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Measuring Household Carbon Footprint: Population-Specific Adaptation and Validation of a Tool for South Asia

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Abstract

The effects of climate change occur across the globe. Without reducing the greenhouse gases through drastic action today, adapting to these untoward effects of it will be challenging and costly. Therefore, estimation of the green-house gases is a prime importance. However, there are no studies conducted in South Asian households and individuals partly due to the non-availability of a validated tool. Therefore, this study aims to validate a screening tool to assess the carbon footprint (CFP) of residents in a Sri Lankan household (HH). The 28-item Resources and Energy Analysis Program (REAP) Calculator which was originally developed in United Kingdom was initially translated, population specific adapted using modified Delphi process with a panel of 10 experts and assessed for judgmental validity. Construct validity was assessed among 210 HHs by performing exploratory factor analysis and confirmatory factor analysis. Reliability was assessed using the test-retest method and internal consistency. After four rounds of Delphi techniques and validation, 20-item CFP-SL tool was found to be valid and reliable for assessing the CFP both urban and rural HHs. Five-factor model of 20 items was identified as explaining 64.3% of the total observed variance. It showed a stable factor structure (RMSEA=0.181, CFI=0.850, NNFI=0.813, SRMR =0.085, GFI=0.643) and reliability (internal consistency of 0.87). Therefore, Sinhala version of the CFP-SL tool is a valid and reliable tool to assess the CFP in urban and rural Sri Lankan HHs.

Keywords: carbon footprint; factor analysis; greenhouse gases.

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1. Introduction

Climate change poses unprecedented threats to human health owing to its direct and indirect impact [1]. It is attributed to an increase in greenhouse gases (GHG) in the atmosphere, which is predominantly the result of carbon emission through human activities. This emission is therefore expressed in tonnes of CO_2 equivalents (tCO_{2e}) for a given period probably a year as the 'carbon footprint' (CFP) [2, 3]. The CFP is used to quantify the GHG emissions caused by an activity or accumulated over the lifespan of an individual, product, organization or city. Of these, estimating the concentration among individuals as well as in groups who have similar behaviour, such as among members living in a household (HH) is crucial in climate change adaptation and mitigation.

Producing a full footprint covering all types of emissions is overtly complex, and therefore most CFP tools report only direct and first-order indirect emissions of GHGs [4]. Accordingly, the relevant information is either collected as direct measurements in the atmosphere or as estimations calculated based on the emission factors derived from consumption-based life cycle accounting techniques or input-output models [5]. Further, several CFP tools are available as paper- or web-based calculators for estimating the GHG emissions using emission conversion factors, which are sepcific for populations. Though such applications are less cumbersome than direct measurements, owing to different methodologies used in the calculation, the outputs may be difficult to interpret [6]. Therefore, selection of the most suitable tool depends on the country- or region-specific emissions, consumption patterns related to direct and indirect energy sources and human activities [7]. Thus, validation of CFP tools has become mandatory prior to its use.

Among the developing regions, South Asia has been the fastest in its economic growth and urbanization, and therefore bears a great potential to contribute to the carbon emission substantially in near future. Sri Lanka is a country in South Asia, which has a tropical climate due to its location near the equator. In addition, with rapid urbanization that is expected to continue in the coming decades, the country is vulnerable to adverse environmental impacts, such as increasing temperature, the variability of rainfall and extreme weather due to climate change. As the first step towards mitigation, the GHG emissions should be measured at HH level. However, owing to the non-availability of a valid and reliable tool to assess the CFP at HH and individual levels, the studies related to such estimations are not available. Tools that had been used previously measure only the direct emissions targeting school children in Sri Lanka [8]. In addition, highly validated footprint tools available in other countries are not directly applicable to Sri Lankan settings owing to the discrepancies with emission factors and energy consumption patterns prevalent in the country. This warrants the development of a population-specific tool, which would be the first-ever locally validated tool to quantify the magnitude of the problem of GHG emission at HH and individual levels in Sri Lanka.

