	*Year of Policy Implementation*
L (%)	100%	*Eq. 1*		*Maximum percentage of new or retrofitted buildings utilizing BEMS* Logistic growth parameter reflecting maximum adoption of BEMS technology for commercial buildings.
k_{new} *(%)*	23%	*Eq. 1*	CBRE (2017)	*Logistic growth rate, BEMS adoption in new construction* Parameter chosen to reflect growth rate of ENERGY STAR and/or LEED certified space in the 30 largest U.S. office markets 2000-2017.
$t_{0,new}$ *(year)*	2039	*Eq. 1*	CBRE (2017)	*BEMS adoption model midpoint year, new construction* Parameter chosen to reflect growth rate of ENERGY STAR and/or LEED certified space in the 30 largest U.S. office markets 2000-2017.
$k_{retrofit}$*(%)*	9%	*Eq. 1*	Molinaroli (2017)	*Logistic growth rate, BEMS adoption in retrofits* Parameter chosen to match the starting percentage of about 19% adoption rate in 2017, reflective of data from Changning District's public building sector.

$t_{0,retrofit}$ *(year)*	2033	*Eq. 1*		*BEMS adoption model midpoint year, retrofits* Parameter chosen to reflect gradual adoption over the lifetime of the loan.
r (persons/ yr)	12,500	*Eq. 2*	XT Health and H Comm	*XT Population growth rate* Annual population growth in XT County, 2019-2045, assuming linear growth.
p_{YH+YT} *(%)*	33.5%	*Eq. 2*	XT City Assessment Report	*Proportion of population in YH+YT* Assumed to remain constant 2019-2045. Population of YH+YT assumed to grow proportional to the population of XT County.
ζ_{pph} *(persons/ household)*	3.10	*Eq. 2*	Xiangtan 2018 Year book	*Population per household* XT GHG Inventory (2015), Ch. 2, City Profile lists 2.84 for YT and 2.86 for YH for an average value of 2.85. ADB Survey of households in August 2019 asked (Q. 2) "How many members in your household?" The average of 406 responses is 3.52. The Xiangtan 2018 Year book reports the value for urban as 3.10 for the year 2017.
$\zeta(i)_{hpb}$ *(households/ building)* *i=1990-1999*	56	*Eq. 2*	Gálvez and Cheshmehzangi (2015), p 6	*Residential units per building (1990-1999)* Starting in 1988, work unit-based housing systems were abolished and replaced by new affordable housing projects characterized by low-cost mass housing construction consisting of housing blocks of 56 mid-sized units each.
$\zeta(i)_{hpb}$ *(households/ building)* *i=2000-2045*	120	*Eq. 2*	Gálvez and Cheshmehzangi (2015), p 8	*Residential units per building (2000-2045)* From 2000-2007, roughly 80% of new urban residential development in China consisted of mid-rise (4-8 floors) and high-rise (up to 34 floors) buildings ("gated community" housing pattern). A typical model in the City of Guangzhou included a mix of buildings with 4-8 units per floor. We assume an average of 6 units per floor, 20 floors per building.
p_{res} *(%)*	64%	*Eq. 3*	Yi et al. (2018), p 21	*Percentage of buildings classified as residential* Used to extrapolate total number of buildings and number of public/ commercial buildings in YH+YT.
τ_j *(years)* *j=1989-1999*	30	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 1989-1999* Following assumptions for average lifetime of urban residential and commercial buildings in China 1980-1999.
τ_j *(years)* *j=2000-2009*	40	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 2000-2009* Following assumptions for average lifetime of urban residential and commercial buildings in China 2000-2019.

