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Non-Price Determinants of Energy Choice for Cooking: Empirical Evidence from Sri Lankan Households

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Abstract

The United Nations' seventh Sustainable Development Goal (SDG) ensures universal access to affordable, reliable, and modern energy services for all by 2030. Modern or clean energy is perceived to be the golden thread that connects economic growth, human development, and environmental sustainability. However, one-third of the world's population still uses solid fuels for cooking, indicating the importance of switching from solid to clean fuels. This paper, therefore, analyses demographic, socioeconomic, and housing characteristics that affect household-level cooking energy choices in Sri Lanka. Further, it identifies the synergies between SDG 4, SDG 6, and SDG 7. The data is obtained from the Sri Lankan Households Income and Expenditure Survey (HIES) for 2009 - 2016, covering about 58,000 households. The results of the random effects panel multinomial logit model identify that household income, household wealth, education of head, age and education of spouse, household size, number of children, housing characteristics (number of bedrooms, water facilities, type of wall, floor, and roof), and residential sector are vital in the selection of clean cooking fuel. More specifically, Advanced Sustainability Analysis (ASA) results show SDG 4 and SDG 6 have a strong synergetic effect on SDG 7. The findings suggest the importance of taking the determinants of energy choice and the synergetic gains of the SDGs into account in formulating a comprehensive national energy policy.

Keywords

energy
clean fuel
solid fuel
cooking
Sustainable Development Goal (SDG)
synergies

JEL Classification

C25, F24, O13, Q01, Q42, R20

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1. Introduction

Energy services are vital contributors to economic, social, and human development (Alem, Beyene, Köhlin, & Mekonnen, 2016; Guta, 2018). It has been extensively debated in recent decades and has become a major policy instrument in the global sustainable development agenda. The crucial role of energy is clearly illustrated with the inclusion of energy as the 7th Sustainable Development Goal (SDG). SDG 7 ensures universal access to affordable, reliable, sustainable, and modern energy for all by 2030. However, one-third of the global population, accounting for about 2.8 billion people, still use solid fuels (i.e., fuelwood, coal, charcoal, agricultural residuals, and animal dung) for cooking. Furthermore, an estimated 2.3 billion people will continue to rely on such fuels by 2030, reflecting the sluggish progress of the energy transition (United Nations, 2020).

The massive use of solid fuels for cooking creates many detrimental effects on human health and environmental sustainability. Incomplete combustion of solid fuels produces carbon dioxide (CO_2), carbon monoxide (CO), particulate matters ($PM_{2.5}$), and other greenhouse gases by directly making substantial indoor air pollution (IAP) (Balakrishnan et al., 2018; Hou et al., 2017; Muller & Yan, 2018; Shupler et al., 2018). IAP is potentially hundreds of times more harmful to human health than outdoor air pollution (Smith & Mehta, 2003). Moreover, it has been classified as the world's ninth-largest health risk, causing 1.6 million premature deaths and 3 per cent of human deaths worldwide (Ritchie & Roser, 2020). In addition, the highest use of solid fuels leads to deforestation and environmental degradation by seriously damaging environmental sustainability (Heltberg, 2005).

A major reduction in IAP comes from improved access to clean cooking fuels (IEA, 2020). Adoption of clean energy (such as electricity, Liquefied Petroleum Gas, natural gas, and biofuel) is considered as the "golden thread" that waves economic growth, human development, and environmental sustainability together (IEA, 2017). Therefore, the transition from solid energy to clean, modern energy is attracting increased attention among scholars.

The process of energy transition was theoretically first addressed by energy ladder theory as early as the 1990s (Hosier & Dowd, 1987). It states that households first move from solid fuels to transitional fuels and then to cleaner fuels when the socioeconomic status of households increases, especially income. This theory assumes that households give up the used fuel entirely and move up to a new fuel, and it is a linear and unidirectional process (Heltberg, 2004; Leach, 1992). On the contrary, fuel or energy stacking theory suggests that an improvement in social status often drives the households to use the portfolio of energy sources. As users can go up or down the ladder, it is considered a bidirectional process (Heltberg, 2005; Ravindra, Kaur-Sidhu, Mor, & John, 2019).

A large and growing body of literature has investigated the determinants of energy choice and transition for cooking at the household level (Amoah, 2019; Baiyegunhi & Hassan, 2014; Dash, Behera, & Rahut, 2018; Rahut, Behera, Ali, & Marenya, 2017; Ravindra et al., 2019; Sharma, Ravindra, Kaur, Prinja, & Mor, 2020; Song et al., 2018). They identified household income, household wealth, characteristics of household head and spouse (gender, marital status, age, education, and employment status), household characteristics such as household size, the number of children and females, and housing characteristics (drinking water source, toilet type, type of wall, floor, and roof) as significant determinants of energy choice.

Some of these determinants are directly linked to the SDGs. For instance, the education level of the head and spouse relates to SDG 4 (quality education). Further, SDG 6 (clean water) relates to the drinking water and sanitation facilities. However, to our knowledge, no research has been done to show the links between these SDGs when looking at the factors that affect energy choice at the household level. Given these circumstances, the purpose of this study is to investigate the demographic and socioeconomic factors that influence the energy choice for cooking (SDG 7) and the synergies between SDG 4, SDG 6, and SDG 7. Accordingly, this study attempts to answer three research questions at the household level: (1) what factors influence the cooking fuel choice; (2) does synergy exist between SDG 4 and SDG 7; and (3) does synergy exist between SDG 6 and SDG 7.

To research this topic, we select Sri Lanka due to two reasons. The first explanation is that the most recent sustainable development report (United Nations, 2020) indicates that Sri Lanka still faces major challenges in achieving SDG 7. Further, it has been rated as a stagnant goal because only about 31% of the population has access to clean fuels and technologies. The second reason is that there has been very little research into the determinants of energy use in Sri Lanka, and most of that has been done over a decade ago (Nandasena, Wickremasinghe, & Sathiakumar, 2012; Rajmohan & Weerahewa, 2010; Wickramasinghe, 2011). Furthermore, none of the studies used an econometrics specification model to elaborate on the determinants of energy choice.

Accordingly, our contribution to the literature is threefold.

(1) Firstly, this study adds to the literature by investigating the driving forces of cooking energy choice using panel multinomial logit regression for 8 years of nationally representative data (2009-2016) covering about 58,000 households. The results can help to prepare effective government measures at the household level for the energy transition.

(2) Secondly, this will be the first research exploring the synergies between SDG 4, and SDG 6 with SDG 7, respectively, using the panel data. A thorough understanding of SDGs' linkages will help to integrate different sector specific programs and develop consistent cross-sectoral policies.

(3) Finally, this will be the first study in Sri Lanka to analyse the possible impact of demographic, socioeconomic, and housing characteristics on energy choice using an econometrics model. This will help properly reflect the characteristics of Sri Lankan households' current energy usage and formulate appropriate energy policies.

The remainder of this paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 and 4 outlines the data and variable description and the empirical model, respectively. Section 5 describes the results and discussion. Finally, section 6 concludes the paper and discusses the policy implications.

2. Literature Review

Many researchers have examined the determinants of energy choice and transition at the household level. As per the energy ladder hypotheses, the majority of them discovered that household income was the most significant determinant of energy choice for cooking (Amoah, 2019; Dash et al., 2018; Ravindra et al., 2019; Song et al., 2018). Furthermore, household wealth, which measures long-term wellbeing, has been described as one of the key determinants of cooking fuel choice (Mottaleb, Rahut, & Ali, 2017; Rahut, Behera, & Ali, 2016; Song et al., 2018). The demographic characteristics of the head and spouse such as gender, marital status, and age are also found to be the significant determinants of cooking fuel choice (Behera, Rahut, Jeetendra, & Ali, 2015; Choumert-Nkolo, Combes Motel, & Le Roux, 2019; Mensah & Adu, 2015; Mottaleb et al., 2017; Rahut, Behera, Ali, et al., 2017). More specifically, several studies have discovered that the household head's and spouse's educational level has a strong connection with energy choice (Acharya & Marhold, 2019; Amoah, 2019; Ravindra et al., 2019; Sharma et al., 2020). In addition, household characteristics such as household size (Paudel, Khatri, & Pant, 2018; Sharma, Parikh, & Singh, 2019; Sharma et al., 2020), number of children (Baiyegunhi & Hassan, 2014; Behera et al., 2015) and number of females (Behera et al., 2015; Dash et al., 2018) have also been reported as significant determinants of cooking fuel choice. Furthermore, housing characteristics such as the number of bedrooms, the type of wall, the type of floor, the type of roof, the source of drinking water, and the type of toilets play a vital role in deciding on cooking fuel at the household level (Heltberg, 2005; Liao, Chen, Tang, & Wu, 2019; Özcan, Gülay, & Üçdoğruk, 2013).

