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Review Paper

Transition Dynamics and Future Pathways of Clean Cooking and Heating Fuels in Sri Lankan Households: A Socio-Technical and Policy Perspective

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Abstract

Moving to clean cooking and heating is essential for making home energy more sustainable, cutting environmental impacts, and lessening health risks linked to the use of traditional fuels. This review analyzes the transition of Sri Lanka's home cooking and heating energy from a socio-technical and policy perspective. A literature review was carried out using Scopus and ScienceDirect, as well as relevant institutional reports and policy documents. We identified 145 records in total. We removed 30 duplicates and screened 115 records. We assessed 55 records by full text review and included 35 sources in the final synthesis. Fuel and technology in the home, economic and technological aspects, health and environmental consequences, and policy opportunities and obstacles were analyzed thematically. While traditional biomass remains an important fuel for household cooking, the data reviewed suggest an increasing use of cleaner alternatives such as electricity and liquefied petroleum gas (LPG). Affordability, accessibility, reliability of supply, and household preferences are some of the factors affecting fuel stacking. Though quantitative data on long-term exposure, health effects, and technology adoption are still absent, Sri Lanka-specific evidence also suggests a link between traditional biomass cooking and household air pollution. The analysis also points to policy coordination and implementation weaknesses that may hold back progress on greener household energy. The results indicate a need for policies to improve the affordability and accessibility of cleaner cooking options, to promote improved biomass technologies where appropriate, to strengthen infrastructure and awareness, and to promote coordinated action across relevant sectors. There is a need for more quantitative household-level research to strengthen the evidence base for assessing transition pathways and policy interventions.

Keywords

Sustainable development goals, Nationally determined contributions, Carbon neutrality

1. INTRODUCTION

Environmental protection has become increasingly vital for sustainable development amid rapid urbanization, industrialization, and escalating energy demands. Global population growth, accompanied by increased urbanization and energy consumption, is expected to drive a rapid rise in demand for both conventional and alternative energy sources in the coming years. In the global context, nearly 41% of households and more than 2.8 billion people depend on solid fuels such as coal and biomass for cooking and heating. Women in developing regions, including Asia and sub-Saharan Africa, predominantly rely on these solid fuels as their primary energy source (Amegah & Jaakkola 2016; Mei & Seo 2024).

The opportunity to access energy sources, in the form of fuels and electricity, is a basic necessity for the growth of a country. The energy sector is concerned with basic power sources such as crude oil, refined oil, coal, natural gas, renewable energy, including hydropower and wind energy, plus secondary energy sources such as electricity generated through various alternative techniques (Verma et al. 2021; Fernandez et al. 2025). Socioeconomic, environmental, and cultural conditions affect the utilization of clean fuels for domestic needs, including Sri Lanka. The contribution of renewable energy and changes in the national energy mix should therefore be interpreted in relation to both energy-security and household-access conditions (Koswatte et al. 2024).

Dirty fuels, such as firewood, biomass, kerosene, and dung cake, are the primary cause of indoor air pollution in the majority of houses in developing countries. In terms of clean, high-quality fuels that cause reduced harmful impacts and less capacity for indoor air pollution (IAP), are considered as liquefied petroleum gas (LPG), electricity, natural gas, and biogas (Chattopadhyay et al. 2021; International Energy Agency 2020; Pallegedara & Mottaleb 2021). However, clean and modernized energy sources are not easily accessible within the low budget of households in developing nations, where they usually depend on firewood as the main source, along with other easily accessible biomass types, to their homes and are inexpensive in terms of economic means. It is also indicated that women in urbanized areas have a strong preference for using clean fuels compared with women living in rural areas of India, and it is similarly applicable to Sri Lanka. Most of the women of Sri Lanka in rural areas are mainly involved in the collection of biomass and firewood for cooking purposes and preparation of food (Pallegedara & Mottaleb 2021).

Sri Lanka, similar to other low-income countries, faces significant challenges due to reliance on traditional heating and cooking methods. The nation's substantial dependence on solid biomass fuels, such as firewood and crop residues, results in considerable indoor air pollution and places pressure on natural resources. Such dependence results in several adverse consequences, including increased health risks, deforestation, and exacerbation of climate change impacts. Addressing these problems becomes crucial as Sri Lanka works to meet its sustainable development objectives and lessen its carbon footprint. When paired with inadequate ventilation, the majority of local wood-burning stoves produce high amounts of pollutants due to incomplete combustion (Amarasekara 2004; Rosenthal et al. 2018).

Moreover, health-damaging concentrations of products resulting from incomplete combustion (PICs) are generated in traditional, domestic biomass-combusting stoves with reduced energy conversion efficiencies during cooking globally. PICs, such as carbon monoxide (CO), nitrogen oxides, methane (CH_4), formaldehyde,

suspended particles, and non-methane hydrocarbons (NMHCs), are considered toxic elements that affect human health and are often detected in places under poor ventilation where wood and other biomass sources are combusted (Maes & Verbist 2012; Smith, 1994; Aunan et al. 2013). Therefore, this pollution has wide-ranging consequences for both the quality of life for households and the natural environment (Pallegedara & Mottaleb 2021).

As it is indicated in Verma et al. (2021), energy consumption is a major source of global greenhouse gas emissions, and cities are responsible for 70–80% of global greenhouse gas emissions and consume more than three-quarters of global energy. Therefore, it is essential to focus on corporate efforts on a low-carbon future. Furthermore, not only the alterations of supplying energy but also the factors such as adjustment of rural or urban household consumption, including the way of living, socio-economic context of the families, and regional policies affect the decarbonization approaches. Thus, policymakers, researchers, and scientists focus on reaching the Paris Agreement's goals, where a reduction of carbon emissions to 5 Gt CO_2 is expected by 2050, along with reaching a scenario of carbon neutrality by the end of the century. Furthermore, SDG 7 of the United Nations is elaborated as “Ensure access to affordable, reliable, sustainable and modern energy for all”, where the goal is to achieve global access to renewable and clean energy, enhancing the efficiency of energy usage (Verma et al. 2021). According to WHO (2002), it is mentioned that more effectively vented stoves, cleaner fuels, and better ventilation permit reduction of the impact of IAP.

