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Consumer Lifestyle Approach to Quantify CO_2 Emissions Caused by Domestic Washing Clothes

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Abstract

Household CO_2 emissions are gaining more attention from researchers in recent years. Domestic washing is an important household routine and one of the main sources of household CO_2 emissions. In this paper, Consumer Lifestyle Approach (CLA) was used to quantify CO_2 emissions from domestic washing. An investigation of 493 families, from 16 cities out of 8 provinces in China, was held to study the five main household characteristics including the demographic composition, living condition, family income and expenditure, education level and most importantly, laundry habit. The relationship between domestic washing characteristics and CO_2 emissions is concluded from multi-variable linear return analysis. The results show that family's washing frequency as well as washing machine's efficiency and capacity are major factors which affect CO_2 emissions. Other factors such as per capita living space, family working population and education level also have an influence to a certain extent.

Keywords: Domestic Washing; CO_2 Emissions; CLA; Multi-variable Linear Return Analysis

1 Introduction

Severer than ever, humankind is facing a gradual rise in earth's temperature, known as global warming. It is generally believed that global warming is caused by high level of Greenhouse Gases (GHGs), mainly caused by human activities [1]. GHGs consist of carbon dioxide (CO_2), methane (CH_4), etc, among which CO_2 has the largest proportion and highest influence on the environment. Analysis of CO_2 emissions from energy consumption has recently gained more attention from researchers and scholars [2]. At the same time, the influencing factors towards energy use and CO_2 emissions are under extensive research and discussions around the world. Munksgaard, et al. argued that the increase of family expenditure level is one of the main reasons for the growth of Danish CO_2 emissions in 2000 [3]. Indian families' household energy consumption accounted for 75% of the total energy consumption, and the increases in population,

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per capita expenditure and energy intensity are the driving factors in the growth of energy demand [4]. Based on Bin and Dowlatabadi's research, more than 80% of the total energy consumption and CO_2 emissions in the U.S were caused by consumer demand and the related economic activities in 2005 [5]. For South Korea, 52% of the primary energy consumption attributed to household needs in 2007 [6]. In terms of China, Wei, et al. believed that energy demanded by Chinese residents and its corresponding CO_2 emissions were as much as 26% and 30% of the total energy consumption and CO_2 emissions respectively in 2007 [7]. Household CO_2 emissions accounted for more than 40% of China's total CO_2 emissions produced by primary energy consumption in 2011 [8]. Wang, et al. pointed out that the alterations of Chinese family's lifestyles stimulate the increase of household CO_2 emissions significantly. Also, they reached the conclusion that urban families from the eastern coastal part of China have a much higher amount of CO_2 emissions than families in western inland in 2009 [9].

Textiles and clothing are important daily necessities for human beings. Usually, the consumption of these commodities causes large amount of CO_2 emissions. For example, CO_2 emissions generated by Americans' expenditure of clothing were approximately 150 Mt/y in 2004 [10]. According to Zeng, et al., apparel is one of the main sources of CO_2 emissions in Chinese urban families in 2012 [11]. There are typically four methodologies to study carbon footprint and CO_2 emissions, namely Input-output Analysis (I-O), Life Cycle Assessment (LCA), Carbon Footprint Models (CFM) and Consumer Lifestyle Approach (CLA) [12-16]. CLA links various consumer activities to economic activity, energy use and CO_2 emissions together. It is a consumer-oriented synthetical methodology to evaluate energy usage and CO_2 emissions. Consumer refers to an entity that purchase and consume products and services for personal or family motive. Lifestyle refers to the ways people would act under the impact of various consuming behaviors. The final purpose of CLA is to help government design better public policies by understanding consumers. CLA has been successfully utilized on a few research, for instance, Feng, et al. applied CLA to the study of relationship between Chinese residents' lifestyles and CO_2 emissions from domestic appliances, transportation, etc [17]. According to Zeng, et al.'s comments on the CO_2 emissions evaluation systems, the results of CLA-based research are comprehensive and accurate [11]. However, there has been few literature published investigating the CO_2 emissions during the domestic washing phase of clothes using CLA. Therefore, this paper chose CLA to investigate CO_2 emissions caused by domestics washing in Chinese household.

