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Lighting energy use in Anding District, Gansu Province, China

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ABSTRACT

An energy use survey of 237 households was carried out in rural Anding district, Gansu province, P.R. China in 2010. Baseline lighting electricity use was assessed for current (2010) and future use (2020) and compared by light bulb type, household room, and seasonal differences. A simple life cycle assessment (LCA) compared strategies such as replacing incandescents with CFLs and reducing total daily hours of lighting to assess possible greenhouse gas (GHG) emission reductions. Replacing incandescent light bulbs with compact fluorescent light bulbs (CFLs) has the potential to reduce current and future annual energy use by 27% and 23% respectively. Within households, replacing bedroom light bulbs with CFLs reduces GHG emissions most, over 38% of the total CO_2 equivalent reductions possible. A focus on bedroom lighting in rural Anding district has the best potential to aid China's carbon intensity reduction goals by 2020.

Introduction and background

Rural people's access to energy has been recognized as a development priority under the UN Millennium Development Goals (Rehfuess, 2006). A great divide still exists between the energy access available to urban and rural residents in China (Crompton and Wu, 2005). Since 1979, rural electricity use has increased over all regions of China in part due to electrification reaching new areas. This increase in energy use, among other reasons, has galvanized Chinese leaders to set specific greenhouse gas (GHG) emission reduction goals. These emission reduction goals are to reduce carbon intensity from 40 to 45% reduction of 2005 emission levels by 2020 (Lan, 2011). Carbon intensity is defined as total GHG emissions produced per unit national gross domestic product (Zhang, 2000). Additionally the 2020 GHG emission reduction goal has been further refined for 2015 to reduce GHG emissions to 17% of 2005 emission levels (Lan, 2011). Recently, China has committed to have carbon dioxide (CO_2) emissions rise no higher after 2030 (The White House, 2014). These goals and commitments demonstrate the importance of addressing climate change in current Chinese national policy goals. National policy goals affect regions across China, including rural northwestern regions such as Anding district in Gansu province where the household energy survey discussed in this paper took place.

Findings from household energy surveys in northwestern China

Other research has considered rural household energy use in parts of northwestern China. A brief overview of their findings as they relate to electricity use in general and for lighting in particular follows. Fan et al. found that for the households they surveyed in Shaanxi and Yunnan provinces in 2004 and 2005 average household energy use was a quarter of the national average for China (Fan et al., 2011). Kaul and Liu interviewed rural households in three counties in Jiangxi, Hunan, and Inner Mongolia provinces in 1988 and found that larger families have lower per capita energy use for certain types of energy (Kaul and Liu, 1992). Van Groenendaal and Gehua surveyed rural households in Gansu and Sichuan in 2006 and found that there is no significant difference in electricity use between households that have biodigesters (biogas) and those that do not (Van Groenendaal and Gehua, 2010). Li, Chen, and Li surveyed rural households in two Gansu districts, Tongwei and Qin'an in 2005, which are directly to the southwest of Anding district the area studied for this research. Li et al. found that on average each household used about 200 kW-hours (kWh) electricity annually or approximately 96 kWh for lighting and 104 kWh for appliances. Their research considers primary sources of CO_2 emissions in rural households (Li et al., 2009). This paper considers secondary CO_2 emissions from household electricity use specifically for lighting.

The average annual household electricity consumption for lighting in the Anding district households surveyed was found to be 123 kWh.

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This value is significantly higher than what Li et al. found for lighting electricity use (96 kWh) for the two districts either adjacent or near to Anding district. Li et al. conducted their survey in 2006; it is possible that the economic growth over those years might explain some of the differences in average lighting use. Nationally in China an average of 370 kWh electricity is used annually per capita (United Nations Statistics Division, 2010; IEA, 2011). Using the assumption that about 12% of electricity use goes to lighting (Liu, 2012), that means that on average about 44 kWh of electricity is used per person annually for lighting in China. Annual average per capita electricity use for kWh for the Anding district was well below this value ranging from 10 to 30 kWh. The average per capita lighting use calculation depends on the time of year and whether to consider lighting usage for the number of people living in the house or by the number of persons and percentage of the year that they lived in the household. Many Anding district families have members who mainly live and work in urban areas returning home for a short period of the year. The difference between the national average and Anding district average for lighting kWh is not very surprising given the relative low average number of light bulbs, between 1 and 2, found in each room in the surveyed households (Fig. 8). Urban dwellers are more likely to have greater numbers of light bulbs in their homes, effectively raising the average kWh used for lighting annually in China.

Why lighting matters

Improving the energy efficiency of lighting always appears to be a smart decision. The United Nations Environment Program (UNEP) identifies lighting as an important focus for the following reasons:

– Lighting electricity use accounts for about 15% of worldwide electricity use;
– Lighting electricity emits nearly 5% of CO_2 equivalent emissions; and
– Making changes to lighting can save an estimated \$140 billion U.S. dollars and 580 million tons of CO_2 emissions (UNEP GEF, 2013).

Furthermore UNEP has created the Global Efficient Lighting Partnership Program to eliminate the use of inefficient incandescent light bulbs by 2016 (UNEP GEF, 2013). These efforts point to the importance of lighting towards CO_2 emission reduction goals. Changing lighting technology is often seen as low hanging fruit for CO_2 emission reduction. Compared to other technologies, with lighting there are fewer social, technological, and economic barriers to changes. However some policies and efforts reduce CO_2 emissions from lighting electricity use more than others. This research seeks to uncover the behavioral context that lighting is used by rural household members to reveal where the greatest electricity savings can be found for a specific area.