Nevertheless, transitioning from solid fuels to cleaner alternatives poses a prolonged and demanding obstacle for many developing nations, necessitating elevated levels of financial, economic, and social development. However, a fundamental aspect of the global transition in developing nations towards clean fuels for heating and cooking is essential, since the choices for preparing meals and warming homes have profound implications for the environment and human well-being. The significance of this transition is especially evident within the context of Sri Lanka's energy landscape, which presents distinct challenges and opportunities for the sector. Previous research has shown that there is a positive relationship between education level and usage of efficient, clean fuel technologies, where education persuades to induce a change in family decisions by evaluating costs and benefits of clean, modern fuels (Pallegedara & Mottaleb 2021).

As per the National Energy Policy and Strategies 2019, which was formulated in line with the UN’s SDG 7, it is imperative to ensure that Sri Lankans have easy access to clean, safe, and financially viable energy sources, considering the current trends in the energy sector and the plans of Sri Lanka (Ministry of Environment 2023). Therefore, as an essential requirement in practices towards the growing need for energy efficiency and security in Sri Lanka, it is aimed to explore the existing literature on clean fuels and cooking/heating technologies, dissecting adoption trends and the environmental ramifications of conventional cooking fuels and domestic heating methods. It is expected to explore potential clean fuel opportunities encompassing different options, from LPG to biogas, ethanol, and electricity. Each option offers distinct advantages, including convenience, health benefits, and contributions to environmental sustainability. Additionally, appropriate cooking and heating technologies, such as improved cook stoves and electric heaters, will be examined to demonstrate their contributions to energy efficiency and reduced environmental emissions.

The significance of this study is further demonstrated by its potential to influence public behavior through the development of cleaner and more efficient biomass fuels, as well as related advanced technologies. The findings are expected to provide insights that may influence investment strategies, strengthen community engagement, and inform policy decisions. Implementation of these measures may mitigate adverse health effects among Sri Lankans, decrease environmental degradation, and strengthen national energy security. Therefore, the study provides knowledge and tools necessary to embark on a journey of a holistic approach towards a more sustainable and environmentally responsible future in domestic practices through a literature review.

Hence, the study is focused on the variations of home cooking and heating energy in Sri Lanka by answering three questions: (1) What fuels and technologies do households in Sri Lanka use, and how have they changed over time? (2) What are the policy, technology, health, environmental, and socio-economic issues influencing the transition to cleaner domestic energy? (3) What are the policy-relevant pathways to support Sri Lanka's transition to cleaner energy for cooking and heating?

2. METHODOLOGY

2.1 Review Design

This study uses the PRISMA framework as a reference for its systematic literature review methodology. With an emphasis on socio-technical systems, policy frameworks, and transition dynamics, the review aims to compile the body of knowledge on household cooking and heating energy transitions in Sri Lanka.

2.2 Data Sources and Search Strategy

Major academic databases, including Scopus and ScienceDirect, were used in a thorough literature search, complemented by institutional reports and policy papers from the World Bank and the World Health Organisation (WHO). Boolean operators and keywords were used to create a search method. The core search string applied across databases was: ("clean cooking" OR "domestic fuels" OR "household energy") AND ("cooking technologies" OR "heating technologies") AND ("energy transition Sri Lanka" OR "renewable energy policy Sri Lanka"). Duplicate records identified across databases and supplementary sources were removed using reference-management software prior to title/abstract screening (see Fig. 1 for the per-database record counts and full screening pathway). The primary keywords utilized were: "clean cooking," "domestic fuels," "household energy," "cooking technologies," "heating technologies," "energy transition Sri Lanka," and "renewable energy policy Sri Lanka." The search was set to English-language publications and covered the years 2002 to 2024 in order to include both fundamental studies and recent breakthroughs. The latest data available at the time of revising the manuscript were a few institutional reports and statistics published in 2025; these additional sources were added after the initial search and were not part of the original 2002–2024 database search.

2.3 Inclusion and Exclusion Criteria

Peer-reviewed journal reviews and publications had to be indexed in Scopus or ScienceDirect and were required to be related to household cooking/heating energy use. Gray literature (government reports, national policy documents, institutional websites such as the Sri Lanka Sustainable Energy Authority, the Ministry of Power and Energy, and multilateral organizations such as the World Bank and WHO) was acceptable only when it provided national statistics, policy content, or program information not available in the peer-reviewed literature. It also had to be from

a government, multilateral or academic institution that was accredited. These were acceptable if they were accessible to the general public and relevant to the energy consumption of Sri Lankan households. Grey-literature sources were checked for institutional legitimacy and currency before being included, but were not held to the same peer-review standards as journal articles.

Table 1: Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Peer-reviewed journal articles and review papers	Studies not related to household energy or cooking/heating applications
Studies focusing on household cooking and heating energy use	Articles lacking empirical, analytical, or policy relevance
	Non-English publications
Research related to clean fuels, energy transitions, or energy access	Conference abstracts, editorials, and non-scientific sources
Studies focused on Sri Lanka or comparable developing country contexts	
Publications available in English	

2.4 Screening and Selection Process

The literature selection was conducted using the PRISMA framework, which comprises the phases of identification, screening, eligibility, and inclusion. An initial total of 145 documents were identified through database searches and additional sources. Following the removal of duplicates, 115 records remained for screening. A total of 55 publications remained for full-text examination after irrelevant papers were excluded through title and abstract screening. After eligibility screening, 35 papers were selected for final review based on their relevance to household energy use, clean cooking transitions, socioeconomic issues, and policy frameworks in Sri Lanka. A PRISMA flow diagram that depicts the study selection process is shown in Fig. 1.