2 Methodology

2.1 CLA Framework

Regarding many interacting factors in consumer lifestyle, CLA attempts to offer an interdisciplinary framework, which explicitly acknowledges the multitude of interacting factors and groups these factors into five aspects: (1) External environmental variable, such as cultural influence and technological development; (2) Individual determinants: factors such as attitude and mentation can influence individual consumer's decisions; (3) Household characteristics: housing size and per capita income, etc; (4) Consumer choices, for example, the choice of an equipment or a service; (5) Environmental consequences of consumer activities, such as the consumption of energy, the production of CO_2 emissions, etc [5].

In this paper, the external environment is set to be urban China's general cultural and techno-

logical background, in accordance with the classification of provinces; the psychological variables are determined through individual questionnaires. In order to study the household characteristics, the questionnaire was designed to include the following facets: demographic composition, living condition, family income and expenditure, education level and laundry habit. The choice of washing equipment (washing machine model) is the major consideration for the variable referred as consumer choices; as the environmental consequences, CO_2 emissions per family and per capita were obtained through the analysis of the above four factors.

Generally speaking, CLA uses two approaches to estimate the direct (on-site) and indirect (embodied) energy use and CO_2 emissions from consumers' activities [5]: (1) direct energy consumption is calculated from actual and estimated fuel use, so that CO_2 emissions can be calculated from the carbon content of the fuel use; (2) indirect CO_2 emissions are acquired using economic data on consumer expenditures and an economic input-output matrix of energy use (and CO_2 emissions). The direct CO_2 emissions are caused by direct household energy consumption (electric energy, water, etc) and transportation, whereas indirect CO_2 emissions are produced during the manufacturing phase of food, clothing and recreation, the indirect CO_2 emissions during housing operation, transportation operation are also included. The subject of this paper is domestic washing (the use phase of clothing). Hence, the research focuses on the direct CO_2 emissions, which are determined by the energy consumptions during the usage of washing machine, dryer and iron, etc. In terms of urban Chinese residents, the majority of households possess one washing machine, while no dryer, at home. Questions regarding ironing frequency were poorly answered during the investigation, for the fact that most families do not use iron, some even never own one. Moreover, according to the answered questions, the ironing frequency is generally very low and people tend to iron their clothes merely for a few minutes each time. Accordingly, this paper concerns about CO_2 emissions generated by washing machines only. All the data involved in this paper were from door-to-door investigation. In the end, the CO_2 emissions (Environmental consequences) during domestic washing were obtained via the analysis of household characteristics, laundry habits (consumer choices and individual determinants), in accordance with different geographic locations (external environment).

2.2 Energy-CO_2 Approach

According to IPCC GHGs emissions list [18], the formula to estimate CO_2 emissions is presented below:

$$C = \sum_{i}^{n} I_i \times f_i \tag{1}$$

where C refers to the equivalent CO_2 emissions; I_i refers to the type of energy consumption and f_i refers to the CO_2 coefficient of different consumptions.

The inputs involved in this paper are electricity ($f_{electricity}$ = 0.96 kg CO_2/kW·h) and water (f_{water} = 0.45 kg CO_2/t). The equivalent CO_2 emissions from electricity consumption, for example, is calculated as the product of electricity consumption (kW·h) and the CO_2 coefficient of electricity consumption (kg CO_2/kW·h). CO_2 emissions are calculated as the sum of equivalent CO_2 emissions caused by electricity and water consumptions.

In order to estimate the average CO_2 emissions per family or per person seasonally and annually, the basic formula can be transformed into four equations. The new formulae for seasonal CO_2 emissions are presented as follows:

The equation for the average CO_2 emissions per family is:

$$C_T = \frac{\sum_{i}^{n}(E_i \times f_E + W_i \times f_W)}{n} \tag{2}$$

The equation for the average CO_2 emissions per person is:

$$C_{p/T} = \frac{\sum_{i}^{n}(E_i \times f_E + W_i \times f_W)}{m \times n} \tag{3}$$

where C_T refers to the average domestic washing CO_2 emissions per family (i.e. C_y is the annual amount of CO_2 emissions. C_{aw} is a seasonal datum representing autumn and winter, while C_{ss} is the other seasonal datum representing spring and summer;) E_i is the electricity consumption (kW·h) during domestic washing, and f_E refers to the CO_2 coefficient of electricity consumption; W_i is the water consumption (t), and f_W refers to the CO_2 coefficient of water consumption; $C_{p/T}$ stands for the average CO_2 emissions per person (i.e. $C_{p/y}$ is the annual amount, and $C_{p/aw}$ represents the seasonal (autumn and winter) amount, while $C_{p/ss}$ is the other seasonal (spring and summer) amount; n refers to the number of households; m refers to the average number of family members in each household.

