CARBON EMISSION ASSESSMENT OF AN URBAN COMMUNITY

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Abstract. This study constructs a community carbon emission assessment system based on the greenhouse gas emissions inventory of the Intergovernmental Panel on Climate Change (IPCC). The system contains three activities, namely, building service, transport, and waste treatment and disposal. A street community in Ya'an, Sichuan, China is taken as a typical case for the study, and its carbon emissions during 2015–2017 are measured to demonstrate the practical application of the proposed assessment system. The results indicate that electricity consumption, transport, and natural gas consumption contribute the most carbon emissions in the community, accounting for 40.3%, 25.6%, and 25.1% of the total emissions on average over the 3 years. The study has policy implications for low carbon consumption, and thus, can promote sustainable community development. Limitations regarding the measurement are given to lay the foundations for future research.
Keywords: *IPCC inventory, building service, transport, waste disposal, sustainable development*

Introduction

Residential living is a notable source of carbon emissions, accounting for about 30% of global emissions (Natarajan et al., 2011; Xu et al., 2015). In urban communities, which act as spaces for daily residential life, carbon emission assessment is an effective way to identify the most carbon-intensive sector and to provide insight into emissions reduction and energy savings, thereby promoting low-carbon development (Kennedy et al., 2009).

Carbon emission assessment for households has been discussed by a number of studies. Kenny and Gray (2009) established a metabolism model for urban households to measure their carbon emissions from the perspectives of energy consumption and waste disposal. Using this model, Christen et al. (2011) further incorporated transport, building usage, and food into the assessment of carbon emission. The results were compared with actual emissions monitoring results to validate the model. Kellett et al. (2013) improved the emission model based on the theory of carbon balance. However, the indirect carbon emissions associated with residential activities were omitted. Life cycle assessment (LCA), an emerging environmental assessment tool, can effectively measure the environmental impact of a product or service at all stages of its life cycle (Hellweg and Canals, 2014). The application of LCA is effective in revealing the embodied carbon emissions from household activities, thereby allowing holistic carbon accounting (Jones and Kammen, 2011). For example, Cuéllar-Franca and Azapagic (2012) used LCA to measure the carbon emissions from three types of common residences in the United Kingdom. Heinonen et al. (2013) applied LCA to dividing the boundaries of household activities into 12 categories to measure their carbon emissions. Wang et al. (2015) coupled LCA with input–output analysis to measure the indirect carbon emissions from household consumption. A similar approach was implemented by Miehe et al. (2016), who assessed the carbon emissions of households to determine their spatial heterogeneity.

Ding et al. (2019) employed process life cycle assessment (PLCA) to measure direct and indirect carbon emissions by China's households.

However, carbon emission assessment of urban communities is scarcely considered in relevant literature. Although LCA is an insightful method for carbon emission assessment, it is difficult for unpractised engineers or designers to use owing to its complexity in the division of the system's boundary, and the acquisition of available data (Chen and Corson, 2014; Zhao et al., 2018a). In such a context, there have been requests for a simplified method to facilitate implementation of assessment in managerial practice, thus to help decision-makers better understand the assessment results and their associated decomposition (Zhang et al., 2018).

The present study aims to fill this gap by applying an assessment to community carbon emissions of various sectors based on the greenhouse gas (GHG) emissions inventory of the Intergovernmental Panel on Climate Change (IPCC), including direct and indirect emissions. Yucheng District in Ya'an City, Sichuan Province, China is taken as the case region for the assessment, owing to its progress in the development of a low-carbon community. The sector with the largest carbon emission in the area is identified, in order to develop policy implications for the creation of low-carbon lifestyles, thereby promoting sustainable regional development.

Methods and data

The Kyoto Protocol classifies carbon emissions into three categories, namely: (1) direct emissions from fossil fuel combustion; (2) indirect emissions from energy consumption, such as power use, cooling, and heating; and (3) emissions from a product or service (Andrew and Cortese, 2011). As households consume various categories of products or services, it is difficult to determine their emissions levels (Fan et al., 2012). Hence, this study mainly focuses on the carbon emissions from use of buildings, transport, and waste disposal within a community. These activities define the emissions boundary for the community, as shown in *Figure 1*.