However, there is substantial heterogeneity between various empirical studies as different studies use different variables, research approaches, study contexts, data sets, and models. Thus, the knowledge about the determinants of energy choice and transition is still questionable. Due to this, there is no single framework to predict the household energy consumption structure (Frederiks, Stenner, & Hobman, 2015). For example, studies undertaken by Choumert-Nkolo et al. (2019) in Tanzania and Dash et al. (2018) in India found male-headed households are more likely to use clean fuels. However, some studies found female-headed homes are more likely to choose clean fuels (Behera et al., 2015; Mottaleb et al., 2017; Rahut, Behera, Ali, et al., 2017). Further, several studies found gender plays no role in selecting cooking fuel (Abebaw, Admassie, Kassa, & Padoch, 2019; Liao et al., 2019; Narasimha Rao & Reddy, 2007; Ouedraogo, 2006). In addition, studies conducted by Sharma et al. (2020), Behera et al. (2015), and Özcan et al. (2013) found a significant positive relationship between age of the household head and clean energy choice. In contrast, Choumert-Nkolo et al. (2019) examined that age of the head is negatively related to clean energy consumption, while Song et al. (2018) conclude no impact. Similarly, a study conducted by Choumert-Nkolo et al. (2019) in Tanzania showed a significant positive relationship between the household size and clean energy choice for cooking. In opposite, some studies found the household size is negatively related to clean energy consumption (Sharma et al., 2019; Sharma et al., 2020). Due to these inconsistent conclusions, it becomes even more important to understand further the factors that influence energy choice and transition, mainly if SDG 7 is to be met by 2030.

On the other hand, although each SDG focuses on different aspects, most SDGs are integrated, indivisible and create synergies. The synergy between two variables exist when their combined outcome is greater or less than sum of their individual outcomes. Therefore, synergy can be positive or negative. Negative synergy is known as trade-off that imposes negative impacts or constraints on another target's achievements (Luukkanen et al., 2012; Mainali, Luukkanen, Silveira, & Kaivo-oja, 2018). However, interactions between SDGs have weak conceptual and scientific underpinnings (ICSU, 2017). In addition, most of the studies conducted to find the synergies and trade-offs are qualitative in nature (Halsnæs & Garg, 2011; Weitz, Carlsen, Nilsson, & Skånberg, 2018), and therefore, it is difficult to provide any quantitative basis for evaluating synergies. Lack of proper understanding of synergies leads to create incoherent policies by delaying outcomes of SDG agenda (Mainali et al., 2018) and thus, there is a clear need for approaches and tools to identify the inter-relationships of SDGs in promoting the SDG agenda more efficiently (Weitz et al., 2018).

Accordingly, one of the purposes of this study is to identify the synergy between SDG 4 and SDG 7 as well as SDG 6 and SDG 7. SDG 4 targets to achieve quality education for all by 2030 by ensuring free, equitable, and quality primary and secondary education for all girls and boys (World Bank, 2019). It has been identified as one of the SDGs which has higher synergetic co-benefits with other SDGs (Pradhan, Costa, Rybski, Lucht, & Kropp, 2017). The SDG 6 guarantees equal access to safe, improved drinking water and sanitation for everyone by 2030 (World Bank, 2019). Water and sanitation facilities make impact on the selection of cooking fuel. For example, a study conducted by Liao et al. (2019) in China found a significant positive association of water and sanitation facilities with cooking fuel selection. Moreover, Fader, Cranmer, Lawford, and Engel-Cox (2018) found that SDG 6 enhances the achievement of SDG 7 and vice versa. Thus, a comprehensive understanding of synergy and trade-offs, and an understanding of the determinants of cooking fuel choice, are needed to implement incoherent cross-sectional policies to achieve the 2030 SDGs.

3. Data and Variable Description

3.1 Data Description

The data used for this paper was obtained by the Department of Census and Statistics (DCS) in Sri Lanka from the Household Income and Expenditure Survey (HIES) conducted in 2009, 2012, and 2016. HIES is a nationwide survey that conducts every three years. HIES offers the most essential socio-economic indicators for the implementation and assessment of policies and strategies for socio-economic development and the finalization of the development priorities of the SDGs. It collects demographics, income, expenditure, school education, health, and household assets data through direct interviews using the survey questionnaire.

The survey's sample design is two-stage stratified, and the sectors (urban, rural, and estate) of each district of the country are selection domains for the stratification. At the primary point, generally, a sample of 2500 primary sampling units was selected from the sampling frame for the survey. 10 housing units (SSU) were then chosen for the survey from each primary sampling unit. In 2009, 2012, and 2016, the total sample sizes of 23641, 25319, and 25640 housing units were selected, respectively, but only 19958, 20540, and 21756 replied in the respective years. Therefore, we included 62,240 households in this study, and after adjusting for the empirical model, we ended up with 57,978 households for the analysis.

3.2 Variable Description

The dependent variable of the study is the cooking energy choice. As stated by the energy ladder hypothesis, the cooking fuel mix in Sri Lanka comprises fuelwood at the bottom, kerosene at the middle, and LPG and electricity at the top of the ladder. On this basis, we divide cooking fuel consumption into three categories: (1) Solid fuel (Fuelwood, saw/paddy husk, and other); (2) Transitional Fuels (Kerosene); and (3) Clean Fuels (LPG & Electricity). The distribution of households by primary cooking fuel choice is presented in Figure 1.

Figure 1: Cooking Fuel Use

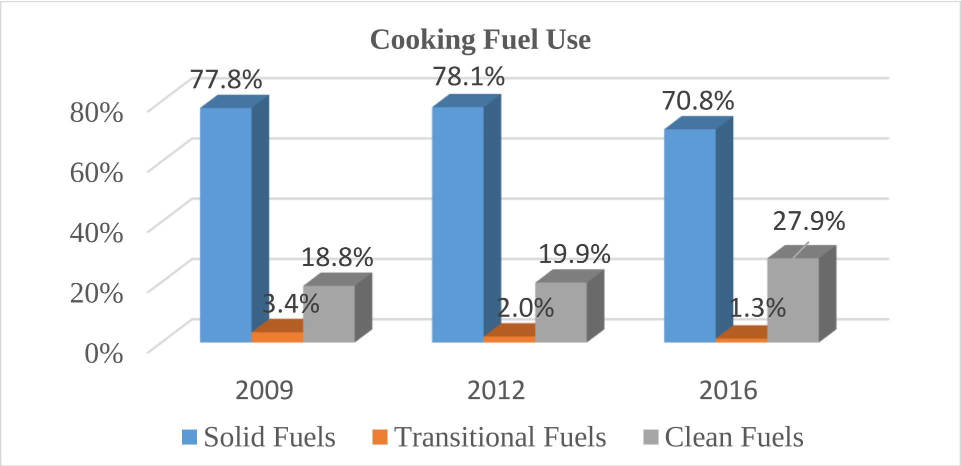


Figure 1 shows that the proportion of households whose main cooking energy is solid is decreasing from 77.8% in 2009 to 70.8% in 2016. There has been a gradual decrease in the proportion of households using transitional fuels as their main cooking energy over the three survey periods (3.4%, 2%, and 1.3% for 2009, 2012 and 2016, respectively). On the other hand, the proportion of households with clean, modern fuels steadily increased as the primary fuel for cooking (18.8%, 19.9%, and 27.9% for 2009, 2012 and 2016, respectively). The most notable feature is that solid fuels still dominate as the main cooking fuel.

The control variables of the study include household income, household wealth, age, gender, education, marital status, and sector of employment of household head, age, and education of spouse, number of children under five, number of females, household size, water and sanitation facilities, number of bedrooms, type of wall, floor, and roof, and residential sector based on the literature. Table 1 shows the descriptive statistics of the variables interested in the study.