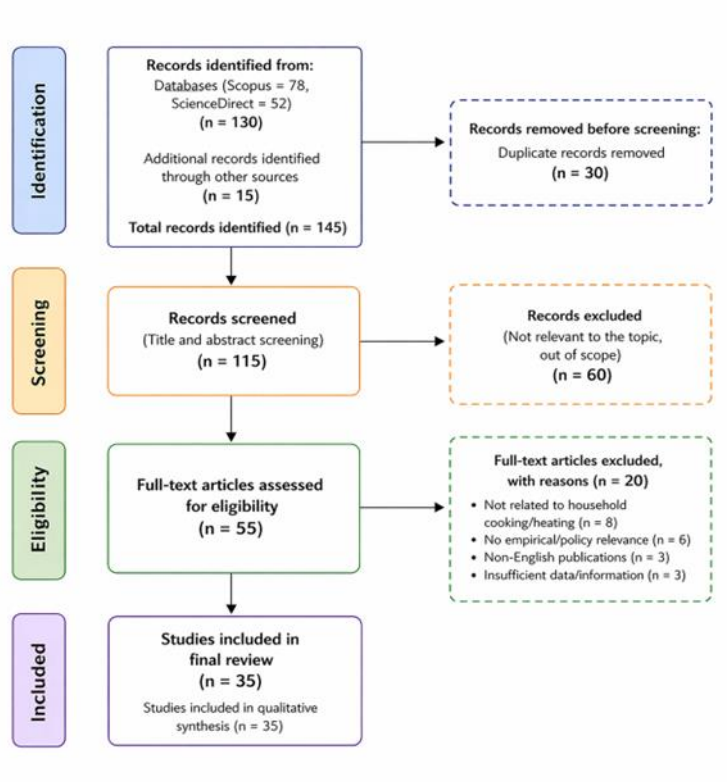


Fig. 1: PRISMA flow diagram

2.5 Data Analysis and Synthesis

The selected study was examined using a thematic synthesis to identify key patterns, trends, and connections across the literature. The analysis primarily examined barriers and facilitators to adoption, legislative frameworks, socioeconomic factors influencing fuel choice, and advancements in cooking and heating technologies. Integrating the results into a socio-technical analytical framework allowed for a comprehensive understanding of transition dynamics and possible future paths for clean cooking and heating in Sri Lanka. A formal risk-of-bias tool was not applied; instead, differences in evidence quality were addressed qualitatively during synthesis by giving greater analytical weight to peer-reviewed empirical studies, while grey-literature and policy sources were used primarily to provide national statistics and policy context rather than as a basis for causal claims.

3. CURRENT ENERGY SCENARIO IN SRI LANKA

About 20 million people live in Sri Lanka, a tropical island in the Indian Ocean. In Sri Lanka, the population is distributed as 14.6% in urban areas, 80.0% in rural areas, and 5.4% in estate areas. With the exception of biomass, fossil fuels have undoubtedly dominated energy mixes in many emerging countries (Nandasena et al. 2012). Global dependence on fossil fuels and fuelwood for energy production has contributed to global warming and subsequent climate change as a result of increased greenhouse gas (GHG) emissions. As a result, the energy ladder and energy stacking models help us better understand how energy is used in developing countries like Sri Lanka. The energy ladder concept suggests a linear shift from traditional biomass fuels to modern energy sources like electricity and liquefied petroleum gas (LPG) when household income and socioeconomic conditions improve. However, recent studies reveal that this change is not precisely linear. The energy stacking model better captures how households continue to utilise different fuel types concurrently in the real world,

rather than completely giving up conventional fuels. In Sri Lanka, the use of firewood, liquefied petroleum gas (LPG), and electricity for heating and cooking is common among households. This mixed fuel use is influenced by several factors, including supply reliability, affordability, accessibility, and cultural preferences. As a result, traditional biomass remains a major part of the household energy mix despite advancements in electrification and the availability of modern fuels (Yadav et al. 2021; Waleed and Mirza 2023).

As per findings from the literature, it is indicated that the level of income of households, access to fuel sources, size of family, price, and supply chain of fuel sources are some of the reasons that influence the decision on the fuel source. As such, the consumption of solid biomass fuels is deeply embedded in the daily lives of rural households in Asia, including Sri Lanka. Therefore, access to clean energy sources like electricity and LPG remains a significant challenge in many developing countries (Pallegedara & Mottaleb 2021). According to data sources from the Sri Lankan government, poor rural residents are more likely to use biomass fuel (Elledge et al. 2012). Furthermore, while biomass, hydropower, solar, wind, and other new renewable energy sources are examples of indigenous energy sources, the country imports petroleum and coal. Moreover, in 2017, coal accounted for 11%, biomass for 37%, and petroleum for roughly 43% of the main energy supply (Asian Development Bank 2019).

Among petroleum energy sources, LPG is primarily used for domestic cooking purposes, and kerosene is generally used for both lighting and cooking purposes (Pallegedara & Mottaleb 2021). Despite an increase in electricity use for lighting since 2000, very few families (0.4%) use it for cooking purposes, as electricity is too costly to be utilized for cooking in Sri Lanka. It is mentioned that wood remained the predominant fuel source for cooking during that period, especially by the estate and rural sector occupants, whereas LPG is less commonly utilized in countryside areas (Elledge et al. 2012; Department of Census and Statistics (DCS) & Ministry of Healthcare and Nutrition (MOH) 2009). It is also indicated that most of the Sinhalese and Buddhists utilize biomass stoves compared with other cultures and religions (Elledge et al. 2012). As per Maes (2012), improved cook stoves minimize air pollution and emissions of GHGs, while saving a significant quantity of fuelwood biomass in cooking practices (Maes & Verbist 2012).

Furthermore, according to Sri Lanka Sustainable Energy Authority (2022), it is mentioned that a shift towards dependence on renewable energy sources from petroleum energy was observed in 2022 in Sri Lanka due to the fuel crisis in energy supply. Thus, the percentage of biomass usage in energy supply was identified as 36.4% and subsequently as 32.5% by petroleum in 2022, as shown in Fig. 2. In addition, the biggest fraction of energy usage in 2022 was by domestic, commercial, and other sections, comprising of 36.2% out of the total energy demand of the country (Sri Lanka Sustainable Energy Authority 2022).

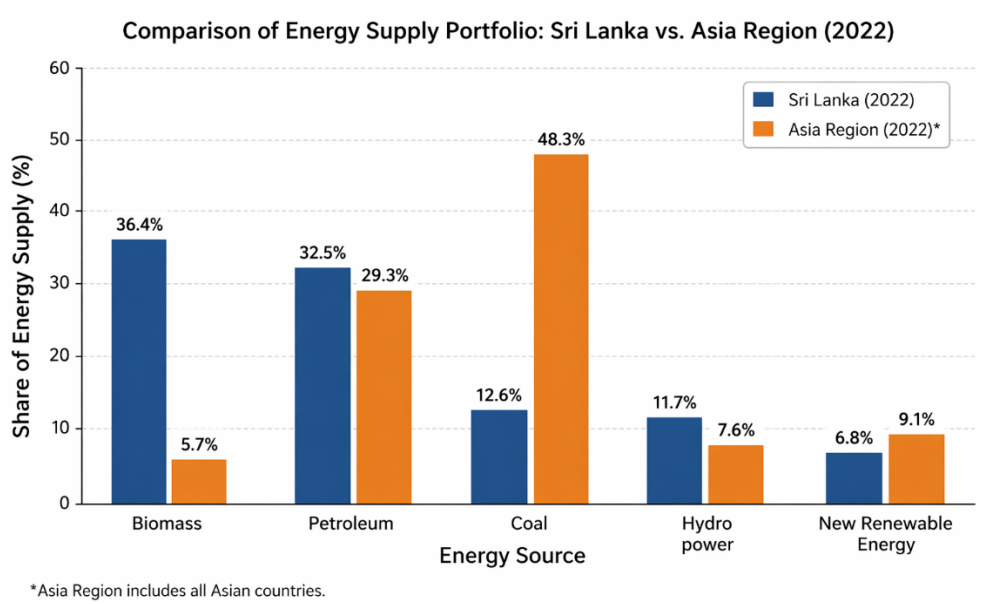


Fig. 2: Comparison of the energy supply portfolio of Sri Lanka and the Asian region in 2022. Source: Sri Lanka Sustainable Energy Authority (2022); International Energy Agency- Energy Balances of Asian Countries (2022)