At individual level, a CFP tool is able to capture the per-capita consumption-based emissions, so that it would enable individuals to understand their personal behaviour on energy and its contribution to environmental impact. At HH level, this tool is able to identify the vulnerable HHs, so that action could be taken to empower such residents to use low carbon emission products or services, and thereby opt for green choices towards a ‘low carbon economy’ [9-11]. At the community level, this tool could be used as a monitoring tool by public health authorities to screen houses on their vulnerability for high CO_2 emissions and to assess the progression made in interventions. Therefore, this study aimed to adapt and validate a population-specific tool to assess the CFP (per household and per individual) of a Sri Lankan household. This tool is also applicable to developing countries of similar socio-cultural backgrounds, for bridging the knowledge gap on the environmental impact, and thereby to design and implement necessary interventions.

2. Methods

A comprehensive literature search was carried out to identify the web-based instruments available for assessing CFP at HH level, of which seven online calculators currently used in developed as well as developing countries were selected for further review [12-18]. All these tools use the consumption-based approach, which represents the calculations based on respondent consumption [19]. To make the best selection, tools were evaluated based on seven criteria, namely the tool should estimate the minimum requirement of emissions related to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O); be based on calculations on conversion to CO_{2e} on 100-year Global Warming Potential conversion factors; describe both direct emissions (energy consumption for cooling, cooking and private travel) and indirect emissions (public transportation, food-related emissions, and energy consumed in handling household waste, goods and services) in detail; and use up-to-date and country or region-specific emission factors wherever applicable [20]. Accordingly, the 28-item REAP Calculator was selected for population specific adaptation and validation for Sri Lanka. It covers CFP related to both direct emissions from fuel burning activities and indirect emissions of the full supply-chain from final demand purchases of goods and services, thus comprising all five sub-sections relevant to the CFP (energy, food, travel, shopping and activities) of individuals, and thereby builds complete footprints for the household. This tool is widely used in developed countries [21].

After translating to the main local language (Sinhala) from the original English version using forward-backward method, REAP Calculator was considered for population-specific adaptation using modified Delphi technique with ten multi-disciplinary experts from the fields of community medicine, chemical engineering, electrical engineering, mechanical engineering, information technology and environmental sciences. The experts rated on the importance of each item in the tool on a five-point Likert scale, ranging from 1 (unimportant) to 5 (extremely important) regarding its relevance, appropriateness and acceptability in a Sri Lankan HH. Further, they were given an opportunity to revise or remove any existing item if not applicable to Sri Lanka as well as to add new items. Both the mean score and percentage of importance were calculated for each item. The items which scored over 50% on importance were identified. Thereafter, if such an item had a mean score of 4.0 or less, it was considered for further modification; if not, it was left as it is in the questionnaire. Several rounds of Delphi process were carried out in a similar manner, until all the clarifications and suggestions made by the expert panel were addressed.

Next, the draft CFP-Sri Lanka (CFP-SL) was pre-tested in 10 HHs purposively selected to represent different social classes and urban-rural sectors of Sri Lanka. Following a few more minor modifications, face validity of the tool was determined by 12 residents in Colombo District and content validity by another independent panel of nine experts who scored on the relevance, appropriateness and acceptability in the local context of each item, on a similar scale used for Delphi process. The items scoring a mean value of more than 3.5 in all three aspects were retained in the questionnaire. For assessing the construct validity, a cross-sectional study was conducted in HHs purposively selected from two ‘gramaniladhari’ (GN) divisions (the smallest administrative division of Sri Lanka) representative of the urban and rural sectors. A HH was defined as dwelling of the main family for a minimum period of one year with/without extended family members, non-relatives and domestic helpers. Households not having at least two adults and one below the age of 18 years; HHs having semi-permanent residents (e.g. staying for less than one month) and/or house tenants sharing only some utilities with the main family; religious institutes; homes for the elders, children or disabled; collective living quarters (police and military barracks: school, university and similar hostels) and household as part of business premises such as shop, office were excluded from the study. A sample of 100 HHs was considered adequate, where the item to participant ratio was 1:5, which was compatible with the minimum recommendation for tool validation [22]. As further recommended, the calculated sample was doubled and randomly split into two halves for carrying out exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) [23].