Research questions

This research illuminates what role changing lighting has in affecting CO_2 emission reduction goals for the rural poor in northwestern China. Three areas are considered: behavior and technology options for reducing household CO_2 emissions; lighting uses in different rooms in houses; and lighting use at different times of year (characterized as summer and winter). The following research questions were investigated:

1. CO_2 emission reduction options: What user behavior and technology options are feasible for rural Anding households to change lighting electricity use?
2. Lighting in household rooms: How does lighting use and lighting technology compare between household room types?
3. Seasonal lighting use: Do households use lighting in different rooms and for different time periods in the summer and winter?

Methods

All of the information about household lighting use in rural Anding district in Gansu province, PR China is based on a household energy survey conducted in August 2010. The survey methodology is described below. Data collected from this survey was analyzed and is presented in Section Results. This data was used in the simplified life cycle assessment (LCA). The LCA method used is also described below.

Survey work accomplished

On July 27th the primary investigator obtained permissions from a Human Subjects Review Committee at the Lanzhou branch of the Chinese Academy of Sciences (CAS) which determined that this research could proceed since the research caused no harm to human subjects involved. A research team of one graduate student at CAS, four university students, and one high school student from the survey region was assembled. Teams of 2 students surveyed houses. Every town was divided into neighborhoods (she). The town Communist party secretary or mayor would provide our research team with each neighborhood's list of residents. These lists included the address of every household. In general, one team would survey a particular neighborhood within a town. A team of students would go to the addresses on the list that corresponded to a certain number, e.g. every house on the list that ended in 3 so 3, 13, 23 etc. If adult members of that household (defined as individuals at least 18 years of age) or if the household residents were not available or willing to participate in the survey, the team would travel to the next or previous house number on the list, e.g. if the 23rd household members were not available or willing to participate the team went to the 24th or 22nd house on the list. A neighborhood leader (shezhang) or resident accompanied each survey team to help them navigate the area. Households can be quite far apart with addresses that were not necessarily clearly marked or in chronological order. Therefore in many of the towns having an accompanier was essential to finding the households on the neighborhood's list of residents.

All potential survey respondents were aware that their participation was voluntary. If the potential respondent was willing to participate, the survey team member writing marks an x as acknowledgement and the other survey team member signs their name as a witness to the survey respondent's agreement to participate. Survey respondents were not asked to sign their own names because of cultural stigma with signing documents, i.e. fear of signing away one's rights.

From July 29th through August 1st, the pilot testing and revision of the survey was accomplished in Shanlin. From August 2nd through 11th, the survey teams surveyed the other 5 towns; Taiping, Guanxing, Chankou, Zhaojiapu, and Sanshilipu (Fig. 1). Depending on the size of the population of the town, the distance between households, access to motorized transit, and the speed of the survey teams, we spent about 2 days in each town to survey households. Answering the survey took approximately 30 min of a respondent's time and no more than 45 min.

Over 2300 households reside in the five towns as a whole. Altogether the research teams surveyed 237 households in 36 neighborhoods at least 10% of households in each town. Additionally, 6 town leaders (party secretaries or mayors) were interviewed about current and future household energy use in their towns.

Data analysis

After we finished surveying households, all survey data was entered into a computer spreadsheet by the survey teams. After the survey forms and spreadsheet had been compared and found to be identical, the survey forms were destroyed to protect privacy of each household responding to the survey. The data was analyzed in aggregate at the town level instead of the neighborhood level in order to protect the privacy of survey respondents.

Fig. 1. Map of research area sites in Anding district, Gansu province.

Simplified life cycle assessment

A simplified approach to life cycle assessment (LCA) was used to assess which changes in energy use technologies and energy utilization behaviors would result in the greatest environmental benefits through energy efficiency improvements. The goal for this LCA was to compare the environmental impact of current energy use for lighting with the predicted "business as usual" future energy use and with scenarios that consider potential changes to energy technologies and energy utilization behavior. Greenhouse gas (GHG) emissions were chosen as the environmental indicator of choice because of current commitments from China to reduce GHG emissions by 2020 (Lan, 2011). The scope of this LCA encompasses the functional unit and system boundary. The functional unit is a year's worth of lighting for all of the 237 households surveyed. The current duration of lighting used, one year, is kept the same in all scenarios. Equivalent lighting technologies were considered as defined by equivalent wattage of energy efficient bulbs to incandescent light bulbs, although the authors acknowledge that energy efficient bulbs may not have the exact same light output as measured in number of lumens as incandescent bulbs. Fig. 2 shows the system boundary reflecting all relevant life cycle stages. The manufacturing, use, and disposal life cycle stages were considered in this simplified LCA due to lack of information available about the other life cycle stages.

The inventory analysis came from multiple sources. For the manufacturing and disposal impacts of light bulbs Welz et al.'s research was used (Welz et al., 2011). Welz et al.'s research breaks down impacts from the life cycle stages mentioned into impacts for fluorescent, compact fluorescent, incandescent (also called tungsten), and halogen light bulbs. Information about the type and wattage of light bulbs and duration of lighting use in different household rooms came from the household energy survey carried out. In the survey, household residents were asked what type of light bulbs they had in each room of their house, and when respondents were answering a picture of each light bulb type was shown to each survey respondent. From the survey results lighting use impacts from mini spiral CFL, spiral CFL, and non-spiral shaped CFL were considered to have the same manufacturing and disposal impacts as the compact fluorescent category in Welz et al.'s research. Fluorescent tube type light bulbs and incandescent light bulbs identified in the survey were considered to have the same manufacturing and disposal impacts as what Welz et al.'s research identified as fluorescent and tungsten light bulbs respectively (Welz et al., 2011). Most conventionally used incandescent light bulbs contain a tungsten filament, which is why Welz et al. call these bulbs tungsten light bulbs. Halogen light bulbs were not readily available at local retail stores for residential applications in the survey area considered and so no data was collected about them. LED lights were slightly more common than halogen light bulbs. However impacts from LED lights were ignored because the watt-hours from LED lights used in the surveyed households (Table 1) were less than 1% of total watt-hours for all types of lights. This low electricity use for LED lights is due primarily