Table 1: Descriptive Statistics of Variables

Variable	Explanation	Mean	Std. Dev.
Cooking Fuel	1: Solid fuels; 2: Transitional fuels; 3: Clean fuels	1.468	0.834
Household[1] Income	Total income of Household	114,342	957,306
Wealth Quintiles	1: Poorest households; 2: poor households; 3: medium wealth households; 4: wealthy households; 5: wealthiest households	3.004	1.413
Household Head[2]			
Age	Age of household head	51.464	14.027
Gender	1: Male; 2: Female	1.245	0.43
Marital Status	1: Never married; 2: Married	1.978	0.146
Education	Years of schooling completed by head	8.837	3.983
Employment Sector	1: government sector; 2: private sector; 3: Other (employer, own account worker, or contributing family member)	2.27	0.696
Spouse			
Age	Age of spouse	45.8	12.62
Education	Years of schooling completed by spouse	9.439	3.767
Household Characteristics			
Household Size[3]	Number of household members	4.183	1.718
Number of Children	Number of children under 5	0.252	0.527
Number of Females	Number of females in the household	2.16	1.173
Housing Characteristics			
Number of Bedrooms	Number of Bedrooms	2.323	1.097
Safe Water	1: Safe drinking water; 2: Unsafe drinking water	1.085	0.279
Toilet Use	1: Indoor toilets; 2: Outdoor toilets; 3: No toilets	1.387	0.498
Toilet Type	1: Improved toilets; 2: Unimproved toilets	1.023	0.149
Type of Wall	1: Permanent wall; 2: Semi-permanent wall	1.066	0.248
Type of Floor	1: Permanent floor; 2: Semi-permanent floor	1.046	0.209
Type of Roof	1: Permanent roof; 2: Semi-permanent roof	1.079	0.269
Sector	1: Urban; 2: Rural; 3: Estate	1.849	0.524

[1]Household is defined as a group or more persons who live together and has a common arrangement for cooking.

[2]Head of household is a person who usually resides in the household and is acknowledged by the other members of the household as the head of the household.

[3]Hosehold size refers to the number of persons usually living in the household, including boarders and servants.

[4]Rural sector includes all the areas other than the areas governed by Municipal Councils (MCs) and Urban Councils (UCs) and the estate sector (Census and Statistics Department, 2012)

Table 1 shows the majority of household heads are married males. The average age for the head and spouse of the household is 51 and 46 years, respectively, and the average schooling year for both is grade 9. The average household income is 114,342, with the vast majority of the families falling into the middle wealth quintile. In addition, the majority of households work in the private sector. The mean size of the household is 4, and the average number of females is 2. On average, the majority of households have safe drinking water facilities, improved toilets, permanent wall, floor, and roof. The majority of households reside in rural areas compared to urban and the estate sector.

4. Empirical strategy and econometric models

4.1 Multinomial logit model (MNL)

The dependent variable of the study is energy choice and, we divide it into three main categories: solid fuel, transitional fuel, and clean fuel. Since the dependent variable has more than two nominal and unordered alternatives, this study adopts the multinomial logit model (Baiyegunhi & Hassan, 2014; Dash et al., 2018; Gebreegziabher, Mekonnen, Kassie, & Köhlin, 2012; Heltberg, 2004, 2005; Hosier & Dowd, 1987; Narasimha Rao & Reddy, 2007; Ouedraogo, 2006; Pundo & Fraser, 2006; Rahut, Behera, & Ali, 2017; Song et al., 2018).

The Independence of Irrelevant Alternatives (IIA) assumption is the key downside of the standard multinomial logit model. IIA ignores individual heterogeneity and assumes that household decisions are made independently, both inside and across alternatives. Panel data can be used to address the problem of unobserved heterogeneity by controlling for fixed or random entity and tine effects since it contains numerous observations for the same individual across time (Zhu, Livote, Ross, & Penrod, 2010). Therefore, as a response, incorporating random errors into the model relaxes the IIA property (Glick & Sahn, 2005; Grilli & Rampichini, 2007). Furthermore, random effect estimates are considered more robust and efficient since they capture the unobserved household impact. Therefore, we adopt random effects panel multinomial logit regression to examine the determinants of household energy choice for cooking (Alem et al., 2016; Choumert-Nkolo et al., 2019).

The MNL model's theoretical framework is based on random utility theory. This theory states that every individual is a rational decision-maker and selects the best among alternatives to maximize utility (McFadden, 1978). As a result, a household selects the primary cooking fuel that provides the most utility from various energy sources (Mensah & Adu, 2015). Accordingly, the indirect utility of a cooking fuel choice j (j=1,2,3) in the time period t (t = 1,2,3) for i^{th} observation of each household with a random effect can be described as:

$$V_{ijt} = X_{it}\beta_j + u_i + \varepsilon_{ijt} \tag{1}$$

Where X_{it} is a vector of explanatory variables for each household's cooking fuel preference, β_j is a vector of cooking fuel choice-specific coefficients, u_i is an unobserved heterogeneity of household characteristics, and ε_{ijt} is an independently and identically distributed random error term.

Correspondingly, the conditional probability that household i chooses cooking fuel j in time t with unobserved household heterogeneity is provided by equation (2).

$$\Pr\left(f_{it} = t_j | x_{it}, u_i\right) = \frac{\exp(x_{it}\beta_j + u_{ij})}{1 + \sum_{k \neq B}(x_{it}\beta_k + u_{ij})}, j \neq B \quad (2)$$

Where B denotes the base outcome of the cooking fuel type. The equation shows that probability of choosing cooking fuel type is conditional on the set of household-level effects and the observable household characteristics (Choumert-Nkolo et al., 2019).

4.2 Principal Component Analysis (PCA)

This study uses Principal Component Analysis (PCA) to construct a household wealth index (Chasekwa et al., 2018; Filmer & Pritchett, 2001; Vyas & Kumaranayake, 2006). PCA is a popular multivariate statistical technique for extracting only the most critical information from observed data and producing a set of new orthogonal variables known as principal components. This study uses the 13 households' durable assets (ownership of radio, TV, VCD, sewing machine, washing machine, refrigerator, cooker, electric fan, computer, telephone, mobile phone, motor bicycle and car) to measure the household wealth (See Appendix 1). The first principal component was selected as the wealth index (Houweling, Kunst, & Mackenbach, 2003; McKenzie, 2005; Vyas & Kumaranayake, 2006), and it was divided into five wealth quintiles from poorest to wealthiest households.

4.3 Advanced Sustainability Analysis (ASA)

The second and third research questions of the study are to identify whether there is a synergy between SDG 4 and SDG 7, as well as SDG 6 and SDG 7. Synergy is statistical interaction among two independent variables, say Y_i and Y_j, and conventionally such interactions are presented as the product of those variables, i.e., $Y_i \times Y_j$ (Luukkanen et al., 2012; Southwood, 1978).

A positive synergy between two variables exists when their combined effect is greater than the sum of individual effects. In mathematically, this can be expressed as:

$$Z = Ax + By + Cxy + D \quad (3)$$

Where Z is the dependent variable, x, y are independent variables, and A, B, C, and D are coefficients. The component of "Cxy" determines the synergy between variable x and y. If we observe the change in these variables (x and y) between two points, say P (x_0,y_0) to Q (x_1,y_1), we can determine the change in the area (Δz) as:

$$\Delta z = A\Delta x + B\Delta y + C\Delta x\Delta y \quad (4)$$

The synergy of the inputs is determined by the third component i.e., $\Delta x\Delta y$ which is represented by the shaded area in Figure 2 (a) and (b). The synergy can be either positive or negative. If the change in y is positive for the positive changes in x, then $\Delta x\Delta y$ is positive, indicating synergy. On the contrary, if the change in y is negative to the positive changes in x, then $\Delta x\Delta y$ is negative, indicating a trade-off situation. The potential synergy can be expressed as the slope of the line AB, i.e. as the ratio of $\Delta y/\Delta x$ (Luukkanen et al., 2012).