τ_j *(years)* *j=2010-2019*	40	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 2010-2019* Following assumptions for average lifetime of urban residential and commercial buildings in China 2000-2019.
τ_j *(years)* *j=2020-2029*	50	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 2020-2029* Following assumptions for average lifetime of urban residential and commercial buildings in China 2020-2050.
τ_j *(years)* *j=2030-2039*	50	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 2030-2039* Following assumptions for average lifetime of urban residential and commercial buildings in China 2020-2050.
τ_j *(years)* *j=2040-2045*	50	*Eq. 5*	Hong et al. (2016), p 50	*Estimated lifetime of buildings built 2040-2045* Following assumptions for average lifetime of urban residential and commercial buildings in China 2020-2050.
s_{BEMS} *(%)*	20%	*Eq. 9*	Shaofang Li (2020)	*BEMS induced energy efficiency improvement* Estimated percentage reduction in building energy consumption for heating and cooling, applied to both policy-based and project-based components.
ζ_{apb} *(m^2/ building)*	4,500	*Eq. 9*	Shaofang Li (2020)	*Average floor area of a commercial/ public building* Estimated from average data from 200 buildings retrofitted with BEMS as part of the project-based component of the loan.
HH_P *(hr/ yr)*	1,321	*Eq. 7*	Shaofang Li (2020)	*Equivalent heating hours for full capacity heating per year* Estimated by Shaofang Li for project-based component, Building Energy Management System expansion and integration in 200 public buildings
CH_P *(hr/ yr)*	1,373	*Eq. 8*	Shaofang Li (2020)	*Equivalent cooling hours for full capacity cooling per year* Estimated by Shaofang Li for project-based component, Building Energy Management System expansion and integration in 200 public buildings
$I_{H,P}$ *(kW/ m^2)*	0.060	*Eq. 7*	Shaofang Li (2020)	*Commercial heating load index, peak load* Estimated by Shaofang Li for project-based component, Building Energy Management System expansion and integration in 200 public buildings

$I_{C,P}$ *(kW/ m²)*	0.080	*Eq. 8*	Shaofang Li (2020)	*Commercial cooling load index, peak load* Estimated by Shaofang Li for project-based component, Building Energy Management System expansion and integration in 200 public buildings
COP_{ASHP}	2.00	*Eq. 7* *Eq. 8*	Shaofang Li (2020)	*COP of air source heat pump* Used for building energy consumption estimates for both heating and cooling.
EF_E *(tCO_2e/ kWh)*	0.000462	*Eq. 10*	ADB	*Emissions factor for electricity use* From Central China Grid.

5. Calculations

The following sections describe methods used in estimating energy and GHG impacts of policies to extend BEMS technology to all public and commercial buildings in the Yuhu and Yuetang districts. Formulas in the following sections are represented in the "Summary Equations" tab of the spreadsheet titled "BEMS Utilization Emissions Calculations - Xiangtan ADB Output 3, 13 May 2020". The results of these calculations have been validated against earlier calculations performed in other tabs of the same spreadsheet, and a thorough dimensional analysis of all tabs of the spreadsheet was conducted May 13, 2020 to confirm dimensional agreement of all calculations.

5.1. Green Building Adoption Rates for New and Retrofitted Buildings

Adoption of BEMS technology in new construction is modeled with user-defined logistic growth parameters. XT demographic data is used to estimate population and residential housing demand growth 2020-2045 assuming linear population growth, and growth in commercial building space is extrapolated from residential building growth based on current proportions of each building type in XT building stock. BEMS adoption rates are applied to commercial building projections to estimate the number of new commercial buildings utilizing BEMS each year. Each year after 2019, a certain number of existing commercial buildings reach the end of their expected lifetime and become prime candidates for retrofit. The number of eligible buildings is based on historic building rates 1989-2019 and average expected lifetime of urban buildings in China. A similar model is applied to eligible buildings each year to estimate the percentage of eligible buildings retrofitted with BEMS each year. Estimates are rounded to the nearest whole building.

$$y(i) = \frac{L}{1+exp(k*(t_0-t_i))} \qquad for\ i \geq t_P \qquad \text{Equation 1}$$

Where:

$y(i) = Percentage\ of\ new/\ retrofitted\ buildings\ built\ to\ utilize\ BEMS\ in\ year\ i\ (\%)$
$L = maximum\ percentage\ (\%)$
$k = logistic\ growth\ rate\ (\%)$
$t_0 = midpoint\ year$
$t_i = year\ i$
$t_p = year\ of\ policy\ implementation$

$$B(i)_{res} = r * p_{YH+YT} * \frac{1}{\zeta_{pph}} * \frac{1}{\zeta(i)_{hpb}} \qquad \text{Equation 2}$$

$$B(i)_{com} = B(i)_{res} * (\frac{1}{p_{res}} - 1) \qquad \text{Equation 3}$$

$$B(i)_{BEMS} = y(i)_{new} * B(i)_{com} \qquad \text{Equation 4}$$

$$\beta(i) = B(i - \tau_j) \qquad \text{Equation 5}$$

$$\beta(i)_{BEMS} = y(i)_{retrofit} * \beta(i)_{com} \qquad \text{Equation 6}$$

Where:

$B(i) = total\ number\ of\ new\ buildings\ completed\ in\ year\ i$
$B(i)_{res} = total\ number\ of\ new\ residential\ buildings\ built\ in\ year\ i$

$B(i)_{com}$ = *total number of new commercial buildings built in year i*
$B(i)_{BEMS}$ = *number of new commercial buildings built to utilize BEMS in year i*
$\beta(i)$ = *number of buildings eligible for retrofit in year i*
τ_j = *average lifetime of buildings built in year j (years), where* $i = j + \tau_j$
$\beta(i)_{BEMS}$ = *number of buildings retrofitted to utilize BEMS in year i*
r = *population growth rate (persons/year)*
p_{res} = *percentage of building stock classified as residential (%)*
p_{YH+YT} = *percentage of Xiangtan residents living in YH and YT (%)*
ζ_{pph} = *average population per household (persons/household)*
$\zeta(i)_{hbp}$ = *average number of households per residential building in year i (households/building)*

5.2. Annual Energy and Emission Savings for New and Retrofitted Buildings

Average annual energy savings for commercial and public buildings utilizing BEMS assume energy savings for both new and retrofitted commercial buildings will mirror percentage reductions in building energy usage for heating and cooling calculated for the project-based component, Building Energy Management System expansion and integration in 200 public buildings (summary data included in the Appendix).

$$\rho_H = HH_P * I_{H,P} * \frac{1}{COP_{ASHP}} \qquad \textit{Equation 7}$$

$$\rho_C = CH_P * I_{C,P} * \frac{1}{COP_{ASHP}} \qquad \textit{Equation 8}$$

$$\Delta P(i)_{com} = \left(\sum_{2020}^{i} B(i)_{BEMS} + \sum_{2020}^{i} \beta(i)_{BEMS}\right) * s_{BEMS} * (\rho_H + \rho_C) * \zeta_{apb} \qquad \textit{Equation 9}$$

$$\Delta CO_{2,com}(i) = \Delta P(i)_{com} * EF_E \qquad \textit{Equation 10}$$

Where:

$\Delta P(i)_{comm}$ = *annual energy savings from commercial heating and cooling in year i (kWh)*
s_{BEMS} = *average reduction in commercial energy demand for heating/ cooling from BEMS utilization (%)*
ρ_H = *annual baseline commercial energy demand per square meter for heating, peak load* (kWh/m^2)
ρ_C = *annual baseline commercial energy demand per square meter for cooling, peak load* (kWh/m^2)
ζ_{apb} = *average floor area per commercial building* $(m^2/building)$
HH_P = *equivalent heating hours, peak load (hr)*
CH_p = *equivalent cooling hours, peak load (hr)*
$I_{H,P}$ = *commercial heating load index, peak load* (kW/m^2)
$I_{C,P}$ = *commercial cooling load index, peak load* (kW/m^2)
COP_{ASHP} = *coefficient of performance for building − integrated air source heat pump*
$\Delta CO_{2,com}(i)$ = *annual* CO_2 *emission reductions from commercial heating and cooling in year i* (tCO_2e)
EF_E = *emission factor for electricity* (tCO_2e/kWh)

6. Key References

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Appendix

A1. Abbreviations and Acronyms

ADB	Asian Development Bank
CO_2	Carbon Dioxide
tCO_2e	Tonnes of Carbon Dioxide Equivalents
EF	Emissions Factor
GHG	Greenhouse Gas
BAU	Business As Usual
XT	Xiangtan
XTMG	Xiangtan Municipal Government
XT PMO	Xiangtan Program Management Office
YT	Yuetang District
YH	Yuhu District
BEMS	Building Energy Management System
ASHP	Air-Source Heat Pump
MW	Megawatt
MWh	Megawatt-hour
kW	Kilowatt
kWh	Kilowatt-hour
^oC	Degrees Celsius

Figure A1: Yuhu District (outlined in red)