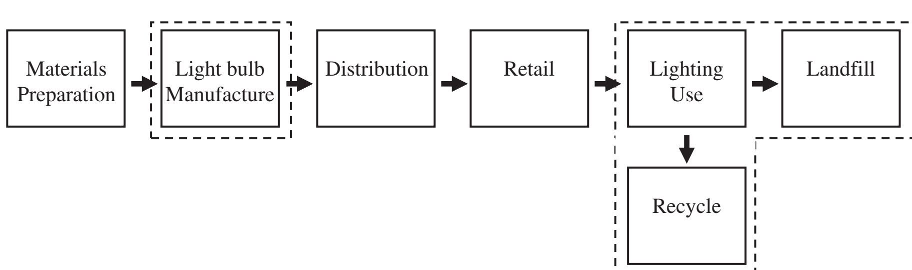

Fig. 2. Light bulb life cycle diagram (life cycle stages considered outlined with dotted boxes).

Table 1
Megawatt-hours electricity used annually by all surveyed households for all light bulb types.

	Total annual MWh
Compact fluorescent	5.8
Fluorescent	6.4
Incandescent	14.7
LED	0[a]

[a] Actually greater than zero, although negligible.

Table 2
Global warming potential CO_2 equivalent factors for key greenhouse gases (Solomon et al., 2007).

	GWP for 100 year time horizon
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_20)	298

to the small number of LED lights in the surveyed households but is also due to LED light bulbs' very low electricity usage.

It should be noted that Welz et al.'s life cycle inventory data and analysis comes from the European Union and specifically assumes adherence to Western European recycling and disposal standards (Welz et al., 2011). Although the recycling standards are not the same in China, in the absence of other recycling and disposal impact data, Welz et al.'s numbers were used. Disposal was by far the smallest impact category, thus it may be slightly understated due to lack of China specific data for light bulb recycling.

In light of China's 2020 GHG emission reduction goals (Lan, 2011), an indicator of environmental performance that tracks GHG emissions was applied to energy reduction possibilities found through the simplified LCA. The global warming potential (GWP) was applied to this research because it is a simple, well-respected, and frequently used method for estimating greenhouse gas impacts (Solomon et al., 2007). The factors used for GWP CO_2 equivalents all came from the 100-year timeline in all calculations (Table 2). Only the three greenhouse gases listed in Table 2, carbon dioxide, methane, and nitrous oxide, were considered in the global warming potential calculations in this paper.

$$GWP_{all} = \sum_1^j (C_i * GWP_i) \quad (1)$$

C_i concentration of greenhouse gas, i, emitted.
GWP_i CO_2 equivalent factor for greenhouse gas, i.
GWP_{all} sum of units' concentration of CO_2 equivalent for all greenhouse gases emitted from i to j.

GHG emission factors (for CO_2, CH_4, and nitrogen oxides specifically) for the manufacturing and disposal life cycle stages came from (Welz et al., 2011), Gansu specific electricity GHG emission factors came from (Ji et al., 2011).

Results

All lighting came from electric sources. Candles, oil lamps and other fuel-based sources of light were not used in the study area (candles are used for ceremonial purposes only). All of the towns studied had had electricity for at least twenty years. The entire Anding district, the rural area where the towns were located, was electrified. The following factors were tracked to see effects to household lighting electricity usage differences: use in different room types, time of use of daily lighting, number of light bulbs per household and per room, seasonal usage, and per capita energy use for lighting.

Terminology and abbreviations

kWh kilowatt-hours.
MWh megawatt-hours.
Peak the highest amount of electricity usage for the day.
CFL compact fluorescent light bulb.

Room types

Fig. 3 shows the number of rooms in each household by type of room. Storage rooms and other types of rooms (responses included chicken coops and garages) were not included in the total. Indoor bathrooms or shower rooms were rare (not all households surveyed had running water inside the house) but included in the number of rooms total for a household, 24 out of 237 households had a shower room. All 237 respondents answered the questions asking about the number of rooms that they have in their home.

The kWh for different room types was compared in Fig. 4. Please note that in the survey the number of light bulbs by wattage and type in a room was collected separately from the time of day and duration that lights were used in that room. Rooms that were not bedrooms,

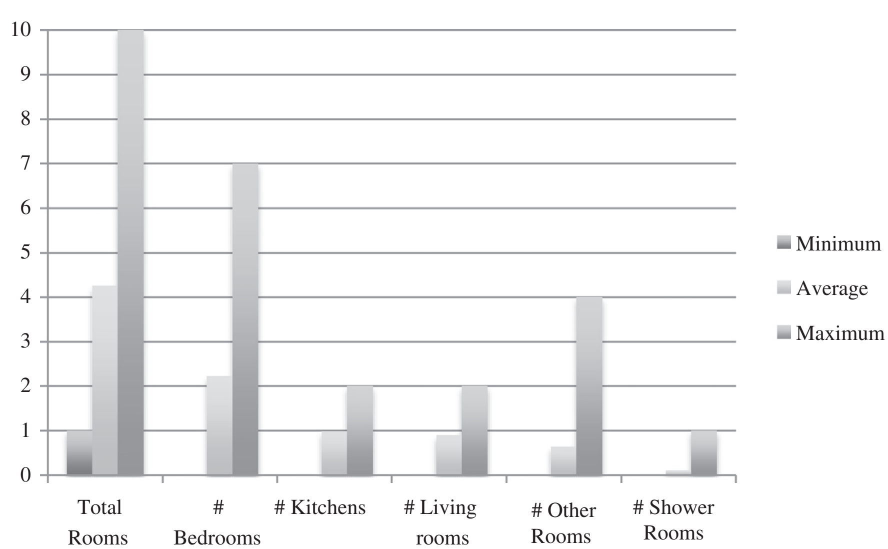

Fig. 3. Minimum, average, and maximum number of rooms in each house by type.