Furthermore, as it is mentioned by the Sri Lanka Demographic and Health Survey 2006-07, most of the houses make use of wood for cooking purposes (79%), where many houses of the rural sector (84%) and nearly all the houses in the estate sector (96%) use firewood for cooking. However, when households from the urban sector are considered, although one-third of the households utilize wood, approximately 50% of the households use LPG or natural gas. Furthermore, it is found that domestic energy requirement is fulfilled by biomass in local houses, with 69% to satisfy the requirement of energy for cooking purposes (Musafer 2020).

It is further mentioned that firewood is a primary source of fuel for cooking purposes in the majority of parts of the country, especially in rural areas (Sri Lanka Sustainable Energy Authority, 2022; Vakalopoulos et al. 2021). Among all biomass-consuming houses using firewood, some users of biomass make use of firewood with coconut husks, coconut residues, sawdust, paddy husks, and shells. It is also found that most of the houses that utilize clean energy (LPG or electricity) as the primary source of fuel, are used to keep the secondary source as biomass. In addition, energy usage for cooling demand in Sri Lanka and the ways to manage energy-efficient requirements for cooling purposes in households should also be a concern (Koswatte et al. 2024).

Consequently, households in developing nations have a more substantial impact on climate change when compared to their counterparts in developed economies (Mensah & Adu 2015). Cooking with polluting (or "dirty") fuels releases HAP, a global environmental health hazard (Shupler et al. 2018). Inadequate cooking methods, such as the use of untreated biomass in open fires and poorly functioning indoor cooking stoves, are responsible for IAP and negatively affect the health of women and young children who often find themselves exposed to such a polluted environment, given their extended time spent indoors. Furthermore, there is a huge variety of chemicals present in biomass smoke, many of which are harmful or damaging to human health. As it is mentioned above, incomplete combustion of solid fuels is a direct source of significant IAP, generating CO, CO_2, particulate matter (PM 2.5), and other GHGs, especially in countries with low and middle-income generation (Chattopadhyay et al. 2021; Shupler et al. 2018; Muller & Yan 2018; Balakrishnan et al. 2018). According to

Smith & Mehta (2003), IAP poses potential health risks hundreds of times more severe than outdoor air pollution (International Energy Agency, United Nations Statistics Division, World Bank, & World Health Organization, 2022). Further, fuelwood harvesting for cooking purposes leads to deforestation, which in turn poses threats to ecosystem services such as local temperatures, wildlife habitat, and water filtration (Gebreegziabher et al. 2012; Heltberg 2005). Despite evidence demonstrating the adverse effects of IAP on birth weight, respiratory health, and various conditions, the health impacts of IAP in conjunction with traditional uses in Sri Lanka remain insufficiently addressed and explored. According to a study by Vakalopoulos et al. (2021), the main source of household air pollution (HAP) in Sri Lanka is stoves powered by biomass (Vakalopoulos et al. 2021).

Additionally, it is highlighted that IAP from the use of dirty fuels causes about half a million kids under the age of five to be at risk for pneumonia each year, and that half a million women die prematurely each year (Pallegedara & Mottaleb 2021). Additionally, according to Verma et al. (2021), it is indicated that around 3 billion of the population still depend on traditional fuel sources, including biomass, where more than 4 million deaths were detected in 2012 in the global context regarding the usage of biomass fuels (Verma et al. 2021). In addition, it is indicated that HAP is responsible for 3% of deaths in the globe each year, where 6% belongs to countries of low and middle income (Vakalopoulos et al, 2021). Therefore, biomass-based cooking fuels/stoves which are biomass-fuelled, are considered as the main cause of indoor air pollution in developing economies (Nandasena et al., 2012; Vakalopoulos et al. 2021). In addition, it is expected that poor people will continue to utilize biomass-based fuels for many years due to the slow rate of development in most of the countries in the Asian context (Nandasena et al. 2012).

Some research has indicated a detrimental impact of air pollution on health in Sri Lanka, where respiratory disorders, particularly respiratory diseases and asthma, have emerged as primary causes of outpatient visits to government hospitals, with morbidity rates rising in recent years (Department of Census and Statistics (DCS), & Ministry of Healthcare and Nutrition (MOH), 2009). It is further explained that 6.7 million deaths occurred due to ambient and HAP in 2019, of which 3.2 million deaths are due to HAP (World Health Organization, 2024). To further reduce the morbidity and premature mortality associated with respiratory diseases, it may be crucial to address unexplored issues such as IAP. As stated by Mitchell et al. (2007), the building itself, the strength of the indoor source, the rates of removal and deposition in the building, indoor mixing and chemical processes, furnishings, the outdoors, and building use and practices all interact in a complex way to affect indoor air quality (Mitchell et al. 2007). As stated in the work of Vakalopoulos et al. (2021), exposure to HAP through the use of biomass fuel during the pregnancy phase is associated with a growth risk of low birth weight compared to that of using clean fuel sources. It is also indicated that kitchens lacking a chimney and conventional biomass stoves have further enhanced the risk (Vakalopoulos et al. 2021). Furthermore, the level of exposure to pollutants and duration of exposure are some key factors that influence the related health impacts (Perera & Sugathapala 2002). More than 70% of the wealthiest households use LPG, which suggests a transition to cleaner fuels in tandem with increasing economic status. The type of cooking fuel used may vary depending on poverty and the availability of a particular energy source. Other factors, such as the attitudes, practices, and lifestyles of both the urban and rural population, can influence the primary cooking fuel used. Despite having a higher population density, the Colombo district has proven to use less biomass (Nandasena et al. 2012).