Figure 2(a): Synergies

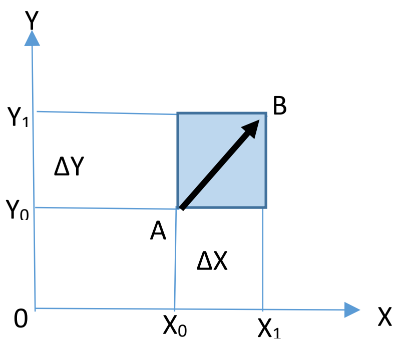
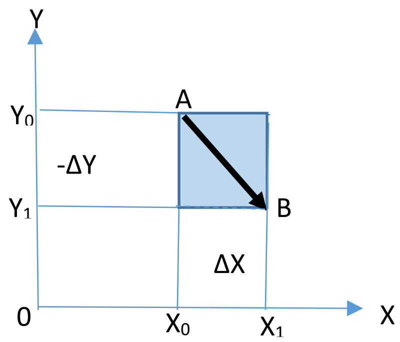


Figure 2(b): Trade-offs

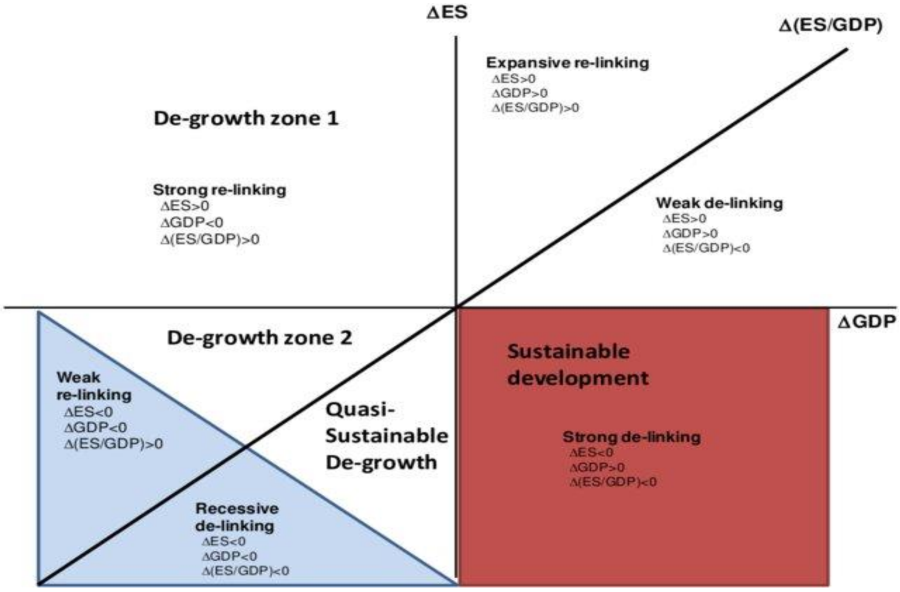


Maximum synergy can be obtained when relative changes are equal ($\Delta x = \Delta y = 1$). Therefore, potential synergy/trade-off between two variables can be measured between -1 and +1. The positive sign indicated the synergy, while the negative sign indicates a trade-off between two variables.

This study uses Advanced Sustainability Analysis (ASA) approach to identify the synergies between SDG 4, SDG 6, and SDG 7. This approach has been used in quantitative evaluations of synergies in several studies (Luukkanen & Kaivo-oja, 2002; Luukkanen et al., 2012; Mainali et al., 2018; Vehmas, Luukkanen, & Kaivo-oja, 2007).

ASA is developed under the European framework programme and it helps in analysing complex sustainable development questions in an integrated manner. Furthermore, ASA approach offers decision-makers a tool for policy analyses and policy formulations regarding different dimensions of sustainable development (Luukkanen et al., 2012). A generic evaluation framework of sustainable development based on ASA approach is presented in Figure 3.

Figure 3: Framework of evaluating sustainable development



(Kaivo-oja, Vehmas, & Luukkanen, 2014; Mainali et al., 2018; Vehmas et al., 2007)

The framework describes the various facets of sustainable development in terms of economic growth (GDP), environmental stress (ES), and environmental intensity of economic growth (ES/GDP). It highlighted two situations: (1) re-linking; and, (2) de-linking. Re-linking indicates that ES increases as GDP rises over time, suggesting synergies between the two variables, while de-linking states that ES falls as GDP rises, meaning a trade-off between the two variables. ASA approach can provide useful insight to identify the synergies between variables.

5. Results & Discussion

5.1 Determinants of household cooking fuel choice: MNL model results

The random-effects panel multinomial logit regression is used to investigate the determinants of cooking energy choice in Sri Lanka. Table 2 presents the results of the estimation of the multinomial logit model on the determinants of household cooking fuel choice. For comparison purposes, Appendix 2 displays the effects of full regression analysis with pooled MNL and a fixed effect MNL. All fuel alternatives are compared to solid fuels, which served as the base category.

Table 2: Random Effects Multinomial Logit Results

Explanatory Variables	Coefficients		Marginal Effect		
	Transitional Fuels	Clean Fuels	Solid Fuels	Transitional Fuels	Clean Fuels
Household Income (log)	-0.023	0.124***	-0.012***	-0.000**	0.013***
	(0.018)	(0.012)	(0.001)	(0.000)	(0.001)
Household Wealth					
Poor Households (Poorest = 0)	0.285***	1.068***	-0.109***	0.002	0.107***
	(0.101)	(0.091)	(0.009)	(0.001)	(0.009)
Medium Wealth Households (Poorest = 0)	1.006***	2.339***	-0.243***	0.009***	0.233***
	(0.096)	(0.085)	(0.007)	(0.001)	(0.007)
Wealthy Households (Poorest = 0)	1.180***	3.116***	-0.321***	0.010***	0.311***
	(0.107)	(0.085)	(0.007)	(0.001)	(0.007)
Wealthiest Households (Poorest = 0)	1.078***	4.019***	-0.409***	0.008***	0.402***
	(0.137)	(0.088)	(0.008)	(0.002)	(0.007)
Household Head					
Gender (Female = 0)	-0.138	0.002	0.001	-0.002	0.000
	(0.104)	(0.053)	(0.005)	(0.001)	(0.005)
Marital Status (No = 0)	0.272	0.140	-0.017	0.003	0.014
	(0.182)	(0.100)	(0.010)	(0.002)	(0.010)
Age (log)	-0.249**	0.129**	-0. 010	-0.003**	0. 013**
	(0.116)	(0.063)	(0.006)	(0.001)	(0.006)
Primary Education (No Schooling = 0)	-0.039	0.169	-0.016	-0.001	0.017
	(0.146)	(0.107)	(0.010)	(0.002)	(0.011)
Secondary Education (No Schooling = 0)	-0.019	0.696***	-0.069***	-0.001	0.070***
	(0.150)	(0.106)	(0.011)	(0.002)	(0.011)
Tertiary Education (No Schooling = 0)	-0.069	1.430***	-0.141***	-0.003	0.144***
	(0.384)	(0.127)	(0.014)	(0.005)	(0.013)
Government Employee (Other Sector = 0)	-0.399***	-0.034	-0.008*	0.005***	-0.003
	(0.132)	(0.042)	(0.005)	(0.002)	(0.004)
Private Sector Employee (Other Sector = 0)	0.160**	0.097***	-0.011***	0.002**	-0.009***
	(0.068)	(0.033)	(0.003)	(0.001)	(0.003)
Spouse					
Age (log)	-0.108*	-0.139***	0.014***	-0.001	-0.013***
	(0.057)	(0.033)	(0.003)	(0.000)	(0.003)
Primary Education (No Schooling = 0)	0.449**	0.060	-0.011	0.005**	0.005
	(0.217)	(0.129)	(0.013)	(0.003)	(0.013)
Secondary Education (No Schooling = 0)	0.171	0.263**	-0.028**	0.002	0.026**
	(0.214)	(0.125)	(0.013)	(0.003)	(0.013)
		0.841***			
Tertiary Education	-0.831	(0.148)	-0.074***	-0.011	0.086***

(No Schooling = 0)	(0.639)		(0.017)	(0.008)	(0.015)
Household Characteristics					
Household Size	0.043*	-0.183***	0.018***	0.001***	-0.018***
	(0.025)	(0.013)	(0.001)	(0.000)	(0.001)
Number of Children Under 5	0.015	0.255***	-0.025***	-0.000	0.026***
	(0.065)	(0.029)	(0.003)	(0.000)	(0.003)
Number of Females	-0.116***	0.042**	-0.003	-0.001***	0.004***
	(0.038)	(0.017)	(0.002)	(0.000)	(0.002)
Housing Characteristics					
Number of Bed Rooms	-0.778***	-0.171***	0.025***	-0.009***	-0.016***
	(0.042)	(0.014)	(0.001)	(0.000)	(0.001)
Safe Drinking Water	0.430***	0.496***	-0.054***	0.005**	0.049***
(Unsafe Water = 0)	(0.157)	(0.066)	(0.007)	(0.002)	(0.007)
Indoor Toilets	2.023*	0.457	-0.067	0.024*	0.043
(No Toilets = 0)	(1.039)	(0.401)	(0.041)	(0.013)	(0.040)
Outdoor Toilets	1.775*	-0.095	-0.010	0.022*	-0.012
(No Toilets = 0)	(1.038)	(0.400)	(0.041)	(0.013)	(0.040)
Improved Toilets	-0.735	0.122	-0.011	-0.001	0.012
(Unimproved Toilets=0)	(0.153)	(0.101)	(0.010)	(0.002)	(0.010)
Permanent Wall	0.013	0.660***	-0.065***	-0.001	0.066***
(Semi-Permanent = 0)	(0.107)	(0.094)	(0.009)	(0.001)	(0.009)
Permanent Floor	0.455**	0.415***	-0.046***	0.005**	0.041***
(Semi-Permanent = 0)	(0.178)	(0.078)	(0.008)	(0.002)	(0.008)
Permanent Roof	-0.030	-0.396***	0.040***	0.000	-0.040***
(Semi-Permanent = 0)	(0.124)	(0.081)	(0.008)	(0.002)	(0.008)
Residential sector					
Urban (Estate = 0)	3.178***	1.944***	-0.227***	0.036***	0.191***
	(0.192)	(0.085)	(0.009)	(0.002)	(0.009)
Rural (Estate = 0)	0.849***	0.277***	-0.037***	0.010***	0.027***
	(0.198)	(0.084)	(0.009)	(0.002)	(0.008)
District Dummy	Yes				
Year Dummy	Yes				
Log psedolikelihood	-24644.123				
Number of Observations	57,978				