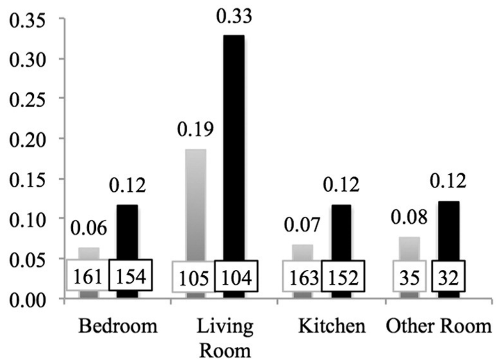

Fig. 4. Average kWh use per room in summer and winter, number of respondents in boxes.

living rooms, or kitchens were reported as having light bulbs under the category "Other rooms." However, the time of day and duration that lights were used were not generally reported. "Other rooms" encompassed a broad range of room types including storage rooms where lighting may only have been used incidentally instead of on a regular basis. We used the time of day and duration values from the Kitchen profile for "Other rooms". The Kitchen lighting duration is one of the shortest duration of all the rooms, which is why we chose to use it for modeling other rooms. Still this assumption may overstate total lighting use in "Other rooms." Most lighting use occurred in living rooms.

Time of use

Fig. 5 shows the overall daily peak for lighting energy use. This chart shows that lighting is primarily used in the evening between the hours of 6 pm and 9:30 pm. The survey results suggest that the winter peak is just under 16.734 kW and occurs at 8 pm, while the summer peak is just over 16.935 kW and occurs at 8:30 pm. Note that the 0 and 24 h were used to denote midnight on the current and next day respectively and that 23 denotes 11 pm.

Figs. 6 and 7 show the summer and winter differences in peak electricity use by room (only the peak period times of day are displayed in the graphs). Winter and summer peaks are close in value and both follow the same time of day trends. Bedrooms have the highest peak value but over a longer period of time, which makes for a flatter peak. Kitchens have an earlier peak of shorter duration, which makes for more of a spike as a peak. Living rooms' and Other rooms' peak uses are both less than bedrooms and kitchens.

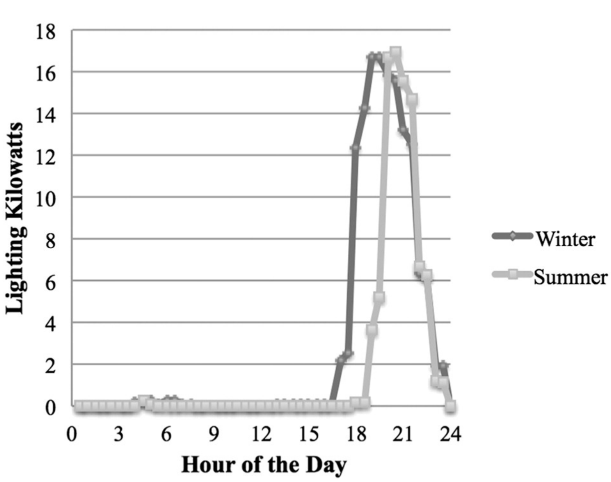

Fig. 5. Time of use lighting usage in kilowatts in summer and winter for all rooms.

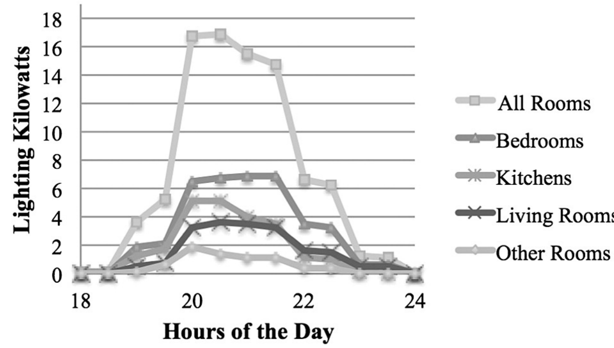

Fig. 6. Time of use summer lighting use by room type in kilowatts.

Light bulbs

Fig. 8 shows the minimum, maximum, and average number of light bulbs for each room. As can be seen, on average living rooms have more than two light bulbs whereas all other rooms have nearly one light bulb per room. Specific households have a large number of light bulbs in a particular room, but not for kitchens, where the maximum number of light bulbs is three. Bedrooms have the greatest percentage of all light bulbs installed in the households (Fig. 9) followed by living rooms.

Fig. 10 shows the total number of light bulbs by type. Table 3 shows the abbreviations for each light bulb type. Incandescent light bulbs are by far the greatest number of light bulbs installed followed by all types of CFLs and then fluorescent tube lights.

Fig. 11 shows the average number of specific types of light bulbs for certain rooms. Certain rooms do not have any number of specific types of light bulbs, e.g. LEDs are only found in bedrooms. Other types of light bulbs are only found in great numbers, such as candle shaped incandescents, which are often found in light fixtures with multiple bulbs. Fig. 12 shows that by far incandescent light bulbs are the most common bulbs in all types of rooms. The most commonly reported wattage for each light bulb type found from responses from survey respondents in the household energy survey is shown in Table 4. It should be noted that survey respondents do not always remember correctly the wattages of the light bulbs in their homes if they know at all. This is a known limitation of allowing survey respondents to self-report wattage values (Dimetrosky, 2013) and is a known source of error in lighting use calculations in this paper. Certain reported values of wattages for types of bulbs seem to be much too high (e.g. CFLs and fluorescent tube light bulbs), resulting in the likely overstatement of electricity use by households in the Anding region. That said, it is still significant that 40-watt incandescent light bulbs are reported to be the most common light bulb found in the surveyed households.