To lessen the effects of climate change, Sri Lanka must continue its shift to renewable energy, building a more resilient and sustainable future. As firewood is likely to remain the predominant cooking fuel in the nation for the foreseeable future, measures should be implemented to reduce health risks associated with indoor air pollution. Improved cookstoves (ICS) must be prioritised nationwide, with a focus on price, usability, and cultural acceptability to guarantee accessibility for vulnerable communities over time. As shown in Fig. 3, according to the World Bank (2023), 34.1% of Sri Lankans had access to clean fuels and cooking technologies in 2021 (World Bank 2023).

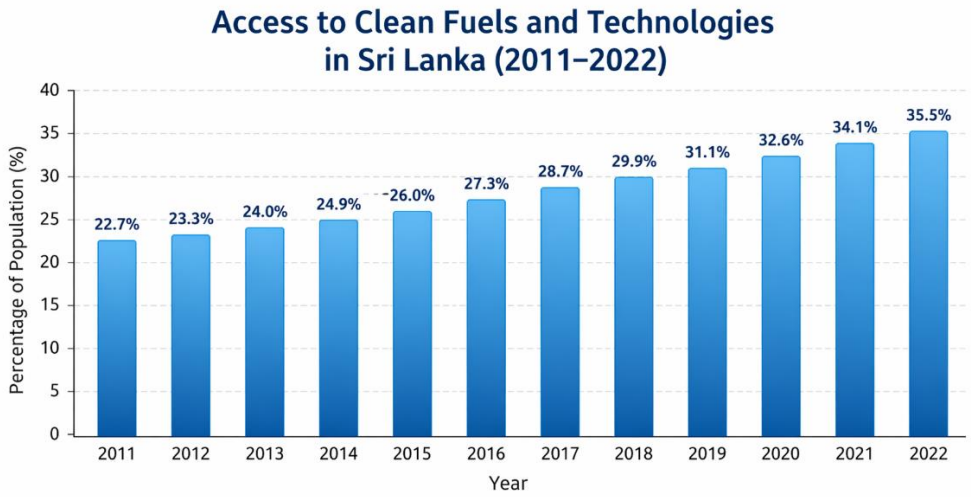


Fig. 3: Percentage of the population in Sri Lanka with access to clean cooking fuels and technologies from 2011 to 2022. (Source: World Bank, 2023).

4. SRI LANKA'S CURRENT USE OF CLEAN FUELS AND ADVANCED TECHNOLOGIES FOR DOMESTIC PURPOSES

Technologies and clean fuels are those that comply with the World Health Organization's (WHO) recommended limits for CO, fine particulate matter (PM 2.5), and other PICs. These technologies and fuels are used primarily for lighting, heating, and cooking. Solar energy, electricity, biogas, LPG, alcohol-based fuels such as ethanol, along with biomass stoves and electrical heaters that meet low-emission standards, are examples of clean fuels and technologies. In contrast, polluting fuels and technologies refer to those that do not meet health-based standards and cause negative impacts on both human health and environmental concerns. These polluting fuels include kerosene, unprocessed coal, and traditional biomass, along with fuel wood with high emission rates and low efficiency, which cause significant risks to the environment and human health, as it is mentioned above (World Health Organization 2021).

4.1 Use of clean fuels in households

In Sri Lanka, propane and butane account for the majority of liquefied petroleum gas (LPG), which is commonly used as a cooking fuel. This substance is a by-product of natural gas processing and crude oil refining. It can be easily liquefied under moderate pressure, which enables convenient storage and transportation in cylinders. With major benefits in reducing greenhouse gas (GHG) emissions and indoor air pollution (IAP), LPG has become a practical, scalable, cleaner-burning fuel. Additionally, it is known for its comparatively clean combustion characteristics and low sulfur concentration (Kypridemos et al. 2020). There has been a discernible shift

from traditional fuelwood to LPG, driven by increased urbanisation, particularly in suburban and urban areas (Perera & Sugathapala 2002). Additionally, when used properly, LPG exhibits a clean emission profile, creates a steady blue flame, and retains efficiency regardless of the equipment's age until it breaks (Bruce et al. 2017).

Despite these advantages, there are several barriers to LPG's widespread adoption. Liquefied petroleum gas (LPG) is widely regarded by consumers as a more convenient, healthier, and cleaner fuel, facilitating faster cooking and improved kitchen environments (Goldemberg et al. 2018; Ozoh et al. 2018). However, the high initial and recurring costs of LPG stoves remain major obstacles, particularly for low-income and rural populations. Electricity is considered the cleanest cooking fuel because it produces no direct emissions. The use of electric cooking technology has increased, particularly among younger generations seeking cleaner, more efficient alternatives that reduce household air pollution (HAP) (Banerjee et al. 2016).

Anaerobic digestion of organic materials, including animal manure and agricultural residues, generates biogas, which serves as a renewable energy source. It typically contains 50–75% methane (CH_4) and 25–50% carbon dioxide (CO_2), with trace gases, depending on the feedstock and operating conditions (Kabeyi & Olanrewaju 2022). Biogas offers a sustainable cooking and heating alternative because its inexpensive feedstock is readily available. High installation and maintenance costs, however, remain major obstacles to its wider implementation (Puzzolo & Pope 2017).

In Sri Lanka, solar energy is becoming increasingly popular as a clean energy source for home use. Growing interest in renewable energy technology is reflected in the continually rising number of solar installations and total installed capacity (Bandara & Amarasena 2020). The Sri Lankan government has already included about 200 MW of solar energy into the country's grid at the policy level, and by 2025, it hopes to increase this capacity to 1000 MW (Koswatte et al. 2024). Furthermore, solar photovoltaic systems are being promoted by private sector initiatives to enhance home energy consumption patterns (Thanthirige et al. 2022).

4.1.1 Climate change impacts/ GHG emissions from household fuel usages

Assessments on the global warming effects of alternative fuel options in households depend on some assumptions, such as associated emissions from fuel and stove technologies and the elements in the climate system. As it is emphasized by US EPA LCA evaluations from China and India, the efficiency of stoves and emissions resulting from their usage are considered as the most vital contributors to the overall climate impact in CO_2 equivalents. In addition, it is found that the impact of LPG lies between both partially and fully renewable biomass in both countries. Moreover, black carbon is a carbonaceous aerosol and one of the short-lived climate pollutants emitted from biomass cookstoves. It is a climate forcing agent having a greater global-warming potential per gram, and the global climate impact is only surpassed by CH_4 and CO_2. LPG is not eligible for carbon credits under the Clean Development Mechanism (CDM) since it is a fossil fuel and the effects on climate change is same or less than the best improved biomass stoves when all the emissions are taken into account. Furthermore, LPG derived from natural gas has a comparatively reduced impact on the environment compared to LPG made from crude oil. In addition, it is mentioned that although LPG has performed the same as biogas, it has depicted the lowest GWP performance among LPG, biogas, and charcoal (Bruce et al. 2017).