Carbon emissions measurement

Carbon emissions are GHG emissions measured by carbon dioxide equivalent (Lin et al., 2013a; Zhao et al., 2017). The carbon emission of an urban community is measured as follows (IPCC, 2006):

$$E_i = L_i \times EF_i \times PV_p \quad \text{(Eq.1)}$$

where E_i is the carbon emissions from the i-th activity, L_i represents the i-th activity level, EF_i denotes the emissions factor corresponding to the i-th activity, and PV_p is the global warming potential of the p-th GHGs, where CO_2 (PV_1), CH_4 (PV_2), and N_2O (PV_3) are 1, 28, and 265, respectively.

The direct carbon emissions (E_1) produced by fossil fuels consumptions are calculated as follows (Ou et al., 2010):

$$E_1 = \sum_j (A_{1j} \times LC_j \times CC_j \times OC_j) \times \frac{44}{12} \times PV_1 \quad \text{(Eq.2)}$$

where A_{1j} refers to the consumption of the j-th fuel (kg), LC_j is the lower heating value of the j-th fuel (kJ/kg), CC_j is the carbon content per unit of heating value of the fuel (kg/kJ), and OC_j refers to the oxidation rate (%).
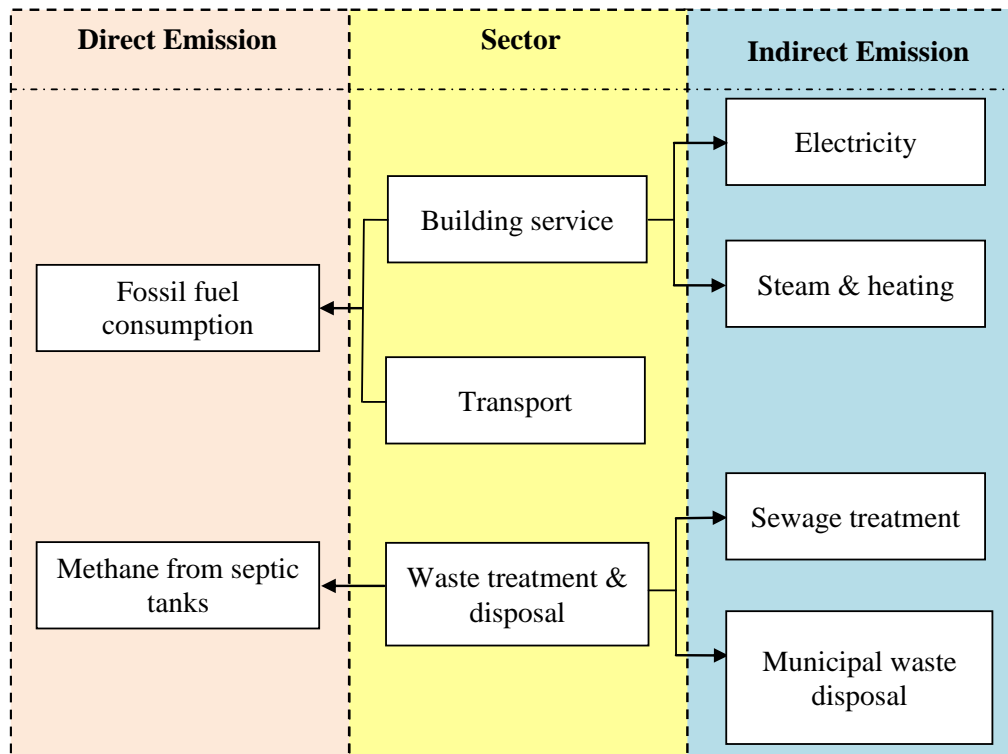
Figure 1. Boundary of an urban community carbon emission assessment system

The direct carbon emissions E_2 from septic tanks, which can be calculated based on the amount of escaped CH_4, are (Diaz-Valbuena et al., 2011):

$$E_2 = \left(A_{2j} \times DOC_j \times \alpha_j - R_{2j}\right) \times \frac{16}{12} \times PV_2 \qquad \text{(Eq.3)}$$

where A_{2j} is the amount of the waste disposed by the j-th septic tank (kg), DOC_j represents the degradable organic carbon content of the j-th septic tank (kg/kg), α_j refers to the disposal rate for the degradable organic carbon in the j-th septic tank (%), and R_{2j} is the amount of recovered CH_4 of the j-th septic tank (kg).