The numerator of Eq. (2) (and Eq. (3)) is the sum of water and electricity consumptions from every household, for a given period of time (annually or seasonally, as mentioned earlier), in the investigations in eight provinces. Divided by the number of households which were involved, the result shows the average CO_2 emissions per family. Divided by the number of people (calculated as the product of total number of households and the average number of family members in those households) who were involved, the result is the average CO_2 emissions per person.

The electricity and water consumptions are calculated on the basis of the door-to-door investigation regarding household laundry habits, demographic composition, washing machine models, etc. The energy data were collected from the energy rating label, which is attached onto each washing machine manufactured after the year 2004. The labels have information such as washing capacity, water and electricity consumptions per working period, machine model and energy grading level [19]. The annual (seasonal) energy consumptions of domestic washing for a specific family are calculated via the following formula (see Eq. (4)-(5)):

The electricity consumption is:

$$E_i = F_i \times e_i \tag{4}$$

The water consumption is:

$$W_i = F_i \times w_i \tag{5}$$

where E_i refers to the electricity consumption of domestic washing; W_i refers to the water consumption; e_i is the electricity consumption per washing cycle for a given machine model; w_i is the water consumption per washing cycle; F_i refers to the frequency of domestic washing for a specific household, annually or seasonally.

The calculation of electricity consumption, for instance, is the product of electricity consumption per washing cycle (every time a family uses washing machine) (kW·h) and the washing

frequency (eg. 100 times a year; 24 times during spring and summer seasons). As mentioned earlier, e_i can be obtained from energy rating labels, and F_i can be obtained through questionnaires.

2.3 Data Analysis Methodology

SPSS 17.0 software was used to process the data, i.e. multiple linear regression analysis for the supplement of missing values; partial correlation analysis for the selection of influencing independent variables; multi-variable linear return analysis for the final regression models, regarding the relationship between domestic washing CO_2 emissions and the selected independent variables.

Before multi-variable linear return analysis, the selection of independent variables is indispensable. If the not-highly associated variables are chosen, not only can they bring extra workload to further analysis, the accuracy of the analysis will also be affected [20]. Therefore, the process of partial correlation analysis is very necessary. Given that the higher the partial correlation coefficient, the higher the association between the independent variables and CO_2 emissions, influencing variables with low partial correlation coefficient were eliminated.

3 Data

3.1 Data Source

The database was from an investigation of 16 cities out of 8 provinces in China. The questionnaire includes household characteristics and questions concerning laundry habits. The provinces were chosen based on the geographic location in China, including Jiangsu province, Zhejiang province, Jiangxi province in eastern China, Hunan province, Hubei province, Henan province in central China, Hebei province in northern China and Liaoning province in northeast China.

PPS method (Probability Proportionate to Size Sampling) was used to determine the sample size of each province, and the national statistical data were the main reference [21]. Two cities were selected in each province randomly to be the sample cities, and their sample sizes were obtained via PPS method as well. In every city, several communities were chosen randomly for the research team to conduct door-to-door investigations in. The survey was conducted from January to April in 2012.

Table 1: Regression equations of power and water consumption and washing machine types

Washing machine model	Electric energy consumption per washing cycle (kW·h/cycle)	Water consumption per washing cycle (L/cycle)
Semi-automatic pulsator	$Esa_i = -0.056 + 0.022x_i + 0.016y_i$	$Wsa_i = -9.645 + 23.300x_i + 5.545y_i$
Fully-automatic pulsator	$Efa_i = -0.049 + 0.018x_i + 0.021y_i$	$Wfa_i = -23.818 + 20.930x_i + 14.052y_i$
Front-loading	$Efl_i = -0.009 + 0.083x_i + 0.170y_i$	$Wfl_i = -21.460 + 12.015x_i + 12.478y_i$

Note: x_i refers to washing capacity (kg); y_i refers to energy efficiency grade.