4.2. Development of advanced household cooking and heating technologies in Sri Lanka

Typically, renewable energy systems convert renewable resources into thermal, mechanical, and electrical energy that can be accessed. They consist of ICSs, biogas digestors, and solar home systems (Koswatte et al. 2024). The ICS employs various advancements, including chimneys, enhanced insulation, and modern designs, to offer significantly improved combustion performance when compared to their traditional counterparts. The technology of improved cooking stoves is primarily defined by its capacity to improve fuel combustion efficiency and decrease HAP by redesigning basic biomass fuel-burning cookstoves. Therefore, introduction of new cookstove designs is necessary to improve the kitchen environment and health aspects to whom expose to difficulties in control over the fire, exposure to smoke and heat, fire hazards, and low cooking efficiency during traditional cookstove usage. Most of the Sri Lankan houses have had the practice of using semi-enclosed mud stoves and three-stone stoves for daily cooking purposes as traditional cookstoves, along with the ICS design developed by Sarvodaya. However, concerns on redesigning of ICSs in Sri Lanka have been raised in several instances to avoid the significant environmental impacts from traditional stoves and enhance the fuel-wood saving potential in the past (Perera & Sugathapala 2002).

Two basic designs were promoted, which are modified configurations of the Sarvodaya stove in 1987: a two-pot stove (Anagi-2) and a single-pot stove (Anagi-1) (Fig. 4). As an exception, of being that Anagi-2 stove is made in one piece and therefore has the practice to be used without applying a cover with mud slurry, and it is the same as the Sarvodaya stove. It is further indicated that although Anagi-1 has a minimal involvement in the cooking sector, Anagi-2 was very popular among women in Sri Lanka in both rural areas and urban. In addition, according to the Sri Lanka Sustainable Energy Authority (SLSEA), the traditional three-stoned hearth has 5-8% of very low efficiency, and Anagi cookstoves have 17-20% efficiency (Perera & Sugathapala 2002).



Fig. 4: Traditional and improved household cooking stoves used in Sri Lanka: (a) three-stone stove, (b) Anagi-1 stove , (c) Anagi-2 improved cookstove, and (d) improved biomass cookstove with chimney design.

LPG cookstoves are found to have efficiencies of 45-60%, which are usually consistent under a wide array of conditions (Bruce et al. 2017). In addition, it is explained that a significant amount of energy is wasted in domestic cooking using inefficient LP gas cookers. Therefore, the reduction of waste energy is possible by pairing burners with appropriately sized utensils. Furthermore, induction cookers have higher efficiency of fuel usage with maximum performance.

Reasonably priced electric cooking products, such as induction burners, electric cookers, ovens, hot plates, etc., have become popular among the young generation. Induction stoves are usually identified as highly effective with greater performance since they use an electromagnetic field to produce heat, and it is found to be significantly quicker than conventional electric coil stoves. However, unlike other stoves, the substance of the pan affects performance, where the most efficient cookware is made of steel or iron, and the usage of induction stoves will remain constrained in nations and rural regions with low levels of electrification (Banerjee et al. 2016).

4.3 Environmental and Health Implications of Household Energy Use

4.3.1 Household Air Pollution (HAP)

Household air pollution (HAP) is largely caused by the use of conventional biomass fuels in inefficient stoves, such as fuelwood, charcoal, and kerosene. Incomplete combustion emits harmful pollutants such as particulate matter ($PM_{2.5}$), carbon monoxide (CO), and additional products of incomplete combustion (PICs). Lung cancer, cardiovascular disorders, respiratory infections, and chronic obstructive pulmonary disease (COPD) have all been closely associated with exposure to these pollutants, especially in women and children who spend more time near cooking areas (World Health Organization 2021). The use of cleaner fuels such as liquefied petroleum gas (LPG), electricity, and biogas can substantially reduce related health risks. Recent evidence also indicates that households using biogas experience lower health risks than those relying on conventional cooking fuels, although these benefits vary according to socioeconomic conditions and household characteristics (Bagdi et al. 2025). However, data relevant to Sri Lanka is still limited to a few localized studies and there is a significant research gap in the absence of data which is representative at the national level linking HAP exposure to clinical health outcomes across different regions and fuel-use patterns.

4.3.2 Climate and Emissions Impacts

Greenhouse gas (GHG) emissions produced by different household fuels exert varying impacts on climate change. Significant amounts of carbon dioxide (CO_2), methane (CH_4), and black carbon, a powerful, transient climatic pollutant, are released during the traditional combustion of biomass. Liquefied petroleum gas (LPG), while classified as a fossil fuel, combusts more efficiently and produces fewer emissions compared to biomass. Electricity offers the lowest emission profile among cooking options, especially when it comes from renewable sources. Therefore, moving from biomass to LPG and, finally, to electrification provides a methodical approach to mitigating the impacts of climate change (Bruce et al. 2017).

4.3.3 Co-benefits of Clean Cooking

The adoption of clean cooking fuels and advanced technologies provides multiple benefits in addition to reducing emissions.

Health benefits: Minimizing exposure to hazardous contaminants improves both cardiovascular and respiratory health.

Environmental benefits: Lower emissions contribute to improved local air quality and support efforts to mitigate climate change.

Socio-economic and gender benefits: Clean cooking enhances the overall quality of life and reduces the time spent collecting fuel, which is particularly beneficial for moms and kids.

These combined advantages demonstrate the importance of promoting clean cooking solutions as part of sustainable development plans.

4.4. Government policies regarding the usage of clean fuels

There cannot be any doubt about the fact that at present, Sri Lanka is at a very important juncture in terms of its path towards a sustainable energy future especially when considering issues pertaining to clean fuels and methods for cooking/ heating. Although a lot of progress has been achieved by Sri Lanka towards harnessing renewable sources of energy, however, a vast amount of energy potential remains untapped in Sri Lanka. As stated by Koswatte et al. it has been noted that the policies of Sri Lanka focus on harnessing both traditional and non-traditional renewable energy sources. In addition, it should be borne in mind that Sri Lanka still does not have a proper regulatory framework which will enable it to exploit the potential of renewable energy sources that are available (Koswatte et al. 2024).