Data collection was carried out by four data collectors who had completed Advanced Level education (Biology stream) through an interviewer-administered questionnaire. It included basic information on the HH members (number, age, sex, vocation, ethnicity, highest education level, monthly income) and the CFP-SL tool comprising the consumption patterns of food & beverages, goods & services, energy used, travel and housing at both HH and individual levels. Following written informed consent, data were obtained from head of the HH or from the person who was most familiar with the HH details.

Ethics clearance was obtained from the Ethics Review Committee, Faculty of Medicine, University of Colombo, Sri Lanka. Data analysis was carried out using EFA followed by CFA. Emissions of only three GHGs, namely CO_2, N_2O and CH_4 were considered. The footprint was calculated in $kgCO_{2e}$ per year by multiplying each activity data by its emission factor. Accordingly, the CFP relevant to all activity data was calculated.

EFA was carried out in one half of the sample (100 HHs) using the Statistical Package for Social Sciences (SPSS) version 23. Factor extraction was carried out using Principal Component Analysis (PCA) followed by varimax rotation. The cut-off for factor loading was set at >0.4. Factor retention was based on the Eigen values and as per Kiser’s criterion, only those with an Eigen value of >1.0 were retained in the factor solution [24]. Further, scree plots were observed to decide on the number of factors selected. Prior to EFA, several statistics were performed to ensure that the assumptions required for this analysis were fulfilled. Normalcy of the data was tested using Kaiser-Meyer-Olkin (KMO) Test and Bartlett’s Test of Sphericity [25]. Further, inter-correlation of all the items were calculated and the anti-image correlation matrix to see whether coefficients were above the accepted level of 0.5 [26]. In order to assess the construct validity of CFP-SL, CFA was carried out in the other half of the sample (100 HHs) using the Software Package Lisrel version 9.2, during which a multitude of goodness of fit measures were evaluated to assess the model fit. The reliability of CFP-SL was assessed using Cronbach’s alpha coefficient and internal consistency, with estimates of 0.7 or greater considered as satisfactory [27]. Test re-test reliability was assessed by re-administering the CFP-SL to a sub-sample of 25 HHs following an interval of two weeks.

3. Results

3.1 Population-specific adaptation of CFP-SL

The translated REAP Calculator underwent major modifications during population specific adaptation. After the first round of Delphi process, only 13 out of the 28 items in the original tool (4 items with no modification + 5 items for further modification + 3 items combined as one + 1 item sub-divided into 3 of the REAP Calculator) were retained for further review in the CFP-SL instrument. The original subscales were renamed, viz ‘power’ as ‘energy’, ‘food’ as ‘food & beverages’, ‘shopping’ as ‘goods’, and ‘activities’ as ‘services’. To avoid under-or over-estimation, the data collection period was prepared as weekly, monthly or yearly. Further, 2 new items, namely organic (kitchen) waste collection by local authorities of municipal, urban or local councils (with 90% agreement of the expert panel); and pipe-borne water consumption provided by the National Water Supply and Drainage Board Sri Lanka (60% agreement) were included through consensus of the expert panel under a new subscale named ‘housing’. Additionally, 24 new items were included in the ‘food and beverage’ subscale, based on the information obtained from ‘Household Income and Expenditure Survey’ (HIES) (2016) on locally relevant food frequently consumed in households in 1000g or more or ten in number or more per month (80% agreement); and non-food items of average monthly expenses of Rs. 500 or above under ‘goods’ and ‘services’ subscales (80% agreement) [28]. The combined list of 39 items (26 new items and 13 items selected from REAP Calculator) was sent for the second Delphi round, during which one item (the amount of wheat flour products consumed over a usual week) was removed due to high variety of wheat flour-based products consumed by members of Sri Lankan HHs and its overlapping with another item. Further, one item was modified to obtain the amount of rice consumed for a usual week not considering its varieties according to the expert panel view. Though consumption of some of the food items is high in Sri Lanka, their contribution to GHG emissions could be small. Therefore, the list comprising 38 items was sent for third Delphi round to decide on the items based on emission factors and data sources, during which five items which had emission factors less than 0.1 $kgCO_{2e}$ were removed. Further, due to non-availability of emission factors for Sri Lanka or recommended list of emission factors, 12 more items were removed [28, 29]. The list comprising 21 items was then sent for fourth Delphi round, during which data on electrical and electronic goods were combined as one. Finally, the CFP-SL contained 20 items (8 new items + 12 modified items) for undergoing validation (Table 1).