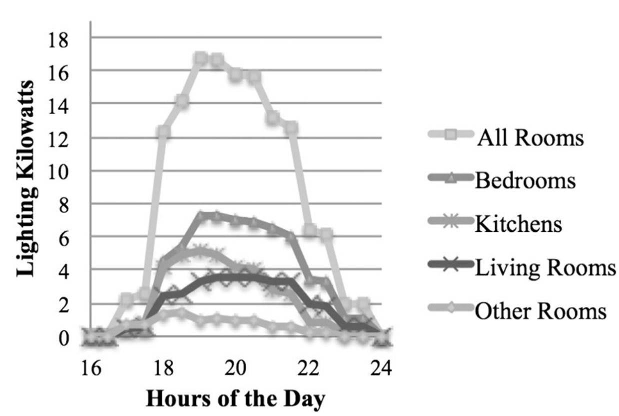

Fig. 7. Time of use winter lighting use by room type in kilowatts.

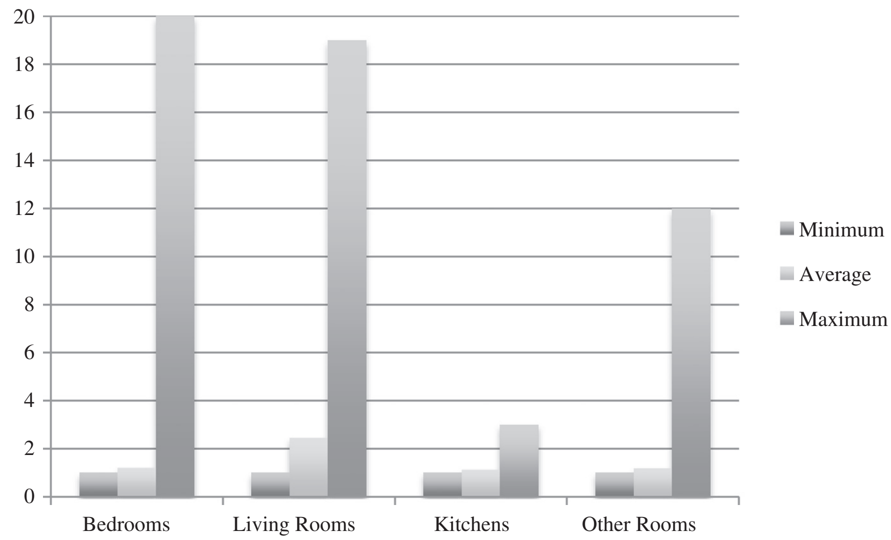

Fig. 8. Minimum, average, and maximum number of light bulbs by room type.

Discussion

The research questions outlined in Section "Findings from household energy surveys in northwestern China" cover the topics of CO_2 emission reduction options, room lighting differences, and seasonal lighting differences. The discussion section will handle each of these topics in the order mentioned.

CO_2 reduction options

Research Question 1: What user behavior and technology options are feasible for rural Anding households to change lighting electricity use?

Lighting user behavior

Changing how residents use electricity in their home is another way to save energy and reduce carbon emissions. Behavioral options for reducing lighting CO_2 emissions focus on reducing: the need for lighting, and the extraneous use of lighting both in physical space and over time. Many user behavior modification options exist to reduce CO_2 emissions, including:

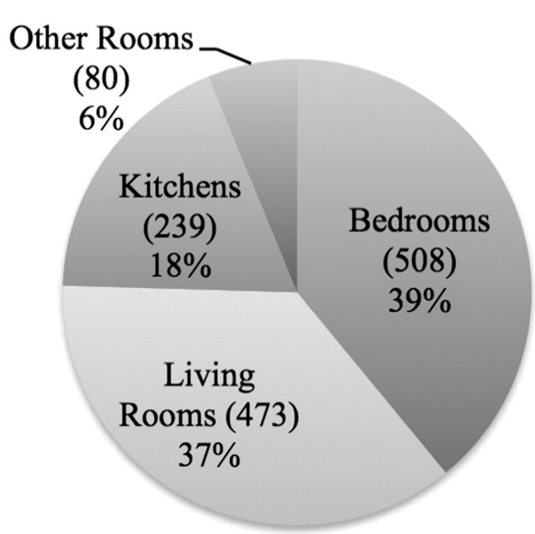

Fig. 9. Total number of light bulbs in parentheses and percentage of total for all households by room.

- Occupancy sensors;
- "Daylight Harvesting" techniques, such as:
  - 3 way bulbs that can dim when there is more natural light,
  - daylight sensors that dim lights according to natural light available, and
  - retrofitting buildings to allow more daylight into spaces;
- Lighting timers that turn lights off or on at a certain time each day;
- Install task lighting;
- Clean lighting fixtures to improve light output and extend light bulb life;
- Paint interior spaces with light colors that reflect light; and
- Turning off lights when not in use (Carbon Trust, 2014).

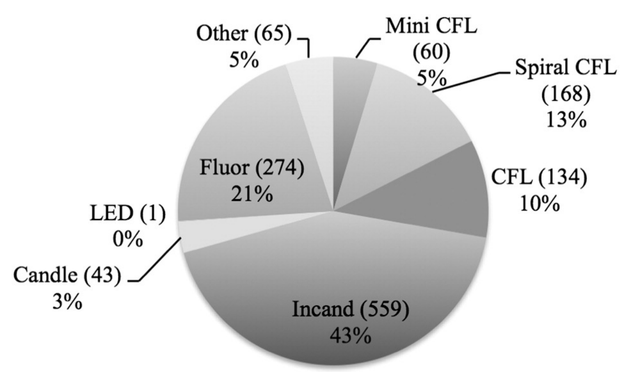

Fig. 10. Total number in parentheses and percentage of all by light bulb type.

Table 3
Types of light bulbs and their abbreviations.