To close current policy gaps and accelerate the transition to clean household energy, a systematic framework for clean energy adoption in Sri Lanka is proposed (Fig. 5). To enable a thorough transition, the framework integrates social, technological, financial, and policy aspects. First, policy strengthening and regulatory alignment are essential for setting clear emission-reduction targets and enforcing standards for household energy systems. Secondly, through promoting clean cooking technologies such as LPG, electricity, biogas, and improved biomass stoves, especially in rural communities, issues of technology access and development should be addressed. Thirdly, financial incentives and subsidy programs must be implemented to lower the initial costs of clean energy technologies, especially for low-income households. Fourth, to improve the acceptability and long-term use of clean fuels, public awareness campaigns and behavioural change programs are crucial, as social and cultural norms have a major influence on household energy choices. Finally, institutional coordination and monitoring procedures should be reinforced to ensure collaboration among key stakeholders, including SLSEA, CEB, and policy-making bodies. This integrated approach advances both Sustainable Development Goal 7 (SDG 7), which prioritises universal access to modern, affordable, reliable, and sustainable energy, and global pathways for a clean energy transition (International Energy Agency 2022; World Health Organization 2021). Implementing such a paradigm can permit a balanced strategy that simultaneously addresses public health, environmental sustainability, and socioeconomic progress in Sri Lanka.

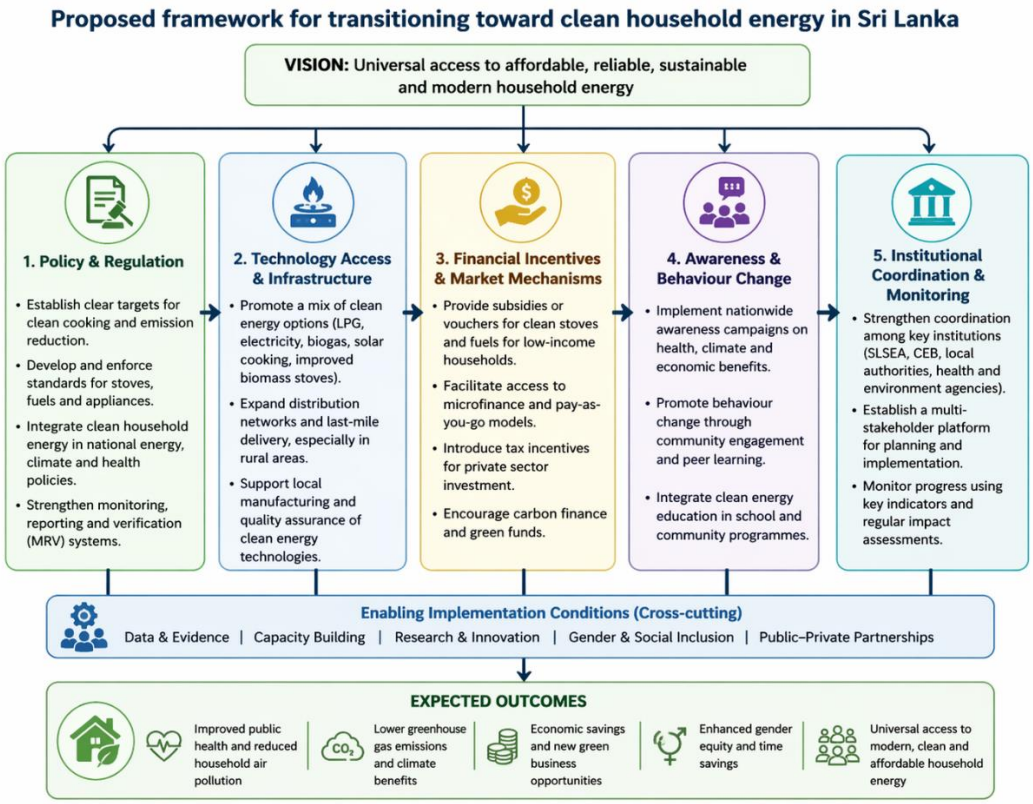


Fig. 5: Proposed framework for transitioning toward clean household energy in Sri Lanka

As explained by Musafer (2020), playing an important part in informing, directing, and urging energy transition is the function of energy policies, while policy instruments assist in emphasizing that renewable energy technologies are crucial in the transition to renewable energy (Musafer 2020). The Ministry of Power and Energy is the primary government agency responsible for Sri Lanka's power and energy sector. The power industry is managed mainly by the involvement of both state-owned institutions and the private sector under the purview of the Ministry of Power and Energy. SLSEA, Lanka Electricity Company (LECO), Ceylon Electricity Board (CEB), and LTL Holdings are the agencies relevant to renewable energy, which are governed by the so-called ministry. The establishment of SLSEA through Act No. 35 of 2007 entrusts it with overseeing the country's renewable energy assets and designates it as the primary governmental body responsible for implementing initiatives in renewable energy development. One of their programme focuses on the use of energy-efficient cook-stoves (Sri Lanka Sustainable Energy Authority 2025). The goal of the 2015 Sri Lanka Energy Sector Development Plan was to increase the percentage of power generated from renewable resources to between 50% and 60% by 2020 (Theiventhran 2022). A declaration of a novel National Energy Policy and a set of strategies took place in 2019 after a review and revision of earlier version in 2008. It emphasizes that complete electrification and development of renewable energy were achieved by 2019 which was set in 2008. The new instrument in 2019 mentions to develop recently evaluated renewable energy sources for the generation of electricity such as biomass, solar, and wind. Furthermore, transforming electrical energy in supplying of thermal energy for households and industries was also a key concern regarding the novel National Energy Policy and a set of strategies in 2019.

The Strategies and National Energy Policy of Sri Lanka (2019) further states that the transition in energy sources, marked by improvements in various energy supply alternatives and modern energy carriers, has increased the complexity of global energy demand. Thus, the changes in the composition of the energy mix have also been observed in recent years in Sri Lanka as a result of focusing on both environmental and economic concerns. A key change in government policies is focused on improving the share of renewables in the main supply of energy from 55% over the last ten years. Furthermore, it has been determined that biomass plays a prominent role in creating a transition to an accessible fuel for household usage purposes. Thus, “enhancing the share of renewable energy” is described as among the ten pillars of the National Energy Policy to enhance the usage of indigenous renewable energy resources for optimum usage to achieve sustainability (Ministry of Power, Energy & Business Development 2019). Section 2e also states that by the end of 2020, SEA will make sure that entrepreneurs who are involved in the distribution and production of equipment that uses these technologies, such as improved cook stoves and mini gasifiers, are given financial incentives to promote better, more convenient, commercial biomass fuel products and conversion technologies for domestic use. By 2021, SLSEA will guarantee that at least 5% of improved stoves powered by commercial biomass fuels are in use (Ministry of Power, Energy & Business Development 2019).