Indirect carbon emissions include emissions from electricity consumption, heating, and waste treatment and disposal. In particular, the indirect emissions from electricity consumption (E_3) are calculated as follows (Bi et al., 2011):

$$E_3 = A_3 \times F_3 \times PV_1 \qquad \text{(Eq.4)}$$

where A_3 is power consumption (kWh), and F_3 is the average emission factor of the regional power grid (kg/kWh).

Indirect carbon emissions from heating (E_4) are calculated as follows (Bi et al., 2011):

$$E_4 = PV_1 \times \sum_j \left(S_j \times t_j \times F_{4j} \right) \tag{Eq.5}$$

where S_j is the residential area by using the j-th type of heating system (m^2), t_j is the time spent using the j-th heating system (h), and F_{4j} is the carbon emission intensity of using the j-th heating system (kg/(m^2·h)).

The carbon emissions from waste treatment and disposal are mainly composed of emissions from sewage treatment and municipal waste disposal. Among them, the carbon emissions from sewage treatment (E_5) are primarily converted from CH$_4$ and N$_2$O, and are calculated as follows (Listowski et al., 2011):

$$E_5 = [(TOW \times B_0 \times MCF_5) - R_5] \times PV_2 + C_N \times F_{N2O} \times 44/28 \times PV_3 \tag{Eq.6}$$

where TOW refers to the total amount of organic matters in the sewage (kg/kg), B_0 is the maximum production capacity of methane (kg/kg), MCF_5 is the methane correction factor, R_5 is the amount of recovered methane (kg), C_N refers to the nitrogen content in the sewage (kg/kg), and F_{N2O} refers to the N$_2$O emissions factor of the sewage (kg/kg).

The nitrogen content C_N in the sewage is calculated as follows (Listowski et al., 2011):

$$C_N = (P \times P_r \times C_{NPR} \times F_{NON-CON} \times F_{IND-COM}) - C_S \tag{Eq.7}$$

where P is the population (person), P_r is the per capita protein consumption (kg/person), C_{NPR} refers to the nitrogen content of proteins (kg/kg), $F_{NON-CON}$ refers to the non-consumption protein factor in the wastewater, $F_{IDN-COM}$ refers to the industrial and commercial protein factor, with a default value of 1.25, and C_S refers to the nitrogen removed from the sludge (kg).

The carbon emissions (E_6) generated from the disposal of municipal waste are measured as follows (Huang et al., 2018):

$$E_6 = (MSW_F \times L_0 - R_6) \times (1 - OX) \times PV_2 + PV_1 \times IW \times CCW \times FCF \times EF \times 44/12 \tag{Eq.8}$$

where MSW_F refers to the amount of municipal waste disposed in landfills (kg), L_0 refers to the methane production potential of the landfills (kg/kg), R_6 refers to the amount of recovered methane (kg), OX is the oxidation factor, IW refers to the total amount of municipal waste treated by incineration (kg), CCW refers to the carbon content of the municipal waste (%), FCF refers to the proportion of mineral carbon to the total carbon of the municipal waste (%), and EF is the combustion efficiency of incinerators (%).

The methane production potential (L_0) of landfills is measured as follows (Huang et al., 2018):

$$L_0 = MCF_6 \times DOC \times DOC_F \times F \times 16/12 \tag{Eq.9}$$

where MSF_6 refers to the methane correction factor of landfills (%), DOC is the content of degradable organic carbon in the municipal waste (kg/kg), DOC_F is the fraction of degradable organic carbon, and F refers to the proportion of methane in landfill gases.