3.2 Supplement of the Missing Values

In China, there are three types of widely-used washing machines, namely semi-automatic pulsator washing machine, fully-automatic pulsator washing machine and front-loading washing machine [22]. For washing machines that lose their energy rating labels or do not possess labels in the first place, the consumption of water and electric energy during working cycle can only be obtained from calculation, via multiple linear regression models. The models were built based on exiting data from energy rating labels. The independent variables chosen for the models are washing capacity and energy efficiency grade, which can also be obtained from the labels. The dependent variables are electricity and water consumption per washing cycle. With the help of SPSS 17.0, the models in Table 1 are generated.

4 Results and Discussions

4.1 Sample Characteristics

The basic questions of the investigation questionnaire were designed on the basis of the third aspect of CLA framework: Household characteristics. The questionnaire consists of five parts, namely demographic composition, living condition, household income and expenditure, education level and most importantly, laundry habits, and thirteen detailed questions, such as working population, annual per-capita income, education level, etc. Not all of them will be the final influencing variables, and results of the selection of the independent variables will be discussed later. Altogether 493 questionnaires were obtained during the investigation, providing 493 samples. Table 2 shows the basic information of the 13 questions of the sample families.

The following equation (Eq. (6)) is used to calculate the average education level, as well as the mean age, of a specific family.

$$M_{edu} = \frac{1 \times x_1 + 2 \times x_2 + 3 \times x_3 + 4 \times x_4 + 5 \times x_5}{m} \tag{6}$$

where M_{edu} refers to the average education level (or mean age); m refers to the number of all family members and x_i refers to the number of people in each group.

According to Table 2, the average resident population in each family is 3.27; sex ratio is close to 1; the majority of family members are young or middle-aged; the average education level is high school. Residents' annual per-capita income is approximately 30000 CNY, and about 1500 CNY is spent on purchasing clothes. The most widely used washing machines, as expected, are semi-automatic pulsator washing machine, fully-automatic pulsator washing machine and front-loading washing machine. In terms of laundry habits, the average washing frequency is 129.36 times a year.

4.2 Distinctions between Provinces

4.2.1 Calculation Methods

Average annual household energy consumptions, average annual (or seasonal) domestic washing CO_2 emissions per family and per capita of the eight different provinces are calculated via Eq. (7),

Table 2: Basic information of the sample families

Household characteristics		Minimum	Maximum	Mean	Standard Deviation
Demographic composition	Permanent resident population	1	7	3.27	0.934
	Working population	0	6	2.13	0.749
	Sex ratio (man vs. woman)	0	3	1.18	0.683
	Mean age group	1.5	5	3.01	0.713
Living condition	Per capita living space (m^2)	10.33	100	35.85	12.071
Household income and expenditure	Annual per-capita income	1	8	4.26	1.775
	Annual per-capita expenditure on clothing	1	8	4.65	1.901
Education level	Education level	1	5	3.43	0.787
Laundry habits	Washing machine type	1	3	–	–
	Electric energy consumption per washing cycle (kW·h /cycle)	0.03	1.42	0.42	0.444
	Water consumption per washing cycle (L/cycle)	41	228	102.87	39.327
	Energy efficiency grade (grade)	1	5	2.13	1.073
	Annual frequency of using washing machine (time)	3.04	365	129.36	67.177

Note: In order to process the data in SPSS software, the non-figure elements, namely age group, average education level, annual per-capita income (CNY), annual per-capita expenditure on clothing (CNY), were given virtual assignments, as shown in Table 3.

(8), and (9).

The equations for average annual household electricity and water consumptions are the following:

$$E_{p/T} = \frac{\sum_{i}^{n}(F_i \times e_i)}{n} \quad W_{p/T} = \frac{\sum_{i}^{n}(F_i \times w_i)}{n} \tag{7}$$

The equation for average annual (or seasonal) domestic washing CO_2 emissions per family is:

$$C_T = \frac{\sum_{i}^{n}(F_i \times e_i \times f_E + F_i \times w_i \times f_W)}{n} \tag{8}$$