Notes: Huber – White cluster-robust sandwich standard errors in parentheses; ***,**, and * represent significant at the 1%, 5% and 10% levels, respectively. Dummy Variables; Household Wealth, Gender, Marital Status, Education, Employment Sector, Drinking Water Source, Toilet use and type, Type of wall, floor and roof, and residential Sector.

As shown in Table 2, the estimated coefficient for household income is positive and statistically significant for clean fuels, indicating that an increase in household income is more likely to increase clean fuels' choice than solid fuels. This finding is consistent with the energy ladder theory, which assumes that households switch their energy consumption from traditional to modern sources as household income rises (Heltberg, 2004; Hosier & Dowd, 1987). Furthermore, this is consistent with the finding of the literature (Baiyegunhi & Hassan, 2014; Behera et al., 2015; Mensah & Adu, 2015; Özcan et al., 2013; Ravindra et al., 2019; Sharma et al., 2019). This outcome is primarily motivated by the affordability of modern fuels against less costly traditional fuels (Mensah & Adu, 2015).

We construct the wealth index to measure the long-term wellbeing of the households. The predicted coefficient for wealth status shows a significant positive relationship with clean and transitional fuels relative to solid fuels. The household's wealth status positively, significantly, and progressively affects the choice of clean and transitional energy. In contrast, it has a negative, significant, and progressive impact on the choice of solid fuels. For example, the marginal effect suggests that an increase in household wealth by 1%, the use of clean fuels would be expected to increase by 10.7% in poor households (Q2), 23.3% in medium wealth households (Q3), 31.1% in wealthy households (Q4), and 40.2% in wealthiest households (Q5) compared to the poorest families. The results are consistent with the literature (Baiyegunhi & Hassan, 2014; Behera et al., 2015; Mottaleb et al., 2017; Paudel et al., 2018; Rahut, Behera, Ali, et al., 2017). A possible explanation is that as households' wealth increases, they shift to clean and modern fuels as economically affluent households are not in favour of solid energy (Mottaleb et al., 2017).

The calculated coefficient for the age of the head is positive and statistically significant for the probability of selecting clean fuels, reflecting that a rise in the age of head is more likely to influence the preference towards the clean energy relative to solid energy. The results are consistent with the previous findings (Behera et al., 2015; Özcan et al., 2013; Rahut, Behera, Ali, et al., 2017; Sharma et al., 2020). This may be because the younger heads are less economically well-off (Rahut, Behera, Ali, et al., 2017). Nevertheless, the findings of some studies contradict the results (Choumert-Nkolo et al., 2019; Liao et al., 2019; Mensah & Adu, 2015; Paudel et al., 2018). In addition, Israel (2002) and Mottaleb et al. (2017) did not find any relationship between the head's age and clean fuel choice. Furthermore, a year's increase in the age of the household head is expected to increase the choice of solid fuels. However, notably the age of the spouse is negatively affected by choice of clean energy. This might happen as most elderly people may have become used to conventional fuels and are therefore less likely to move towards modern energies (Mensah & Adu, 2015). Moreover, Heltberg (2005) mentions that households will continue to use dirty energy like fuelwood through established loyalty, taste preferences, and traditional cooking methods.

The variable "Education" has identified as one of the main determinants of clean fuel choice for cooking (Choumert-Nkolo et al., 2019; Hou et al., 2017; Mottaleb et al., 2017; Paudel et al., 2018; Ravindra et al., 2019). By confirming these studies, our findings also show that having secondary and tertiary education levels for head and spouse is positive and statistically significant for clean fuels choice compared to solid fuels. This consequence can emerge for three reasons: (1) growing levels of education can raise the awareness of negative impacts of health and the environment of using solid fuel for cooking (Sharma et al., 2019); (2) higher levels of education can increase the household income and thus improve their affordability for more commercial, clean fuels (Baiyegunhi & Hassan, 2014); and (3) higher the levels of female education can increase the opportunity cost of collecting fuelwood, and thereby increase the commercial fuel consumption (Farsi, Filippini, & Pachauri, 2007; Ravindra et al., 2019).

Furthermore, the MNL estimates show that the employment sector of the head significantly impacts cooking fuel choice. If the head employs in the private sector (compared to the other sectors), he is likely to increase the likelihood of choosing clean and transitional fuels. This is especially likely in Sri Lanka, where private-sector workers receive greater financial benefits than government-sector employees.

Household size has also been identified as the key variable for the choice of cooking fuel. In contrast to solid fuels, the projected coefficient for household size is negative and statistically significant for clean fuels at a 1% level. This implies that an increase in a the number of family members in the household reduces the probability of using clean fuels. The outcomes are consistent with the findings of Sharma et al. (2019), Paudel et al. (2018), and Sharma et al. (2020). According to Sharma et al. (2019), large families have a high demand for cooking fuel, and therefore to maintain a low monetary burden, households may choose more home-produced or collected solid fuels. Also, Mottaleb et al. (2017) highlighted having more family members may have more unpaid labour to collect biomass, and the opportunity cost of collecting biomass is low. However, theoretically, household size is expected to negatively influence the usage of fuelwood alternatives, as households with many members may have larger labour input to collect fuelwood. Thus, this observation contradicts the findings of some studies (Baiyegunhi & Hassan, 2014; Choumert-Nkolo et al., 2019; Mensah & Adu, 2015; Ouedraogo, 2006). Furthermore, Amoah (2019) found no impact of household size in selecting cooking fuel.

The estimated coefficient of the variable "number of children under 5" is positively and significantly related to the household choice of clean fuels. The marginal effect interprets that adding one child under five to the family is more likely to increase the clean fuel choice by 2.6%. Noticeably, the results are opposed to the findings of Behera et al. (2015). In addition, Baiyegunhi and Hassan (2014) specify that having more children is more likely to have more child labour to collect fuelwood, increasing the solid fuel consumption. Similarly, the number of females in the household also plays a vital role in selecting clean fuel for cooking. The estimated coefficient for clean fuel is positive but negative for transitional fuels. The studies conducted in Bhutan by Rahut et al. (2016) and Sub-Saharan Africa by Rahut, Behera, and Ali (2017) find similar results.

Besides that, housing characteristics such as the number of bedrooms, type of wall, floor, and roof are also defined as vital factors in selecting the cooking energy. The estimated coefficient for the number of bedrooms is statistically significant for both clean and transitional fuel at a 1% level. Our result is inconsistent with Heltberg (2005) study, which found the number of bedrooms positively affects clean fuel demand for cooking, and Özcan et al. (2013), who find no impact. Having permanent walls and floor generates a significant positive impact on the use of clean fuels. Surprisingly, an increase in the permanent floor leads to a decrease in the the clean energy choice. Yet, Liao et al. (2019) could not find any significant impact of housing conditions on cooking fuel choice.

For drinking water and sanitation facilities, the estimated coefficient for safe drinking water is positive and statistically significant for the probability of household choice of clean fuels at a 1% level. This is consistent with Liao et al. (2019) which found families that use in-house tap water are more likely to use gas instead of firewood. However, type of toilet and the availability of toilets do not impact selecting cooking fuels.