Survey light bulb type	Abbreviation
Mini spiral CFL	Mini CFL
Spiral CFL	Spiral CFL
Non-spiral CFL	CFL
Incandescent	Incand
Candle shaped incandescent	Candle
LED	LED
Fluorescent tube	Fluor
Other	Other

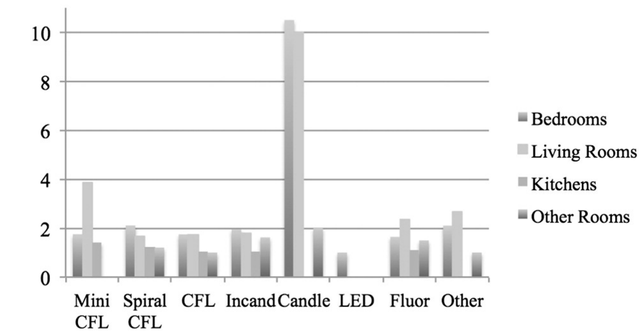

Fig. 11. Average number of light bulb types per household by room.

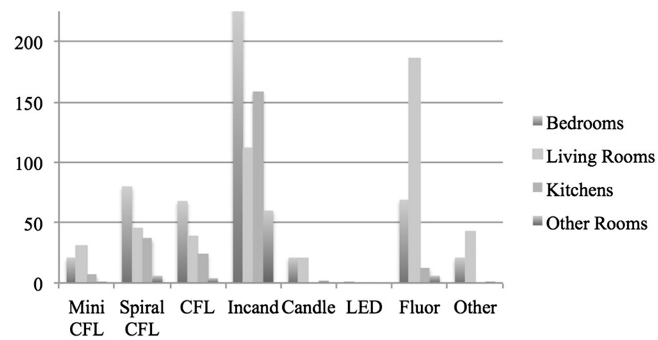

Fig. 12. Total number of light bulbs for all households by room.

Occupancy and daylight sensors, building retrofits to increase daylighting, and installing task lighting are expensive options and so were considered as unfeasible for Anding households. Painting to reflect light and cleaning light fixtures would improve lighting differently depending upon the design of each house and room and the placement and type of light fixtures. Thus, the CO_2 emission reductions possible through these two types of changes seem too complicated to generalize to the entire Anding district. Using lights for shorter amounts of time during the day, e.g. turning off lights when no one is in a room, is a simple and no cost way to save energy. We assumed that as compared to lighting use described by the survey, all lights in every household could be used for 10 min less each day in 2020. In total, 1.74 tons of CO_2 equivalent emissions could be reduced for a total of 1.75 MWh electricity saved annually (Table 5).

Energy efficient lighting technologies

Technology options for reducing lighting CO_2 emissions most often involve swapping out light bulbs. More efficient light bulbs span a variety of technologies including incandescent (tungsten and tungsten halogen light bulbs), discharge (fluorescent light bulbs), and solid-state (LED light bulbs). In the Anding district at the time of the household energy survey, fluorescent light bulbs were readily available for purchase as were battery powered lamps or flashlights using LED light bulbs. Only compact fluorescent light bulbs (CFLs) would be able to replace conventional incandescent tungsten light bulbs in light fixtures since energy efficient incandescent and solid-state light bulbs were not available for easy purchase by Anding residents. Thus the energy technology substitution considered was to replace incandescent light bulbs with CFLs by 2020. It was assumed that 40, 60, 75, and 100-watt incandescent bulbs can be replaced with 10, 15, 20, and 29 W CFLs. Table 6 shows the total number of incandescent bulbs that can be replaced with CFLs in the Anding district households surveyed. In total more than 6.40 tons of CO_2 equivalent emissions can be reduced annually for the households surveyed by avoiding the use of more than 6.44 MWh of electricity when switching incandescent bulbs to CFLs (Table 7).

Future energy use in Anding district

The future of energy for each of the towns surveyed was discussed with town mayors and party secretaries. None of the leaders mentioned any specific predictions for use of lighting. The leaders did mention other expected energy use trends such as: greater acquisition of appliances such as solar water heaters, refrigerators, and washing machines and changes in the type of fuel used for heating. However, energy use, even for lighting, tends to increase with increased economic development and increased wealth (Dzioubinski and Chipman, 1999). Thus some growth in lighting use can be expected in the future. The International Energy Agency (IEA) predicts an average growth rate in electricity use in China of 5.3% from now until 2035 (Cheung, 2011). Compared to other sources the IEA has much more conservative growth predictions for electricity demand (Kahrl and Roland-Holst, 2006). Thus we assumed a 5.3% increase in lighting use over a ten-year period ending in 2020. This assumption is not unreasonable, often survey respondents said that they only had one light bulb in a single room — more well off households might have more than one bulb or a light fixture with multiple bulbs in a particular room.

In addition to trends that show increases in lighting energy use over time, population affects total energy use. Relocation patterns in China mirror worldwide trends as China becomes rapidly more urban while rural residents move into cities. This trend is also exhibited in the Anding district as some of the households surveyed had family members that lived much of the year in other areas. However, how much population may change in 2020 is not clear, and thus any energy use changes for lighting due to population changes were ignored. Population was assumed to remain the same during the time period from 2010 to 2020 for this analysis.

Environmental impact comparison to status quo

The scenarios that describe possible CO_2 equivalent emission reductions from energy technology and energy use behavior changes were compared with the current (2010) and future (2020) status quo use of electricity for lighting. Table 8 shows that the greatest energy savings and CO_2 equivalent emission reductions are possible from energy

Table 4
Light bulb types and most commonly reported wattage by type.

	Range of reported wattages	Range of typical wattages sold	Most commonly reported wattage (MCW)	# of bulbs with MCW	% MCW bulbs of total bulbs	Total # bulbs of this type
Mini CFL	7–100	5–26	40	14	21%	66
Spiral CFL	8–65	5–26	40	46	27%	171
CFL	5–156	11–42	15	32	21%	153
Incand	5–100	40–100	40	200	35%	576
Candle	20–40	25–60	20	4	9%	43
LED	25	5–22.5	25	1	100%	1
Fluor	15–120	8–39	40	99	35%	281
Other	10–120		40	12	15%	78
All types	5–156		40	386	28%	1369

Table 5
Annual GHG reductions achieved from using lights 10 min less each day.