Table 1: CFP-SL contained 20 items used validation.

Subscale	Item
Energy	What is the monthly consumption of electricity at HH and workplace?
	What is the monthly consumption of LPG?
	What is the monthly consumption of oil as an energy source (kerosene, coconut oil, and diesel)?
Housing	What is the amount of organic (kitchen) waste collected by the local authorities from your household in a usual week?

	What is the usage of pipe-borne water provided by the water board in a usual month?
Food and Beverages	What is the consumption of meat (chicken, beef, pork, mutton, processed meat) in an average week?
	What is the amount of rice consumed for usual week?
	What is the amount of bread consumed for usual week?
	What is the amount of coconut oil consumed for usual week?
	What is the amount of milk powder and milk-based product (yogurt, butter, cheese, curd) consumed for usual week?
	What is the amount of fish consumed in an average week?
	What is the consumption of hens' eggs in an average week?
	What is the amount of sugar consumed for usual week?
	What is the consumption of alcoholic drinks (beer, wine, spirit) in an average week?
Travel	Distance travel by own vehicle/s (petrol car, diesel car, van, motor cycle, three-wheeler) for daily routines and other works for a typical week.
	Distance travel by public transport (train, bus, truck, lorry) for daily routines and other works for a typical week
	How many return flights in total by households in the past year?
Goods & Services	What is the number of general clothing and jackets (adults and children) bought during last month?
	How many electronic (mobile phone, desktop computer, laptop computer) electrical items (refrigerator, television, washing machine were bought during last year?
	How many hours the mobile phone used per month?

3.2 Validation of CFP-SL

Majority of the 100 HHs selected for EFA were detached houses (59.0%); owned by family (88.0%); having three members (57.0%); and drawing less than Rs. 40,000.00 per month (62.0%). KMO measure for the overall data set was 0.77, which is well above the average value between 0.5 and 0.6 that is acceptable for sample sizes of 100-200 [29]. Bartlett's Test of Sphericity was significant (χ^2=3351.28; df=190; p<0.001), confirming the rejection of null hypothesis that variables in the population correlation matrix are correlated. All the coefficients were above the accepted level of 0.5; the minimum being 0.58 [30]. During EFA, all items including the eight new items loaded well to the factors. Each item had a factor loading of 0.6 or more with only a single component. Further, there were no cross-loadings exceeding 0.4. Examination of the individual factor loadings revealed that the items were grouped to the five-factor model (Table 2). The Eigen values ranged from 7.98 to

1.66. The five-factor solution accounted for 90.5% of the variance and was supported by the scree plots. The five factors of CFP-SL were named as ‘food and beverages’, ‘goods and services’, ‘energy’, travel’ and ‘housing’.

Table 2: Factor Coefficients of Individual Items of CFP-SL after Varimax Rotation in PCA (n=100).