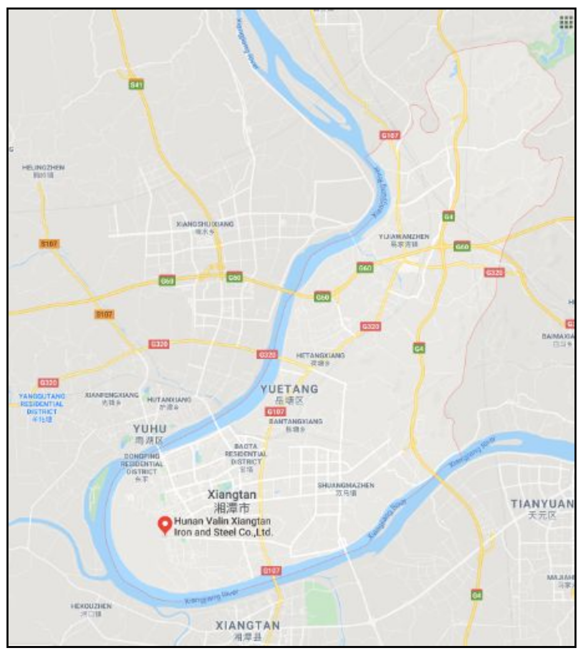

Figure A2: Yuetang District (outlined in purple)

Table A1. Policy-Based Interventions

Code	Interventions (Tranche 1 Policies)	Details and Effects on BEMS Design and Adoption
03-Tr1b	Xiangtan implementation plan on piloting a Building Energy Management System	Detailed information about building-wide energy usage revealed by BEMS will lead to implementation of targeted energy saving measures.
		Demonstrated ROI of BEMS will increase the utilization of BEMS in new buildings and retrofits.
		Efficiency improvements identified with BEMS removes knowledge barriers to green building retrofits and will increase the number of building owners retrofitting buildings to green building design standards.
		Possible substitution effect could cause a decrease in demand for building energy audits.
		Cooperation between business and local authorities can support the development of new, innovative technologies (such as sensors, controls, smart thermostats, energy consumption visualization, etc.) by creating the necessary research facilities and encouraging commercialization through the introduction of incentives and enabling regulation.
		Lowered cost barriers to BEMS adoption will increase utilization of BEMS in new buildings and retrofits .
03-Tr1c	Mandatory energy audit on large public and commercial buildings	Detailed information about building-wide energy usage revealed by audit will lead to implementation of targeted energy saving measures.
		Removing the knowledge barriers to green building retrofits will increase the number of building owners retrofitting buildings to green building standards and adopting BEMS technology.
		Demonstrated ROI of building energy audit will lead to an increased demand for building energy auditors.
Interventions (Tranche 2 Policies)		
03-Tr2b	Xiangtan implementation plan on expansion of smart energy and energy/utility management systems	Setting clear targets and a defined strategy will increase adoption of smart energy systems.
		Providing training to building occupants linked to improved data promotes energy conservation.
03-Tr2c	Xiangtan implementation plan on Building Energy Performance Database (BEPD) and management rules	Identification of better technology and processes for better ROI will increase use of BEPD.
		Increased data availability of technology and data will identify avenues for cost savings and increase participation in the BEPD.

03-Tr2d	Xiangtan implementation plan on Energy audit professional training program	Increased availability of energy audit professionals will lead to greater demand for services.

A2. Summary Data

A2.1. Building Energy Management for 200 Public Buildings

Energy savings per unit floor area for new and retrofitted commercial buildings utilizing BEMS are extrapolated to all commercial buildings from estimates for the project-based component, Building Energy Management for 200 Public Buildings.

Table A2. Basic assumptions and expected benefits for Building Energy Management for 200 Public Buildings (Shaofang 2020).

Basic Assumptions/ Information	
Average floor area of a public building (m^2)	4,500
Equivalent hour of full capacity for heating per year (hr)	1,321
Heating load indicator (W/m^2)	60
Equivalent hour of full capacity for cooling per year (hr)	1.373
Cooling load indicator (W/m^2)	80
Coefficient of performance	2.00
BEMS induced energy efficiency improvement (%)	20%
Benefits Calculation	
Total floor area of 200 public buildings (m^2)	900,000
Total annual energy consumption for heating (BAU) (MWh)	35,667
Total energy consumption for cooling (BAU)	49,428
Annual energy savings (MWh)	17,019
Annual energy savings (TCE)	3,336
Annual CO_2 emission reductions (tCO_2e)	7,863

A3. Summary of Equation Changes

Equation 1

- domain bounded to only show effects on adoption rate after year of policy implementation (Apr 21, 2020)

Equation 2-3

- components separated to explicitly calculate new residential buildings before calculating new commercial buildings (Apr 21, 2020)

Equation 5

- buildings eligible for retrofit defined using average building lifetime (Apr 21, 2020)