Data sources

This study takes a community in Ya'an city as a case example to assess its carbon emissions from 2015 to 2017. The community was established in March 2002. It covers a total area of 1.8 square kilometers. It consists of administrative departments, vocational and technical colleges, primary schools, shops, and residential quarters. There are a total of 14,311 residents and 835 shops. Through a community survey, the major sources of carbon emissions have been identified, as shown in *Table 1*. Since the community has not established a central heating system, the carbon emissions are measured by electricity and natural gas consumption from household heating.

Table 1. *Identification of sources of carbon emission*

Activity	Emission source	Emission category
Building service	Natural gas consumption	Direct
	Electricity consumption	Indirect
Transport	Gasoline consumption	Direct
Waste treatment and disposal	Waste landfill disposal	Indirect
	Sewage treatment	Indirect

The data corresponding to different activity levels are shown in *Table 2*. The electricity and natural gas consumption of administrative departments, colleges, and primary schools, as well as their gasoline consumption from transport are obtained directly through questionnaire survey. Owing to a large number of households and shops in the community, a sample survey was conducted to obtain the corresponding activity levels.

Table 3 shows the emission coefficients, which are given priority over local emission coefficients, including the lower heating value of natural gas, the ratio of landfill disposal, and the degradable organic carbon content. The remaining emission factors are the default values provided by the Guide of Provincial Greenhouse Gases Inventory.

Results

The assessment results of the community from 2015 to 2017 are shown in *Table 4*. The carbon emissions for these 3 consecutive years are 14,446.69 t, 20,651.10 t, and 26,137.19 t, respectively. It is apparent that the carbon emissions of the community increase gradually, but their contributions differ by source.

From the perspective of carbon emission decomposition, *Figure 2a–c* illustrates that electricity consumptions contribute most of the total emissions during the period 2015–2017, accounting for 40.3% on average. The survey revealed that residents used a large variety of household appliances in their daily lives. In particular, because Ya'an has not implemented a central heating system, residents mainly rely on air conditioners for heating in winter, resulting in excessive power consumption and associated carbon emissions. The emissions caused by transport are the second largest, accounting for 25.6% of the total on average over the 3 years, followed by emissions from gas consumptions (25.1%). The findings are similar to those of Kellett et al. (2013) and Li et al. (2015), indicating that energy consumption and transport are major sources for household carbon emissions.

***Table 2.*** *Activity levels of different emission sources in the case community*

Emission source	Data acquisition	Activity level			Unit
		2015	**2016**	**2017**	
Community population	Capita	9263	12982	14311	person
Natural gas consumption	Consumption	1,603,604	2,808,096	3,604,023	m^3
Electricity consumption	Consumption	10,305,642	15,852,530	20,760,705	kWh
Gasoline consumption	Consumption	1,944,096	2,303,386	2,922,453	L
CH_4 release from sewage treatment	Total organic matter	33.57	33.30	23.59	t
Waste disposal	Yield	3007.8	3363.7	3458	kg
N_2O release from sewage treatment	Per capita protein consumption	25.185			kg/person
	Non-consumption protein factor	1.5			%
	Protein factor in the sewage	1.25			%
	Nitrogen content in proteins	0.16			kg/kg
	Nitrogen removal by sludge	0			kg

Table 3. *Data of emission coefficient*

Emission source		Emission coefficient	Unit	Value	Source
Electricity consumption		Average emissions factor of the regional power grid	kg/kWh	0.5257	NDRC (2014)
Natural gas consumption		Lower heating value	kJ/m^3	34541	Field survey
		Carbon content per unit of heating	kg/kg	15.32	NDRC (2011)
		Carbon oxidation rate	%	99	NDRC (2011)
Gasoline consumption		Lower heating value	kJ/kg	43,070	SAC (2008)
		Carbon content per unit of heating	kg/kg	18.90	NDRC (2011)
		Carbon oxidation rate	%	98	NDRC (2011)
Sewage treatment	CH_4 emission	Maximum production capacity of CH_4	kg/kg	0.6	NDRC (2011)
		Methane correction factor	%	0.165	NDRC (2011)
		Amount of recovered CH_4	kg	0	NDRC (2011)
	N_2O emission	N_2O emissions factor	kg/kg	0.005	NDRC (2011)
Landfill disposal		Ratio of landfill disposal	%	100	Field survey
		Degradable organic carbon	kg/kg	0.1588	Local environmental protection agency
		Methane correction factor	%	40	NDRC (2011)
		Proportion of DOC	%	50	NDRC (2011)
		Proportion of CH_4 to landfill gases	%	50	NDRC (2011)
		Amount of recovered CH_4	kg	0	NDRC (2011)
		Oxidation factor	%	10	NDRC (2011)