Item number	**Factors/Components**				
	1*	**2***	**3***	**4***	**5****
New Item 5	**.957**	-.047	-.034	-.036	-.202
Item 13	**.989**	-.028	.042	-.020	.058
New Item 11	**.896**	.023	.140	-.055	-.098
New Item 14	**.943**	-.035	-.007	-.007	.043
New Item 16	**.942**	-.024	.058	-.021	.097
New Item 12	**.749**	.033	.217	-.091	.085
New Item 3	**.979**	-.045	.077	.008	.057
New Item 15	**.899**	-.038	.038	.021	.127
Item 16	**.968**	-.026	.027	-.002	.074
Item 22	-.053	**.967**	-.024	-.015	.029
Item 23	-.007	**.988**	-.013	.077	.049
Item 26	-.040	**.969**	.005	.075	.012
Item 6a	.139	-.009	**.969**	-.005	.068
Item 6b	.109	-.014	**.929**	.044	.022
Item 6c	.042	-.011	**.907**	-.014	.080
Item 19	-.054	.063	.051	**.940**	.120
Item 20	.015	.004	-.069	**.906**	.084
Item 21	-.074	.068	.050	**.956**	-.051
New Item 1	.047	.057	-.096	.084	**.977**
New Item 2	.105	.034	.370	.076	**.906**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.
*Corresponds to following subscales: 1=” Foods”; 2= “Shopping and Activities; 3= “Power”; 4= “Travel” in REAP Petite calculator
**Corresponds to newly added subscale “Housing”, following final Delphi round

Out of the 100 HHs selected for CFA, most were detached houses (41.0%); were family-owned (79.0%); having more than three members (55.0%); and drawing less than Rs. 40,000.00 per month (70.0%). The data were found to be non-normal based on the visual inspection using histogram, and the standardized skewness and kurtosis values exceeding +/-3 [31]. Thus, the robust maximum likelihood method was adopted. A random sample of bivariate scatter plots was examined to ensure the linearly of the data. There were no outliers in the dataset. It was assured that multi-collinearity was not present. Accordingly, the model parameters were estimated using three different models to identify the best fitting model for the dataset (Table 3). Finally, the five-factor model was taken as the best fitting model for CFP-SL.

Table 3: Model Fit Indices for Selected Models (n=100).

Model	Absolute fit indices			Comparative fit		Parsimony correlation	
	X^2	GFI	SRMR	NNFI	CFI	RMSEA	NCP
1 Factor model	1984.945 (df=170) p < 0.0001	0.43	0.14	0.45	0.47	0.33	1814.95
3 Factor model	1165.7 (df=167) p < 0.0001	0.54	0.13	0.68	0.71	0.25	998.72
5 Factor model	676.447 (df=160) p < 0.0001	0.64	0.09	0.81	0.85	0.18	516.45

Chi-square test (p=>0.05 desired)

GFI = Goodness of fit index (>0.9 desired)

SRMR = Standardized root mean square residual (<0.08 desired)

NNFI = Non-normal fit index (>0.9 desired)

CFI = Comparative fit index (>0.9 desired)

RMSEA = Root Mean Square Error of Approximation (<0.05 desired)

NCP = Closer to Zero is better

With regards to reliability (Table 4), the statistics obtained were well above the satisfactory level of 0.7 [32]. The correlation coefficient values in test re-test reliability also ranged from 0.85 to 0.96. The overall value was 0.88.

Table 4: Test Re-Test Reliability Analysis of Selected Variables in the Questionnaire (n=160).