We use three dummies for the residential sector: urban, rural, and estate. As per coefficients, urban and rural households are more likely to use clean and transitional fuels than estate sector households. The marginal effects highlighted that it is more likely to use clean fuels in the urban sector than the rural sector. Choumert-Nkolo et al. (2019), Paudel et al. (2018), Mensah and Adu (2015), and Sharma et al. (2019) also found that urban sector families use more gas and electricity than fuelwood as the main cooking fuel. The possible explanation would be the difference in accessibility, reliability in supply, and nature of buildings (Mensah & Adu, 2015). This indicates that supply-side factors are also key drivers in the transition of energy from traditional to modern fuel use.

5.2 Identification of synergies: SDG 4, SDG 6, and SDG 7

Although each SDG focuses on different aspects, most SDGs are integrated, indivisible and create synergies to meet the 2030 SDG targets. Thus, gaining a greater understanding of these relationships will assist governments in prioritizing highly influential goals and improving cross-sectoral coordination. This segment describes synergies in detail between SDG 4 and SDG 7, as well as SDG 6 and SDG 7 using ASA approach (Luukkanen & Kaivo-oja, 2002; Luukkanen et al., 2012; Mainali et al., 2018; Vehmas et al., 2007).

Although the analyses of synergies and trade-offs can go beyond these three SDGs, we have limited our analysis within these specific SDGs due to data unavailability and deeper understanding of their linkages. Table 3 shows the targets and measurement variables in each selected SDG for synergy identification.

Table 3: SDG Targets and Measuring Variables

SDGs	Targets	Measuring/Tracking Indicators
SDG 4	4.1 Ensure that all girls and boys complete free, equitable and quality primary and secondary education	The highest level of education of head and spouse
SDG 6	6.1 Achieve universal and equitable access to safe and affordable drinking water for all	1.Main source of drinking water (Safe/Unsafe) 2.Ownership of water 3.Sufficiency of water for drinking
	6.2 Achieve access to adequate and equitable sanitation and hygiene for all	1.Type of toilet facility that members of your household usually use (Improved/Unimproved) 2.Sharing of the toilet facility with other households (Shared/Unshared/no toilet) 3. Sufficiency of water for cooking & washing
SDG 7.1	7.1 Ensure universal access to affordable, reliable and modern energy services	Type of fuel household is mainly use for cooking

5.2.1 Synergy among SDG 4 and SDG 7

SDG 4.1 targets to provide free, equitable and quality primary and secondary education, while SDG 7.1 ensures access to affordable, reliable and modern energy services for all. We use the mean of the highest level of education of both household head and spouse to measure the SDG 4.1 target (see Figure 4a). On the other hand, to operationalize the SDG 7.1, we use the mean of households who uses clean cooking fuels (electricity and LPG) for cooking (see Figure 4b).

Figure 4(a): Clean Cooking Fuel Use

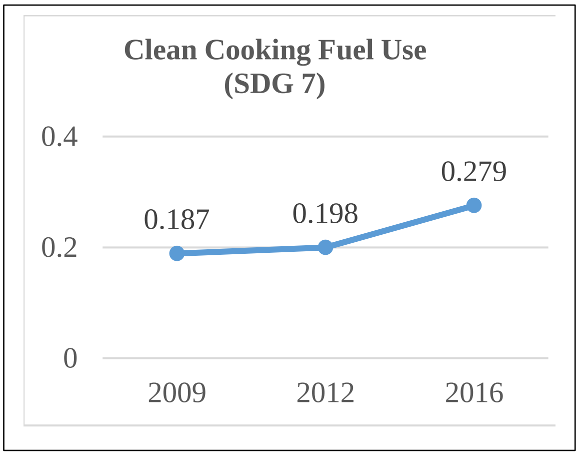
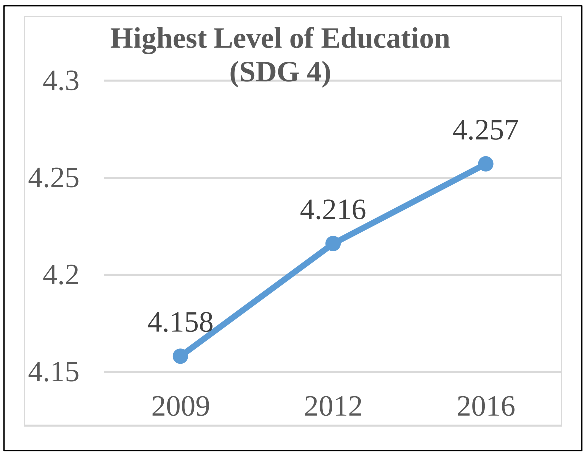


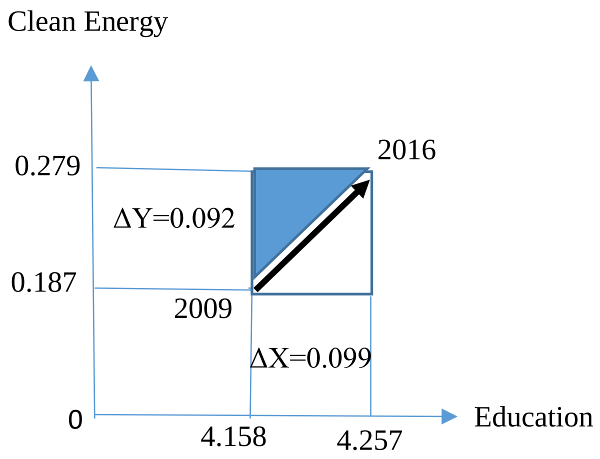
Figure 4(b): Highest Level of Education



From 2009 to 2016, Figure 4(a) depicts the gradual increase in the use of modern cooking fuels. In 2009, the average number of households using clean, modern cooking fuels was 0.18 and by 2012 and 2016, that figure had increased to 0.19 and 0.27, respectively. Following the same path, the average education of household heads and spouses continuously increased between 2009 and 2016. The average education level in 2009 was 4.19, rising to 4.20 and 4.23 in 2012 and 2016, respectively as shown in Figure 4(b).

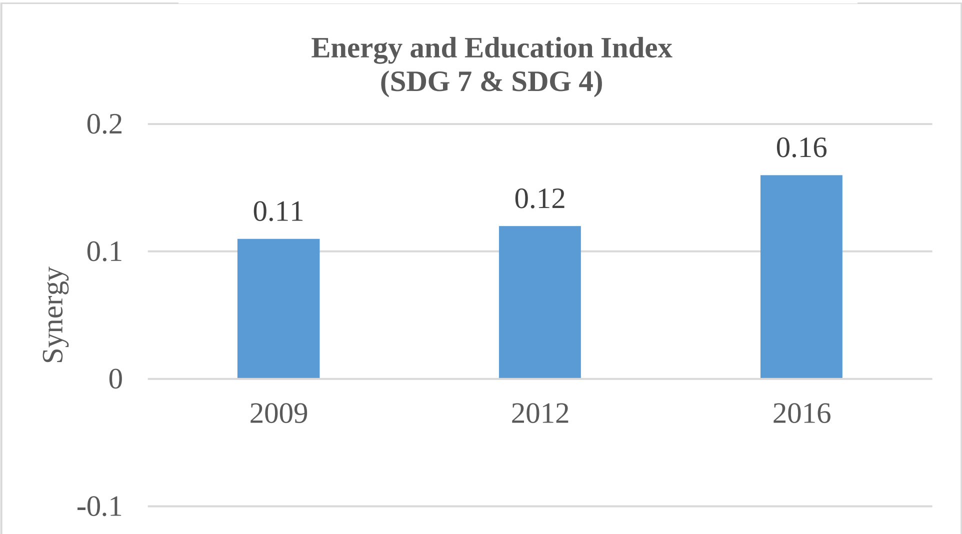
Figure 5 indicates that there has been synergy between energy and education because both the indicators have been increasing during the time. The shaded area shows, expansive re-linking ($\Delta CE/\Delta Edu = 0.93$) between education and clean cooking fuel use. i.e. it shows the strong synergy between SDG 4 and SDG 7, indicating that increase in the education level of both head and spouse increase the use of clean fuel for cooking.

Figure 5: Synergy between clean energy and education



Similarly, we construct the index for synergy between energy and education, ranging from +1 to -1. The results show the index value is positive and close to +1 (see Figure 6), indicating the synergy between education (SDG 4) and clean cooking fuel (SDG 7).

Figure 6: Synergy between Energy and Education



Overall, the results indicate that the greater the degree of schooling for heads and spouses, the greater the use of modern, clean energy sources. This demonstrates that education is an important determinant of fuel switching and shows the synergetic effect of SDG 4 on

SDG 7. The results are consistent with Pradhan et al. (2017). Therefore, education can be used as a long-term policy to shift household fuel use from traditional biomass to cleaner cooking fuels (Chambwera & Folmer, 2007).