Table 4. *Carbon emissions of the case community*

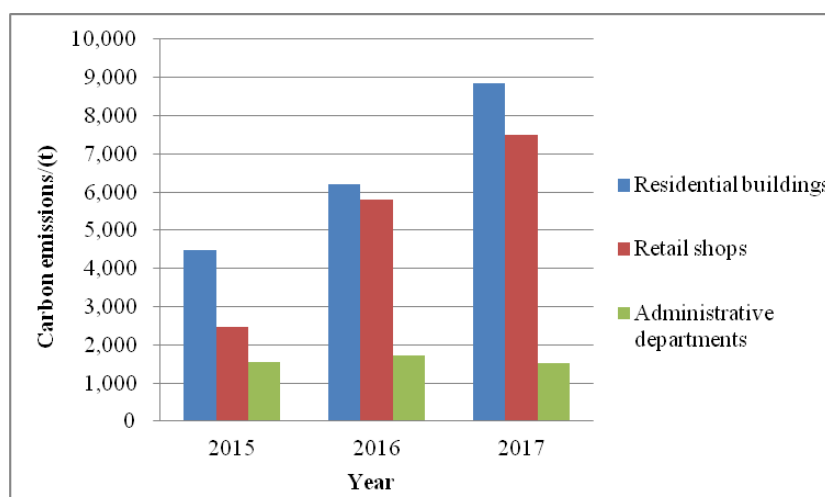| Emission source	Carbon emissions (t)		
	2015	**2016**	**2017**
Natural gas consumption	3,080.34	5,394.03	6,922.92
Transport	4,250.73	5,036.31	6,389.88
Electricity consumption	5,417.68	8,333.68	10,913.90
Municipal waste disposal	1,604.87	1,794.77	1,845.08
Sewage treatment	93.08	92.32	65.41
Total emissions	14,446.69	20,651.10	26,137.19
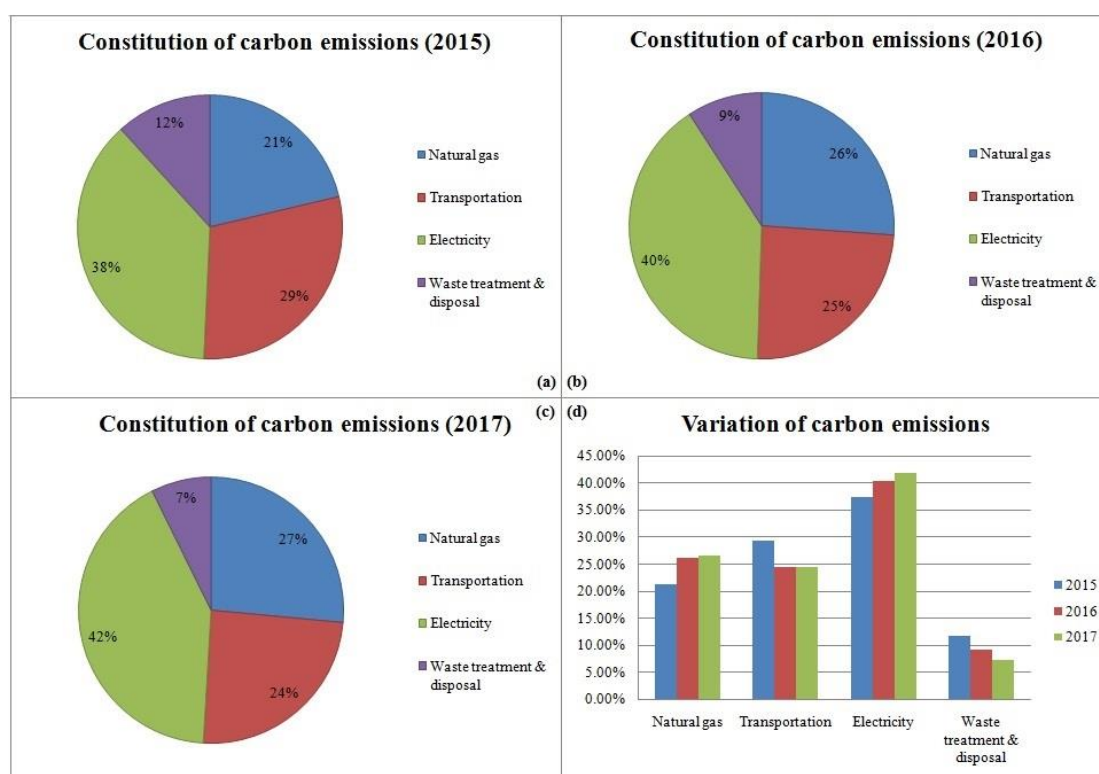
Figure 2. *The constitution of carbon emissions regarding the community*