Variable	Level of agreement between PI and observer (Kappa coefficient)			
	Interviewer 1*	Interviewer 2*	Interviewer 3*	Interviewer 4*
Sugar consumption	0.825	0.845	0.832	0.841
Egg consumption	0.995	0.994	0.914	0.943
Alcohol consumption	0.816	0.890	0.843	0.857
LP gas usage	0.942	0.875	0.987	0.945
Travel by own vehicle	0.845	0.858	0.991	0.961
Waste disposal	0.895	0.812	0.914	0.861
Water consumption	0.978	0.995	0.914	0.942

*Number interviewed=40

4. Discussion

The current study was conducted to adopt and validate the REAP Calculator to assess the CFP of a typical Sri

Lankan HH. The findings demonstrate the reliability (internal consistency of 0.88) and validity of CFP-SL for estimating the individual as well as HH level CFP in Sri Lanka. In our study, considering the relatively comprehensive information that it gathers, despite being originally developed and validated for developed countries, REAP Calculator was identified as the most suitable tool for population-specific adaptation for Sri Lanka. This selection was based on a thorough literature review of the existing tools on Publicly Available Specification 2050, such as relevance, completeness, consistency, accuracy and transparency anchored as guiding principles for estimating the CFP [33]. In concurrence with the original tool, our findings support a five-factor structure with a stable factor structure (RMSEA=0.181, CFI=0.850, NNFI=0.813, SRMR =0.085, GFI=0.643), however the items within the factors are found to be grossly different following adaptation, highlighting its population-specific nature. To our knowledge, this is the first ever study that has assessed the validity of a tool using rigorous validation techniques to estimate the CFP of HHs in developing countries. For example, in India, due to the absence of a valid tool, HH CFP had been estimated only by carrying out an input output analysis with data matched to HH expenditure data [34]. Therefore, the CFP-SL could provide guidance to other countries in the region for estimating the CFP at HH level and also to be used as the basis for population-specific adaptation. Furthermore, the validated tool incorporates a comprehensive list of items most relevant to HHs in South Asia. As described by Padgett and his colleagues (2008), a complete footprint of HHs should include both direct and indirect emissions. Incompleteness of this input data will invariably lead to under-estimation of the size of CFP. Nevertheless, due to wide variations in the consumption patterns and activities in HHs, it is extremely difficult to develop a tool that estimates a complete footprint. However, the validated Sinhala version of CFP tool covers the scope 1, 2 and 3 which supported the all-possible emissions at household such as energy, housing, food and beverages, travel and good and services. As shown, only 13 items of the original REAP Calculator were retained after population specific adaptation. As being a country with a tropical climate, many items in the ‘power’ domain (39%) were removed due to non-relevance to Sri Lanka (e.g. heating house). Also, 12 variables were removed owing to the unavailability of emission conversion factors relevant to Sri Lanka. Of the newly added items into CFP-SL, HH waste and water consumption have not been considered in most tools developed for developed countries, including REAP Calculator. It should be noted that indiscriminate waste disposal and contamination of water sources are major issues in developing countries. Especially in South Asia, garbage collection is in operation, but its disposal has several practical limitations owing to the poor initiation of systematic garbage disposal techniques due to cost or less political commitment. Additionally, unlike in developing countries, meat consumption is shown to be much higher in developed countries, especially those engaged in meat production industry, thus leaving larger footprints. Being an agricultural country, the meat consumption is relatively less in Sri Lanka, as evident by the national average values per month reported for the consumption of pork (30.69 grams), processed meat (25.30 grams) and cheese (16.05 grams) [27]. In contrast, the emissions are very low for fruits and vegetables, even if there is a high degree of processing and substantial transportation [35, 36]. This has implications for CFP differences between countries. Also, some food items are consumed in small amounts, therefore scientifically excluded based on HIES. Further, there is usually high level of complexity involved with variations in the workplace environment, thus most HH CFP tools are limited on this aspect [37]. A unique feature of CFP-SL tool was the incorporation of energy usage at workplace. In countries with tropical climate, cooling contributes to energy at large scale. However, its usage at workplace, unlike central heating, is dependent on social hierarchy, thus we assessed it in relation to bulbs, cooling equipment such as fans and air conditioners, and computers available within 2m radius of office space. Thus, Sinhala version of the CFP-SL tool is a valid and reliable tool to estimate the CFP in urban and rural Sri Lankan HHs. The currently available tools on CFP are mostly limited to assessments at macro level organizations such as industry and institutes, and only a few at micro level, such as of the smallest functional unit in the community, which is a HH. Household members function as a group and resort to similar practices, and therefore from a public health perspective, initiating action at HH level would be more effective for a greater impact on mitigation of climate change. In line, the validated CFP-SL is comprehensive in obtaining the footprint of HH members inside as well as outside home (e.g. at work), and applicable for estimating the CFP at HH as well as individual level (e.g. services and food consumed on individual basis). It is however shown that differences in estimations especially when measuring CFP per individual may exist, but are likely to be small in our study. Estimating the CFP per HH is complex, which is influenced by several drivers. In response, there were several precautions taken in our study for ensuring an almost complete footprint. To this end, the original REAP questionnaire was modified to the Sri Lankan context, as elaborated using a rigorous adaptation and validation procedure. The study population recruited represented a 'typical' Sri Lankan HH comprising the average family size with or without extended family members, non-relatives and domestic helpers living with the main family [38]. In South Asian countries, extended family concept is stronger than in developed countries, thus should invariably be incorporated into CFP tools at HH level. However, excluding HHs having semi-permanent members (e.g. visitors on short stay or recently returned members of the main family) was essential, as all the assessments were limited to activities over a minimum period of one month. Also, houses with units given on rent were excluded, as only some of the items would be shared with the main family, thus difficulty in making the assessments. The sample recruited can be considered as adequate for validation for a tool of 20 items [39]. The present study depended on primary data collection on CFP through household interviews, which could have led to obtaining incomplete data from HHs, especially on food, services and fuel consumption. To minimize these errors, precautions such as visual guides on serving sizes used for food and beverages and objective measurement of waste product were used. Therefore, compare with other tool structures from developing countries, this tool ensure that five factor structure is most suitable for estimating the CFP at HH.