The equation for average annual (or seasonal) domestic washing CO_2 emissions per capita is:

$$C_{p/T} = \frac{\sum_{i}^{n}(F_i \times e_i \times f_E + F_i \times w_i \times f_W)}{m \times n} \tag{9}$$

where $E_{p/T}$ refers to average annual electricity consumption of domestic washing; $W_{p/T}$ refers to average annual electricity water consumption of domestic washing; C_T refers to average domestic washing CO_2 emissions per family (i.e. C_y is the annual amount of CO_2 emissions. C_{aw} is a seasonal datum representing autumn and winter, while C_{ss} is the other seasonal datum representing

Table 3: Virtual assignments

Age group	Education level	Annual per-capita income (CNY)	Annual per-capita expenditure on clothing (CNY)	Washing machine model	Virtual assignment
≤ 18	Primary school diploma or below	< 10000	< 600	Semi-automatic pulsator	1
19-34	Junior high school diploma	10000-16000	600-900	Fully-automatic pulsator	2
35-45	Senior high / technical school diploma	16001-22000	901-1200	Front-loading	3
46-59	College degree	22001-30000	1201-1500	Stirring	4
≥ 60	Bachelor degree or above	30001-38000	1501-1800	Others	5
—	—	38001-50000	1801-3000	—	6
—	—	50001-100000	3001-4000	—	7
—	—	> 100000	> 4000	—	8

spring and summer); $C_{p/T}$ stands for average CO_2 emissions per person (i.e. $C_{p/y}$ is the annual amount, and $C_{p/aw}$ represents the seasonal (autumn and winter) amount, while $C_{p/ss}$ is the other seasonal (spring and summer) amount; e_i is the electricity consumption per washing cycle; w_i is the water consumption per washing cycle; F_i refers to the frequency of domestic washing; f_E refers to the CO_2 coefficient of electricity consumption; f_W refers to the CO_2 coefficient of water consumption; n refers to the number of households; m refers to the average number of family members in each household.

4.2.2 Calculation Results

For the investigated families, the average annual energy consumptions of domestic washing are: 56.75 kW·h/(family·year) (electric energy consumption) and 13.08 t/(family·year) (water consumption). The CO_2 emission is 60.37 kg CO_2/(family·year). In the aspect of individual consumption, the electricity and water consumed per person every year are 18.68 kW·h/(person·year) and 4.15 t/(person·year) respectively, equated to 19.61 kg CO_2 emissions every year. Energy consumption differs greatly between seasons: CO_2 emissions during Autumn and Winter (AW) seasons are much less than Spring and Summer (SS). The average washing frequency of AW seasons is 23.59 time/season. The average seasonal CO_2 emissions are 11.01 kg CO_2/(family·season) and 3.61 kg CO_2/(person·season). For SS seasons, the frequency is 41.10 time/season, and the emissions are 19.17 CO_2/(family·season) and 6.30 CO_2/(person·season) (see Fig. 1).

There are notable differences in residents' lifestyles among different provinces, so are their laundry habits (see Table 4). Residents in Jiangsu province have the highest washing frequency, 161.63 time/(family·year), more than twice the washing frequency in Liaoning, only 78.46 time/(family·year). From Fig. 2, it is clear to see that Zhejiang province has the highest annual CO_2 emissions: 83.72 kg CO_2/year. Jiangsu province comes the second, by reaching 74.87 kg CO_2/year, followed by Hunan province 74.42 kg CO_2/year. CO_2 emissions from domestic