Figure 2d shows that the proportions of carbon emissions contributed by electricity and natural gas consumptions increase gradually during the period 2015–2017. This may correspond to the population growth in the community. The carbon emissions contributed by transport increase slowly. On the contrary, the proportion of carbon emissions from waste treatment and disposal decreases during the 3 years. This may be the result of the promotion of waste sorting and recycling in the community, thereby reducing the volumes of landfill disposal.

Decomposition of the carbon emissions from building service

The carbon emissions of the community building usage in 2015, 2016, and 2017 are 8,498 t, 13,738 t, and 17,836 t, respectively. *Figure 3* shows that there are primarily three types of community building services that produce carbon emissions, namely,

residential buildings, retail shops, and administrative departments. The emissions of the first two categories increase significantly during these 3 years.

***Figure 3.** Carbon emissions from usage of various buildings*

Decomposition of the carbon emissions from transport

The carbon emissions from transport in 2015, 2016, and 2017 are 4,250 t, 5,036 t, and 6,389 t, respectively, a significant increase, as shown in *Figure 4*. According to the survey, the transportation vehicles in the community are mainly comprised of private cars and business cars, of which the former contribute most of the carbon emissions.
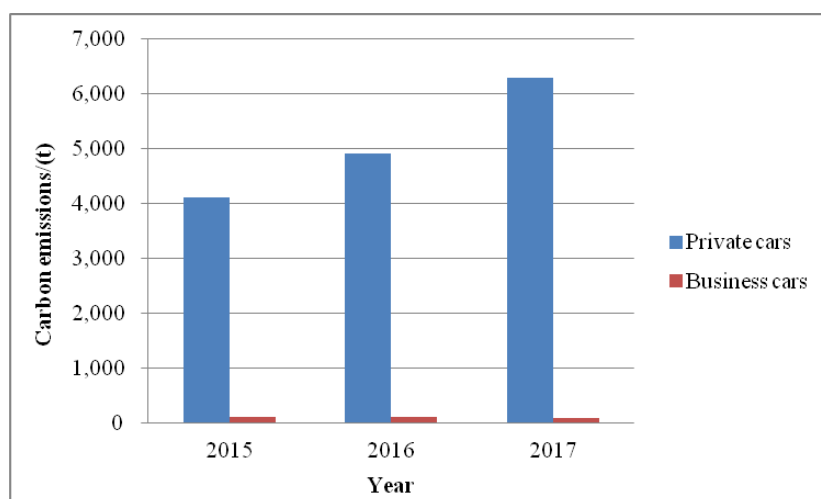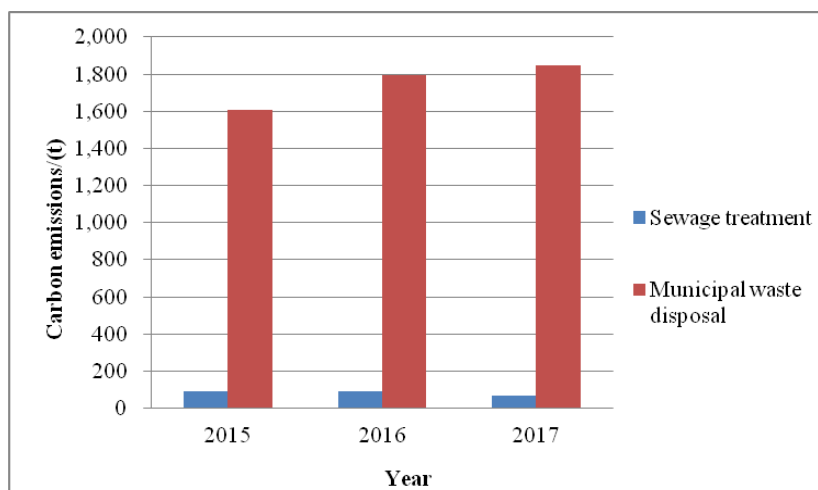