5. Limitations

There were few limitations with regard to the assessment of CFP.

- Due to unavailability of emission factors, 12 items were removed, nevertheless, the items of concern (e.g. vegetables and fruits) are assumed to contribute to the CFP in smaller proportion, thus the estimation of CFP is most likely minimally affected.
- Almost all of the data on CFP (except utility bills on electricity and water) were self-reported and obtained retrospectively, which could distort the interpretations owing to recall bias. However, data collection as in a longitudinal study was not feasible; instead, a cross-sectional design was considered suitable as most of the data could be collected based on recall and records from previous years. To describe the household CFP in India, a similar study design was considered [40].
- Reporting of the CFP was carried out for one year, while assuming the collected data were usual measures

and stable over one year. Due to unavailability of country-specific emission factors except electricity for Sri Lanka, default emission factors given by the IPCC guidelines were used.

- Lifecycle emission assessments from housing and appliances were not included.
- Emission factor for fuel varies with the type of vehicle used. Although the exact fuel consumption could not be assessed, the distance travelled including the vehicle mode was obtained, so that emission factors for fuel could be applied to each standard vehicle. Owing to the poorly maintained records, liquefied petroleum gas and fuel consumption calculations included some assumptions. Thus, when comparing the CFP of Sri Lankan HHs with other countries, these limitations need to be taken into account.

5. Conclusions

CFP-SL was found to be valid and reliable for assessing the CFP in typical Sri Lankan HHs. Variation in the items of CFP-SL reiterates the importance of developing population-specific CFP tools, at least at regional level. Such tools would help in estimating the current status of CFP at HH level, and thereby provide first-hand evidence for obtaining the commitment of political as well as other professionals to initiate in mitigation activities. It should be kept in mind that activities targeting climate change mitigation cut across several fields (e.g. health, environment, fisheries, housing, roads and travel, commercial and mercantile sector, education, urban development), so that corporation from all sectors is essential. In this regard, availability of valid and reliable tools for assessing population-specific CFP is of immense use especially in developing countries, where the carbon emissions are expected to rise in the near future.

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