	Average daily summer hours	Annual summer MWh savings	Average daily winter hours	Annual winter MWh savings	Total annual MWh savings	Total CO_2 equivalent reductions (tons)[a]
Bedroom	1.90	0.30	3.34	0.30	0.60	0.59
Living room	1.95	0.27	3.39	0.29	0.56	0.55
Kitchens	1.35	0.22	2.43	0.21	0.43	0.43
Other rooms	1.35	0.09	2.43	0.07	0.16	0.16
Total	1.64	0.88	2.90	0.87	1.75	1.74

[a] Assuming that 0.99 kg CO_2 is emitted per kWh or 0.99 tons CO_2 is emitted per MWh based on an emission estimate for Lanzhou which comes from Ji et al. (2011).

technology changes, in this case swapping out incandescent light bulbs for CFLs. This finding agrees with the general consensus that replacing incandescents is one of the first things to do to save energy. These results also highlight that carbon emission reduction policy resources for the Anding district targeting lighting electricity use should focus on incentives for rural households to replace incandescents before pursuing energy use behavior modifications. For other impoverished areas like the Anding district, although these findings cannot be assumed to be generalizable across other energy end uses and geographic areas, the technological solution may provide the greatest carbon emission reduction improvements instead of focusing on changing end user behavior and habits.

The scenarios described in Table 8 only consider the impact of electricity or the use life cycle stage. In addition to electricity use, the environmental impact of the manufacture and disposal of the light bulbs was considered. The production of lighting fixtures also has impacts, but the fixtures are more likely to stay with the house whereas light bulbs will eventually need to be replaced.

As can be seen from Tables 9 and 10, the environmental impact in the form of the GWP is the greatest for the use life cycle stage. The manufacturing and disposal life cycle stages are much smaller than the use life cycle stage's CO_2 equivalent emissions. These results emphasize that the most important changes in reducing lighting CO_2 equivalent emissions are to reduce the amount of electricity used. Comparing the energy technology and use changes considered, switching technologies from incandescent light bulbs to CFLs is by far the most effective method to reduce lighting electricity use. This switch's effectiveness is simply due to CFLs' lower wattage for similar luminosity output in comparison to incandescent light bulbs.

Table 11 shows the annual lighting use reported by the surveyed households in the Anding district. Environmental impacts for lighting use in terms of CO_2 emissions are much greater in the winter. This finding makes sense because of the reduced hours of natural light that occur during the winter in the Anding district.

Lighting in household rooms

Research Question 2: How does lighting use and lighting technology compare between household room types?

The greatest savings in Anding households reside in making changes to bedroom lighting. Residents tend to light bedrooms and living rooms for more time than other rooms in the houses (Table 6). Anding district household has on average more than 2 bedrooms and on average slightly less than one living room (Fig. 3). In total there are 469 bedrooms versus 210 living rooms in the surveyed households (this does not include rooms that serve multiple purposes such as kitchens or living rooms that also serve as bedrooms). Thus Anding residents use lighting in bedrooms for the most hours as compared to other rooms.

In terms of lighting technology (i.e. light bulbs) present in rooms, most of the incandescent bulbs that could be replaced are located in bedrooms and kitchens (Table 11). The findings for the number of hours that each type of household room is lit (user behavior) and the rooms that have incandescent light bulbs that could be replaced in households both suggest that focusing on making changes to the

Table 6
Number of incandescent light bulbs that can be replaced with CFLs.

Incandescent bulb wattage	CFL wattage	No. of bulbs that could be replaced
40	10	265
60	15	93
75	20	1
100	29	28
	Total	387

Table 7
Annual GHG reductions achieved from replacing incandescents with CFLs.

	No. of bulbs that could be replaced	Annual summer MWh savings	Annual winter MWh savings	Total annual MWh savings	Total CO_2 equivalent reductions (tons)[a]
Bedroom	146	0.95	1.53	2.48	2.47
Living room	85	0.61	0.72	1.32	1.32
Kitchens	111	0.73	1.24	1.97	1.96
Other rooms	45	0.29	0.38	0.67	0.66
Total	387	2.58	3.86	6.44	6.40

[a] Assuming that 0.99 kg CO_2 is emitted per kWh or 0.99 tons CO_2 is emitted per MWh based on an emission estimate for Lanzhou which comes from Ji et al. (2011).

Table 8
Current and future environmental impacts compared with potential change scenarios.

	Total MWh	CO_2 equivalent emissions (metric tons)[a]
Current (2010)	27.73	27.57
Current + technology changes	21.29	21.16
Current + use changes	25.98	25.83
Future (2020)	29.20	29.03
Future + energy technology changes	22.42	22.28
Future + energy use changes	27.36	27.20

[a] Assuming that 0.99 kg CO_2 is emitted per kWh or 0.99 tons CO_2 is emitted per MWh based on an emission estimate for Lanzhou which comes from Ji et al. (2011).

Table 9
Current environmental impacts (in kg CO_2 equivalents) for different scenarios over the life cycle.

Carbon emissions (kg CO_2 equivalents)	Current (2010)	Future (2020)	Current + technology changes	Current + use changes
Manufacturing[a]	0.04	0.04	0.04	0.04
Disposal[a]	0.0[c]	0.0[c]	0.0[b]	0.0[c]
Total	0.04	0.04	0.04	0.04
Use[b]	27,567	29,028	21,163	25,830
Entire life cycle	27,567	29,028	21,163	25,830

[a] These estimates come from Welz et al. (2011); each incandescent, fluorescent, and compact fluorescent bulb documented in the household energy survey was assumed to be the same type of bulb as described by Welz et al. Differences in wattage were ignored for manufacturing and disposal impacts only.
[b] Assuming that 0.99 kg CO_2 is emitted per kWh or 0.99 tons CO_2 is emitted per MWh based on an emission estimate for Lanzhou which comes from Ji et al. (2011).
[c] Actually greater than zero.