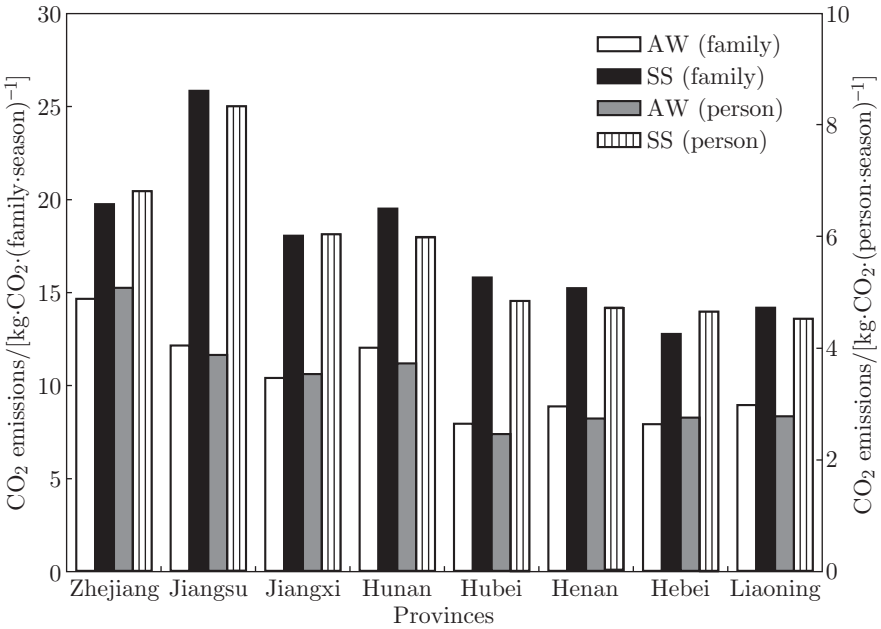

Fig. 1: Seasonal domestic washing CO_2 emissions per family and per capita in eight provinces

Table 4: Laundry habits and inputs in different provinces

Province	Annual frequency of using washing machine (time/(family·year))	Annual domestic washing electricity consumption (kW·h/(family·year))	Annual domestic washing water consumption (t/(family·year))
Zhejiang	150.94	80.38	14.55
Jiangsu	161.63	70.23	16.61
Jiangxi	134.07	57.39	12.66
Hunan	126.54	71.78	12.24
Hubei	128.54	48.53	13.76
Henan	121.79	47.37	12.96
Hebei	119.70	37.87	12.52
Liaoning	78.46	45.00	7.12

washing in Jiangxi province, Hubei province and Henan province are at the same level, roughly 50 to 60 kg CO_2/year. Families in Liaoning and Hebei provinces have the lowest washing CO_2 emissions, 46.40 kg CO_2/year and 41.99 kg CO_2/year respectively. In terms of annual domestic washing CO_2 emission per capita, the lowest is 14.67 kg CO_2/(person·year) (Liaoning province), while the highest is 28.89 kg CO_2/(person·year) (Zhejiang province).

Given that Zhejiang, Jiangsu and Jiangxi are located in the eastern China; Hubei, Hunan and Henan are in the central China; Hebei belongs to the northern China and Liaoning belongs to the northeast, we conclude that in general, families in the north have lower CO_2 emissions than the eastern part. The differences in climates and residents' washing habits are the reasons that cause distinction in washing frequency among provinces. Specifically speaking, temperature and relative humidity are generally higher in southern coastal part of China, compared to the north, and people who live in these environments are easier to sweat and get their clothes stained, so

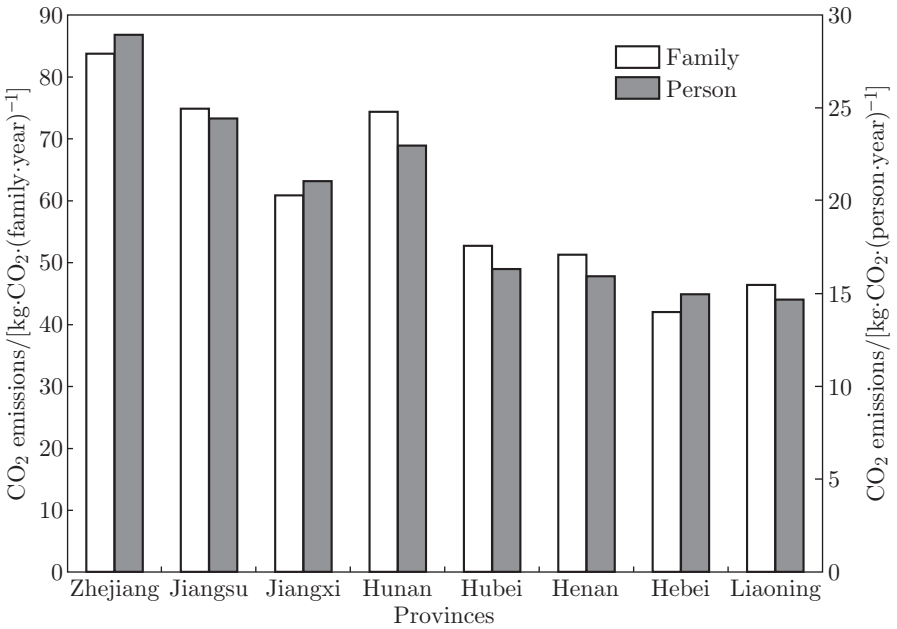

Fig. 2: Annual CO_2 emissions

that they wash their clothes more often. In addition, differences in washing frequency are the main reason that causes the difference in CO_2 emissions. Therefore, southeastern China has a relatively high CO_2 emissions, while northern and northeast have much lower emissions.