***Figure 4.** Carbon emissions from transport*

Decomposition of the carbon emissions from waste treatment and disposal

Figure 5 shows that the carbon emissions from waste treatment and disposal in 2015, 2016, and 2017 are 1,698 t, 1,887 t, and 1,910 t, respectively. These account for approximately 4.7% of the total carbon emissions from the community. Sewage treatment contributes to less carbon emissions than waste disposal does.

Figure 5. *Carbon emissions from waste treatment and disposal*

Discussion

According to the assessment results, this study finds that electricity consumptions contribute most of the community's carbon emissions. This is similar to the findings of Lin et al. (2013b), indicating that more attention needs to be paid to emissions reduction of power supply. Transport and natural gas consumption account for 25.6% and 25.1%, respectively, of the total carbon emissions in the community, which is in line with the result of Ahmad et al. (2015). However, Büchs and Schnepf (2013) as well as Lee and Lee (2014) concluded that transport produces the most household carbon emissions. This difference may be due to variations in the boundary division, as the latter two studies incorporated long-distance travel of residents into the carbon emissions assessment by transport. Waste treatment and disposal produce a certain amount of carbon emissions, but the contribution is relatively small, indicating that it is not the key emissions source of the community (Kenny and Gray, 2009; Shirley et al., 2012).

Although electricity and natural gas consumptions are important sources of carbon emissions, our field survey reveals that there are huge variations among households. For example, the maximum average electricity consumption is 181 kWh per month while the minimum is only 74 kWh per month, indicating a polarization of carbon emission in the daily lives of households. In addition, there is large potential for emission reduction regarding transport in the community, since the residents mainly choose to use private cars. Thus, public transport can be encouraged through, for example, community buses and shared bicycles to reduce transport carbon emissions.

The research results have policy implications for low-carbon living. This study may provide impetus for the design of a community "carbon credit" incentive program (Zhao et al., 2018b). Through such a policy, the public can obtain credits to offset their carbon footprints through a number of environmentally friendly activities, such as green consumption, low carbon transport, waste sorting, and recycling (Starkey, 2012).

Conclusion

This study applies the IPCC GHG emissions inventory to assess the carbon emissions of a community located in Ya'an City during 2015–2017. The sector that

contributes to the largest emission is identified to propose appropriate policies on implementation of low carbon development. The results show that electricity, transport, and natural gas consumptions are the three largest emission sources, accounting for 40.3%, 25.6%, and 25.1% of the total, respectively. The energy consumption behavior significantly influences the community carbon emissions. Private cars leave large room for transport emission reduction of the community. The carbon emissions of waste treatment and disposal are lower than those of community building service and transport.

This study has certain limitations, mainly reflected in the uncertainties of the assessment results. First, the energy consumptions of shops and households are based upon the sampling estimation. Second, a number of default emission factors are used instead of actual measured values, which may have an impact on the results. Future study should focus on establishing a holistic inventory of emission related activities, and a corresponding emission factor database, to enable dynamic updates on urban community carbon emissions.

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