As per the sustainable development report 2020, Sri Lanka has already achieved the targets of SDG 4. The statistics show that the net primary enrolment rate in Sri Lanka was 99.1%, and the literacy rate (people aged 15 to 24) was 98.8% in 2018 (Sachs et al., 2020). However, according to the same report, achieving SDG 7 remains a major challenge since only 26.3% of people have access to clean fuels and cooking technology. They also assert that the score is stagnating or growing at less than half the expected rate, suggesting that the SDG 7 will not be reached by 2030. As a result, the responsible governing bodies should develop educational policies to promote clean cooking fuels, as education creates synergetic impact on clean cooking fuel choice.

5.2.2 Synergy among SDG 6 and SDG 7

SDG 6.1 strives to provide universal and equal access to safe and affordable drinking water, while SDG 6.2 aims to provide adequate and equitable sanitation and hygiene to all by 2030. As a whole, SDG 6 ensures the availability and sustainable management of water and sanitation for all. To operationalise the SDG 6, we make additive index by using the variables safe drinking water, water ownership, water sufficient for drinking, improved toilets, unshared toilets, and water sufficient for wash and bath.

Figure 7(a): Clean cooking fuel use

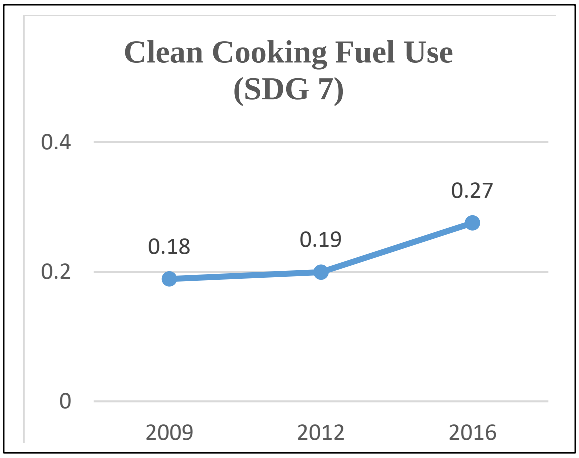


Figure 7(b): Water and sanitation facilities

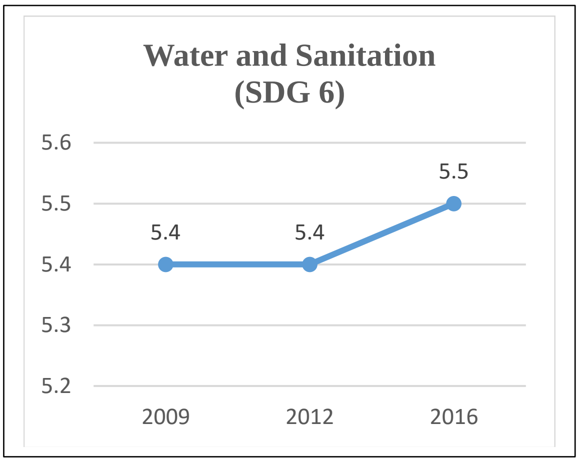


Figure 7(a) depicts the steady rise in the use of modern cooking fuels from 2009 to 2016 (0.18%, 0.19%, and 0.27% in 2009, 2012, and 2016 respectively). Between 2009 and 2016, the average number of water and sanitation facilities grew slowly. In 2009, the average number of water and sanitation facilities was 5.4, remain the same in 2012 and increases to 5.5 in 2016 (Figure 7b).

Since both measures have been rising over time, Figure 8 shows that there has been a synergy between energy and water and sanitation. The shaded area depicts a wide re-linking

(ΔCE/ΔWS = 0.9) between education and the use of clean cooking fuels. i.e., it demonstrates a strong synergy between SDG 4 and SDG 6, suggesting that improved water and sanitation facilities could lead to increased use of clean cooking fuel.

Figure 8: Synergy between Clean Energy and Water and Sanitation

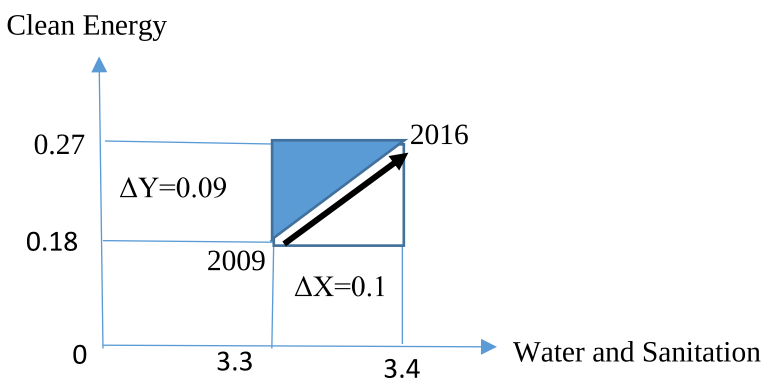
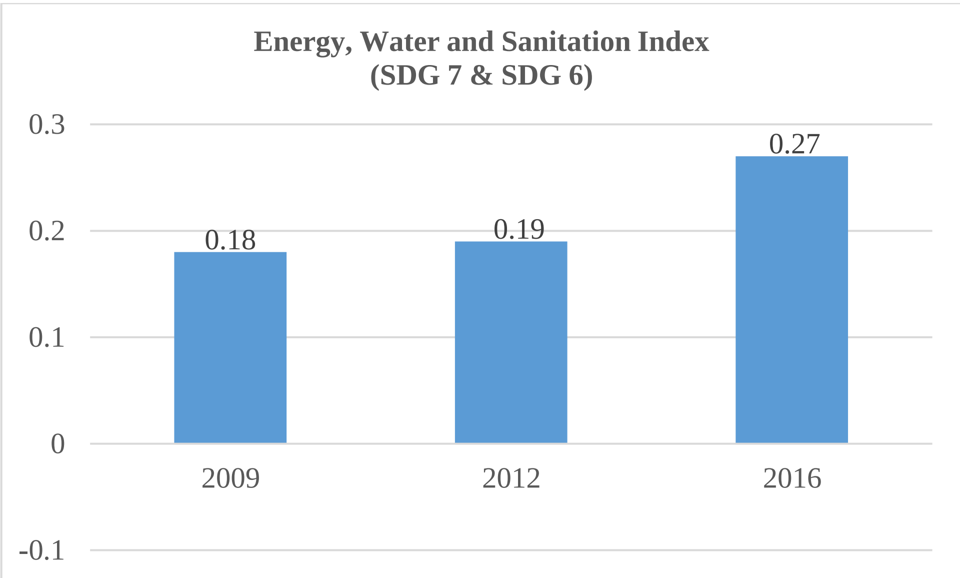


Figure 9 illustrate that the index for synergy between energy and water and sanitation. In all time spans, the value is positive and close to +1 suggesting, the synergy between water and sanitation (SDG 6) and clean cooking fuel (SDG 7).

Figure 9: Synergy between Energy, and Water & Sanitation



The result is consistent with Fader et al. (2018) and Mainali et al. (2018) who found that SDG 6 reinforces the achievement of SDG 7. Further, Khan, Mainali, Martin, and Silveira (2014) found that access to energy plays a vital role in providing clean water in many remote locations in Bangladesh.

In Sri Lanka, the government of Sri Lanka developed a national policy in 2010 to ensure that all people have access to clean drinking water and basic sanitation. As a result, the synergy between SDG 6 and SDG 7 improves steadily and consistently. However, according to the 2020 Sustainable Development Report, the score for SDG 6 is moderately growing, suggesting that achieving the target by 2030 would be inadequate. According to Sachs et al. (2020), 89.4% of the population used at least basic drinking water services, and 95.85% used basic sanitation services in 2017. Consequently, since SDG 6 has a synergistic impact on SDG 7, it is preferable to develop policies that improve basic water and sanitation facilities to encourage the use of clean cooking fuels, allowing both SDGs to be achieved by 2030.

6. Conclusion and Policy Implications

This paper analyses the determinants of cooking fuel choice and synergy between SDG 4, SDG 6, and SDG 7 using panel data from Household Income and Expenditure Surveys (HIES) in Sri Lanka for three years, 2009, 2012, and 2016. The descriptive statistic shows that 75.5% of households still use solid fuels as the primary cooking fuel, and demographic, socioeconomic, and housing attributes significantly affect the choice of cooking fuel.