Table 10
Future environmental impacts (in kg CO_2 equivalents) for different scenarios over the life cycle.

Carbon emissions (kg CO_2 equivalents)	Current (2010)	Future (2020)	Future + technology changes	Future + use changes
Manufacturing[a]	0.04	0.04	0.04	0.04
Disposal[a]	0.00[c]	0.00[c]	0.00[c]	0.00[c]
Total	0.04	0.04	0.04	0.04
Use[b]	27,567	29,028	22,285	27,199
Entire life cycle	27,567	29,028	22,285	27,199

[a] These estimates come from Welz et al. (2011), each incandescent, fluorescent, and compact fluorescent bulb documented in the household energy survey was assumed to be the same type of bulb as described by Welz et al. Differences in wattage were ignored for manufacturing and disposal impacts only.
[b] Assuming that 0.99 kg CO_2 is emitted per kWh or 0.99 tons CO_2 is emitted per MWh based on an emission estimate for Lanzhou which comes from Ji et al. (2011).
[c] Actually greater than zero.

lighting use and technology in bedrooms would have the greatest impact on CO_2 emission reductions for Anding households at 3.06 tons CO_2 equivalents reduced if both measures characterized in Tables 5 and 7 were implemented.

Seasonal light use

Research Question 3: Do households use lighting in different rooms and for different time periods in the summer and winter?

Fig. 4 shows that a greater number of kWh is used in all household rooms in the winter. This increased kWh corresponds directly to more hours of lighting use in the shorter days and longer nights of winter. Summer and winter total kilowatt-hours for each room type per room were compared (Fig. 4) using the Wilcoxon rank sum test since the data is not normal. Each room showed a significant difference between medians for summer and winter values ($p < 0.0001$). Differences between room types were compared, when comparing all rooms the Kruskal–Wallis test found that the medians differ for both summer and winter ($p < 0.0001$). When considering the pairs separately using the Wilcoxon signed rank test on each pair of rooms some rooms potentially have the same medians. This finding suggests that kitchen and living room lighting use may be similar.

Regarding seasonal daily peaks in lighting electricity use, the winter peak tends to start earlier than the summer peak for households: the winter lighting electricity use peak ranges between 6 pm and 9:30 pm (Fig. 7), while the summer peak tends to occur slightly later between 8 pm and 9:30 pm (Fig. 6). Figs. 6 and 7 show that in general for all rooms, the winter lighting use peak is slightly higher than and of a longer duration (7 pm–9 pm) than the summer peak that is of shorter duration (from 8 pm to 9 pm). These results make sense because of increased darkness and need for lighting during the winter months. Similarly the peak lighting usage in specific rooms is of longer duration in the winter than in the summer; bedrooms have the consistently highest peak value. This finding further confirms that focusing lighting energy efficiency efforts on bedrooms could create the most significant household lighting CO_2 emission reductions in the Anding households surveyed.

Table 11
Annual average and annual total GHG impacts for households' lighting usage.

	Annual average kWh	Annual average CO_2 emissions kg[c]	Total kWh	Total CO_2 emissions kg[c]	No response or no use[a] (total # households)
All	120	119	27,732	27,566	6 (237)
Summer[b]	45	45	10,132	10,071	14 (237)
Winter[b]	78	77	17,600	17,495	10 (237)

[a] Households with no use or no response were not included in the calculation of the average.
[b] Respondents gave daily summer and winter values for lighting use which were multiplied by 182 and 183 days respectively to get the annual summer and winter lighting kWh totals.
[c] Assuming that 0.99 kg CO_2 emitted per kWh is an estimate for Lanzhou which comes from Ji et al. (2011).

Conclusions and summary

This research discusses findings about lighting electricity use for a rural household energy survey carried out in Anding district, Gansu, PR China in 2010. 237 households in 5 towns in the Anding district were surveyed totaling over 10% of households in each town. These data were analyzed using a simplified LCA that considered energy efficiency options available to the rural households surveyed. Specifically the LCA compared energy technology and possible energy utilization changes for households in this rural area. The potential of these changes for reducing GHG reductions was used to compare effectiveness of these possible changes and to recommend the best options for this area. By far the most effective option for reducing greenhouse gas emission reductions was found by replacing incandescent light bulbs with CFLs. Reductions in CO_2 equivalents of 23% over current (2010) GHG emission values or over 27% of future (2020) predicted GHG emission values area achievable when replacing incandescent light bulbs with CFLs. Within households, the greatest lighting electricity use is found in bedrooms. Specifically focusing efforts to change light bulbs in bedrooms results possibly in over 38% of CO_2 equivalent emission reductions. Replacing light bulbs seems to be a very simple and straightforward solution to GHG reduction goals that could work in many other rural areas besides Anding district. Although some energy efficiency efforts in urban areas and for buildings in particular focus on modifying user behavior to reduce lighting energy use, for impoverished rural areas simply incentivizing the switch to energy efficient technologies may be the most effective carbon emission reduction policy strategy. Additionally, knowing which rooms in a household to target for light bulb replacement can improve the energy efficiency gains of any policies where finite funding available targets where the greatest gains can be made. In light of China's goals of reducing carbon intensity in 2020 by 40 to 45% of 2005 values, replacing incandescent light bulbs with CFLs emphasizing changing bedroom lights is a sound approach to meeting these goals. CFLs have a higher initial purchase price than incandescent bulbs, although lower energy costs for lighting over the bulb lifetime. The specifics of how to successfully promote rural residents adoption of CFLs and other energy efficient technologies in Anding district (and other parts of rural China) is an area for future research that may lead to actionable policy recommendations.

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