The relationship between domestic washing characteristics and CO_2 emissions is complicated. In order to get deeper understanding, multi-variable linear return analysis was used for further analysis.

4.3 Relationship between CO_2 Emissions and Influencing Variables

4.3.1 Partial Correlation Analysis

Drawn upon the investigation, thirteen aspects were regarded as the key factors, namely geographic location, permanent resident population, working population, sex ratio, per capita living space, mean age, education level, annual per-capita income, annual per-capita expenditure on clothing, washing machine's model type, capacity, and energy efficiency grade, annual frequency of using washing machine. As for CO_2 emissions per capita, the influencing factors are reduced to twelve, removing permanent resident population. Partial correlation analysis was used to select the independent variables from the 13 (or 12) influencing factors. Results are as follows: (1) when the dependent variable is CO_2 emissions from domestic washing per family (y'), the selected independent variables are: washing machine model type, defined as x'_1; annual washing frequency, defined as x'_2; and washing machine capacity, defined as x'_3. The other 10 (or 9) independent variables have limited influences towards CO_2 emissions, and thus eliminated. (2) When the dependent variable is CO_2 emissions from domestic washing per capita (y''), the selected independent variables are: washing machine model type, defined as x''_1; annual frequency of using washing machine, defined as x''_2; per capita living space, defined as x''_3; washing machine capacity, defined as x''_4; working population, defined as x''_5; and education level, defined as x''_6. The other 7

(or 6) independent variables have limited influence towards CO_2 emissions, and thus eliminated.

4.3.2 Multi-variable Linear Return Analysis

(1) CO_2 emissions per family

After analysis of the three independent variables (x'_1, x'_2, x'_3) and dependent variable (y') in SPSS17.0, three regression models were generated (see Eq. (10), Eq. (11) and Eq. (12)). The highest coefficient of determination (R-squared) is 0.647, indicating that the simulation degree of the equation is not satisfactorily high enough (the associated formula is Eq. (12)).

$$y' = -103.642 + 74.316x'_1 \tag{10}$$

$$y' = -146.252 + 68.468x'_1 + 0.429x'_2 \tag{11}$$

$$y' = -184.853 + 67.760x'_1 + 0.429x'_2 + 7.405x'_3 \tag{12}$$

Accordingly, Eq. (12) was chosen to be the final formula, showing the relationship between domestic washing CO_2 emissions per family and influencing factors of washing machine model type (x'_1), annual frequency of using washing machine (x'_2) and washing machine capacity (x'_3). Several conclusions can be brought forward: (1) from the perspective of CO_2 emissions per washing cycle, the rankings (from the lowest discharge to the highest) of the three types of washing machines are semi-automatic pulsator washing machine, fully-automatic pulsator washing machine, and front-loading washing machine. If a family alters their washing machine from a front-loading one to a fully-automatic pulsator one, 67.760 kg CO_2/family of emissions can be saved annually from clothes washing; (2) each time a family uses washing machine to do laundry, 0.429 kg CO_2 of emissions are produced; (3) in terms of washing capacity, one kilogram the larger the washing machine is, 7.405 kg CO_2/family of extra emissions will be produced annually.

(2) CO_2 emissions per person

After analysis the six independent variables (x''_1, x''_2, x''_3, x''_4, x''_5, x''_6) and dependent variable (y'') in SPSS17.0, six regression equations were generated (see Eq. (13) $\sim$ Eq. (18)). The highest coefficient of determination (R-squared) is 0.630 and the associated formula is Eq. (18).