The empirical findings from the random effects panel multinomial logit model find that household income, wealth, education of head, age and education of spouse, household size, and the number of children are statistically significant at 1% level for clean cooking fuel choice compared to solid fuels. In addition, housing characteristics such as the number of bedrooms, drinking water sources, and housing materials (type of wall, floor and roof) are also important for selecting clean fuels for cooking. Moreover, the geographical location, such as the urban and rural sector, is statistically crucial to obtain clean cooking fuels. About transitional fuels, household wealth, employment sector of the head, household size, the number of females, the number of bedrooms, and the residential sector are statistically significant at 1% level.

More interestingly, we find a strong synergy between education and clean, modern forms of fuel such as gas and electricity over time, which indicates the synergistic benefits of SDG 4 in achieving SDG 7. In parallel, access to safe and sufficient drinking water facilities promotes clean fuels, reflecting synergies between SDG 6 and SDG 7. The findings are consistent with the results of previous research and provide several new policy insights as well.

The results of the current study have major implications for achieving SDG 7 by 2030. First, it is important to formulate a sustainable national energy policy by providing households with the right incentives to move from solid to clean energy, particularly by addressing the demographic, socioeconomic, and housing factors that influence selecting energy sources. Secondly, the government should attempt to achieve SDG 4 and SDG 6, as they benefit synergistically for achieving SDG 7.

Although a large nationally representative data set is used in this paper, some of the key variables influencing the choice of cooking fuel, i.e. fuel price, are not included in our current research due to data unavailability, which might be addressed in future research.

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Appendix

Appendix 1 – Principal Component Analysis (PCA)

This study uses Principal component analysis (PCA) to construct the household wealth index based on literature (Chasekwa et al., 2018; Filmer & Pritchett, 2001; Vyas & Kumaranayake, 2006). PCA is one of the most popular multivariate statistical techniques that exact only the most crucial information from the observed data and develop the set of new orthogonal variables called principal components. There are four main objectives of PCA: (1) detach the most information from the data table; (2) reduce the size of the data set by keeping only the necessary information; (3) simplify the description of the data set and (4) analyse the structure of observations and the variables (Abdi & Williams, 2010).

PCA makes uncorrelated components from an initial set (suppose n) of correlated variables, and those components are considered linear weighted components of the initial variables (Vyas & Kumaranayake, 2006). The derivation of principal components from a set of variables X_1 to X_n are as follows:

$$PC_1 = \alpha_{11}X_1 + \alpha_{12}X_2 + \ldots + \alpha_{1n}X_n$$

$$PC_m = \alpha_{m1}X_1 + \alpha_{m2}X_2 + \ldots + \alpha_{mn}X_n$$

where α_{mn} represents the weight for the m^{th} principal component and n^{th} variable, the weight for each component is ordered from 1 to m. The first components (PC_1) shows the largest possible amount of variation in the original data, which is subject to the sum of squared weights ($\alpha^2_{11} + \alpha^2_{12} + \ldots + \alpha^2_{1n}$). The second component is entirely uncorrelated with the first component and shows the additional variation subject to the same constraint. Likewise, each additional component explains the further variation at a decreasing rate. Element is given by the eigenvector of the correlation matrix or covariance matrix. The eigenvalue measures each principal component's variance and indicates the percentage of variances in the total data explained. Fewer components are required if there is a higher degree of correlation among the original variables in the data (Vyas & Kumaranayake, 2006).

Following the rule of thumb, we first select the variables in the data set that have a frequency of between 5% and 95% to include in the PCA. Then we looked at the correlation and eliminated any variables with a correlation of less than 1.0 or greater than 0.9. Finally, we use the 13 households' durable assets (ownership of radio, TV, VCD, sewing machine, washing machine, refrigerator, cooker, electric fan, computer, telephone, mobile phone, motor bicycle and car) to measure the household wealth. The sample adequacy is satisfied by the Kaiser-Meyer-Olkin measure value of 0.89 (kmo > 0.6). The wealth index, which has a 4.18 eigenvalue and a cumulative variation of 32.22 percent, is chosen as the first principal component. After that, we divide the all the households into five wealth quintiles: the poorest households; the poor households; the medium wealth households; the wealthy households; and he wealthiest households.

Appendix 2 – Multinomial Logistic Regression Results for Clean Fuels

Explanatory Variables	(1) POMLOGIT	(2) RELOGIT	(3) FELOGIT
Household Income (log)	0.089***	0.124***	0.156***
	(0.012)	(0.012)	(0.015)
Household Wealth			
Poor Households	0.984***	1.068***	1.196***
(Poorest = 0)	(0.092)	(0.091)	(0.121)
Medium Wealth Households	2.174***	2.339***	2.290***
(Poorest = 0)	(0.086)	(0.085)	(0.117)
Wealthy Households	2.942***	3.116***	3.020***
(Poorest = 0)	(0.087)	(0.085)	(0.119)
Wealthiest Households	3.820***	4.019***	3.954***
(Poorest = 0)	(0.091)	(0.088)	(0.125)
Household Head			
Gender (Female = 0)	0.057	0.001	0.018
	(0.055)	(0.052)	(0.080)
Marital Status (No = 0)	0.016	0.140	0.150
	(0.107)	(0.100)	(0.158)
Age (log)	-0.116*	0.129**	0.157
	(0.065)	(0.063)	(0.097)
Primary Education	0.137	0.169	0.179
	(0.110)	(0.107)	(0.166)
Secondary Education	0.624***	0.696***	0.702***
	(0.110)	(0.106)	(0.166)
Tertiary Education	1.410***	0.840***	1.440***
	(0.133)	(0.148)	(0.209)
Government Employee	0.034	-0.0344	-0.055
(Other Sector = 0)	(0.044)	(0.042)	(0.069)
Private Sector Employee	-0.103***	0.0968***	-0.065
(Other Sector = 0)	(0.035)	(0.033)	(0.073)
Spouse			
Age (log)	-0.143***	-0.139***	-0.159***
	(0.035)	(0.033)	(0.049)
Primary Education	0.024	0.0605	0.044
	(0.135)	(0.129)	(0.193)
Secondary Education	0.213	0.263**	0.312*
	(0.131)	(0.125)	(0.185)
Tertiary Education	0.810***	0.841***	0.823***
	(0.155)	(0.148)	(0.230)
Household Size	-0.178***	-0.183***	-0.192***
	(0.013)	(0.013)	(0.020)
Number of Children Under 5	0.275***	0.255***	0.277***
	(0.030)	(0.029)	(0.047)
Number of Females	0.029	0.041**	0.023
	(0.018)	(0.017)	(0.027)
Number of Bed Rooms	-0.058***	-0.170***	-0.060***
	(0.015)	(0.014)	(0.022)

Drinking Water Source			
Safe Water	0.415***	0.496***	0.276***
(Unsafe Water = 0)	(0.069)	(0.066)	(0.110)
Toilet Use			
Indoor Toilets	0.486	0.457	0.322
(No Toilets = 0)	(0.441)	(0.400)	(0.643)
Outdoor Toilets	-0.116	-0.095	0.037
(No Toilets = 0)	(0.440)	(0.400)	(0.644)
Improved Toilets	0.206	0.121	-0.009
(Unimproved Toilets=0)	(0.114)	(0.101)	(0.170)
Type of Wall			
Permanent Wall	0.664***	0.660***	0.608***
(Semi-Permanent = 0)	(0.100)	(0.094)	(0.133)
Type of Floor			
Permanent Floor	0.195**	0.415***	0.600***
(Semi-Permanent = 0)	(0.084)	(0.078)	(0.121)
Type of Roof			
Permanent Roof	-0.248***	-0.396***	-0.308**
(Semi-Permanent = 0)	(0.085)	(0.080)	(0.127)
Sector			
Urban (Estate = 0)	1.700***	1.944***	1.735***
	(0.090)	(0.085)	(0.139)
Rural (Estate = 0)	0.100	0.277***	0.417***
	(0.090)	(0.084)	(0.135)
District Dummy	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes
Log pseudolikelihood	-22462	-24644	-4494
Pseudo R2	0.3866		0.4892
Number of Observations	57,978	57,978	23,880

Notes: Huber – White cluster-robust sandwich standard errors in parentheses; ***,**, and * represent significant at the 1%, 5% and 10% levels, respectively.

(1) Pooled Multinomial logit (mlogit), (2) Random effects Multinomial logit (gsem), and (3) Fixed effects Multinomial logit (femlogit)