$$y'' = -35.540 + 25.082x''_1 \tag{13}$$

$$y'' = -48.508 + 23.302x''_1 + 0.131x''_2 \tag{14}$$

$$y'' = -56.239 + 21.462x''_1 + 0.126x''_2 + 0.347x''_3 \tag{15}$$

$$y'' = -64.836 + 21.294x''_1 + 0.125x''_2 + 0.349x''_3 + 1.640x''_4 \tag{16}$$

$$y'' = -61.205 + 21.846x''_1 + 0.130x''_2 + 0.314x''_3 + 2.032x''_4 - 2.751x''_5 \tag{17}$$

$$y'' = -66.205 + 21.103x''_1 + 0.130x''_2 + 0.270x''_3 + 2.151x''_4 - 2.983x''_5 + 2.214x''_6 \tag{18}$$

Therefore, Eq. (18) is chosen to be the final formula, showing the relationship between domestic washing CO_2 emissions per family and influencing factors of washing machine model type (x''_1), annual frequency of using washing machine (x''_2), per capita living space (x''_3), washing machine capacity (x''_4), working population (x''_5) and education level (x''_6). Several conclusions can be brought forward: (1) the rankings of washing machines are the same as the previous descriptions. If a family alters their washing machine from a front-loading one to a fully-automatic pulsator one, 21.103 kg CO_2/person of emissions can be saved annually from clothes washing; (2) Each time a person uses washing machine to do laundry, 0.130 kg CO_2 of emissions are produced; (3) if per

capita living space increases, 0.270 kg CO_2/person of extra emissions will be produced for every square meter of the increase annually; (4) in terms of washing capacity, for every one kilogram larger, the washing machine will produce 2.151 kg CO_2/person of extra emissions annually; (5) 2.983 kg CO_2/person of extra emissions will be produced for every loss of working population in each family; (6) The higher average education level in a family is, the higher the annual domestic washing CO_2 emissions (per person).

5 Conclusions

According to the investigation of 493 families from sixteen cities out of eight provinces in China, the paper analyzes the relationship between household characteristics and CO_2 emissions, caused by domestic washing, drying and ironing, via multi-variable linear return analysis. The conclusions are drawn as follows:

1. The average annual domestic washing CO_2 emissions is 60.37 kg CO_2/(family·year) and 19.81 kg CO_2/(person·year).

2. CO_2 emissions in autumn and winter seasons are lower than in spring and summer.

3. Families in northern part of China produce less CO_2 emissions than families in southeast part of China during domestic washing.

4. Among all the eight provinces, Zhejiang province has the highest annual domestic washing CO_2 emissions per family, while Hebei has the lowest.

5. In terms of annual domestic washing CO_2 emissions per person, Zhejiang province still has the highest, while Liaoning has the lowest.

6. There are three impact factors, which affect annual CO_2 emissions per family (or per person) the most, namely washing machine model type, annual frequency of using washing machine and washing machine capacity. From the perspective of CO_2 emissions per washing cycle alone, the rankings (from the lowest discharge to the highest) of the three model types are semi-automatic pulsator washing machine, fully-automatic pulsator washing machine and front-loading washing machine. Other influencing factors are per capita living space, working population and education level.

7. Among the five aspects of CLA framework, External environment and Household characteristics are difficult to alter by individual efforts. However, Individual determinants and Consumer choices are much easier to change by individuals in comparison, and the changes can exert significant impact on the fifth aspect, the Environmental consequences, CO_2 emissions in this case. Consequently, in order to reduce CO_2 emissions, consumers should enhance their awareness towards environmental protection and energy saving. Specifically speaking, they can increase the number of pieces of clothes each time they use washing machine, so that the total frequency can be fewer; they can also choose their washing machine models wisely, reduce CO_2 emissions by purchasing a pulsator washing machine instead of a front-loading one.

Despite the fact that there were 493 families in 16 cities involved in the survey, the sample size was not large enough, given that Chinese population is huge and land area of China is vast. Also, this paper mainly focuses on the washing habits of households in cities, overlooks lifestyles of residents in rural areas and remote mountain areas, and therefore results in deviation of the samples. In addition, the research concerns about CO_2 emissions caused by washing machines only, ignores CO_2 emissions from dryer, iron, etc. Although the majority of Chinese households does not possess dryer and seldom uses iron, as explained earlier, neglecting their contribution towards CO_2 emissions can lead to deviation in calculation results. Lastly, clothes which are normally sent to dry-cleaner's and professional laundry stores for cleaning were not taken into consideration. Further research to conduct investigation inside dry-cleaner's, and include CO_2 emissions caused by transportation (sending to and picking up clothes from cleaner's) is still necessary.

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