SLSEA, through the Renewable Energy Resource Development Plan 2021-2026 aims a broad-scale development of renewable energy from a holistic national context, focusing on methodologies of current project developments. It also mentions on maximizing the potential for the main renewable energy resources including biomass. It also outlines the strategy for building a renewable energy park over 2021-2026. Also, the Ministry of Power and Energy's Sri Lanka Energy Sector Development Plan for a Knowledge-driven Economy: 2015 to 2025 aimed to increase the proportion of electricity generation from 50% in 2014 to 60% in 2020 by integrating renewable energy sources (Koswatte et al. 2024; Musafer 2020).

Sri Lanka has marginally upgraded its commitments towards sustainability, incorporating the production of renewable energy as highlighted from measurement of the progress in accomplishment of SDG 7 by the country, in its newest optional national assessment of SDG accomplishments. According to the latest trends of public health policies in Sri Lanka, the HAP is not a popular aspect into consideration at the policy level. Therefore, it is apparent that there is a disorganization and lack of cooperation among different government agencies from a policy perspective, and a greater coherence is essential between government officials in the proper management of the process of building relevant decisions and policy making (Shi et al. 2018).

5. LIMITATIONS, RESEARCH GAP, AND NEEDS

The study was only based on a systematic literature review, and the evaluation was mainly regarding the current situation of domestic households in Sri Lanka, emphasizing on fuels or energy usage for domestic activities. Furthermore, the attention of transition to modernized fuels and technologies focusing on net zero targets by Sri Lanka in 2050 was also focused during the study. However, since the study primarily relied on secondary data in the Sri Lankan context, which has not yet been explored through systematic empirical research, the data and information provided might hinder the insights into ongoing transformations happening in Sri Lanka.

Although there is evidence for the adoption of clean fuels/energy in domestic household practices as per the previous studies, empirical evidence in more recent studies is essential since statistical analysis of such practices in the Sri Lankan context is under-researched. In addition, there is a lack of previous studies regarding the quantification of impacts from the usage of dirty fuels for domestic cooking/heating purposes and continuous improvements of clean technologies in Sri Lanka. Moreover, there is a lack of real-time data, and it might have an effect on the accuracy of findings.

5.1 Barriers to Transition toward Clean Household Energy

Despite increased awareness and governmental initiatives, Sri Lanka's transition to clean household energy is hindered by a number of interconnected challenges covering institutional, cultural, technological, and economic dimensions.

5.1.1. Economic Barriers

One of the main barriers to the adoption of clean fuels and technology is affordability. Low-income people cannot afford the initial and recurring costs of cleaner fuels, such as electricity and LPG, despite their substantial health and environmental benefits. The continued use of these energy sources is also hindered by the volatility of fuel markets, which is more pronounced for rural inhabitants who depend on biomass because it has an economic value of zero (Goldemberg et al. 2018; Bruce et al. 2017). The disparity in adoption rates between urban and rural areas is intensified by insufficient targeted subsidies and limited financing mechanisms, which restrict access to modern energy technologies.

5.1.2 Cultural and Behavioural Factors

Household energy decisions are heavily influenced by cultural preferences and traditional cooking techniques. Many Sri Lankan houses still utilize firewood because of a long-standing understanding of the traditions and preferences related to traditional cooking methods. Another factor that limits the use of such cleaner fuels is the difficulty in getting people to change their behaviour and the ignorance about the health implications of HAP (Rehfuess et al. 2013). Decision-making is also influenced by social norms and gender roles, especially in rural households where women are mostly responsible for cooking.

5.1.3 Technological Limitations

The implementation of sustainable energy sources faces challenges in terms of technology as well. The use of modern cooking technologies can face various challenges, such as suitability and reliability, among others. For instance, the use of induction stoves requires the availability of appropriate cookware as well as constant availability of energy, which may not always be available. In the case of biogas, the availability of a consistent source of feedstock and regular technical support hinders scalability (Puzzolo & Pope 2017). Furthermore, the lack of standard quality control procedures makes the use of improved cookstoves less effective.

5.1.4 Institutional and Policy Barriers

Even then, such a coordinated approach towards the adoption of clean energy in households faces challenges due to inadequate institutional coherence and inefficient policy implementation processes. There are numerous agencies managing the energy sector in Sri Lanka, with most of them having overlapping roles and not working together (Shi et al. 2018). Poor resource allocation and policy implementation are inevitable as a result. Also, the adoption of health-related aspects, especially HAP, remains low in the country's energy policies.

These challenges must be overcome by integrated policy design, stakeholder coordination, and focused interventions in order to hasten Sri Lanka's transition to clean, sustainable household energy systems.

6. CONCLUSION

This analysis reviewed the change in household cooking and heating energy in Sri Lanka, with an emphasis on fuel consumption, available technologies, determinants, health and environmental impacts, and policy context. The data analyzed suggests that Sri Lankan families have gradually moved from traditional biomass fuels to greener energy sources such as electricity and LPG. However, biomass remains an important source of energy for households especially where the penetration of greener options is hampered by behavioral, technological, economic and accessibility issues.

The study also shows that household energy choices are shaped by the socio-economic status of households, the availability and cost of fuels and technologies, existing infrastructure and policy support. Yet, there are still important problems with the use of traditional biomass and the resulting indoor air pollution. But there is still limited data on household exposure, health consequences, technology performance and long-term changes in home energy use specific to Sri Lanka. This indicates the need for more household-level research to supplement the pool of knowledge informing future energy planning.

These results suggest that policies promoting a transition to cleaner household energy should consider affordability, accessibility, technical compatibility, and long-term household adoption. Financial support, infrastructure development, awareness campaigns and implementation of coordinated policies can help in the adoption of cleaner alternatives at a broader level, but improved cooking technologies and better ventilation of kitchens may offer a temporary solution for households still relying on biomass. These measures need to be adapted to the socioeconomic situation of different groups of households and incorporated into the current framework of Sri Lanka’s energy and environmental policy.

In general, the data suggests that Sri Lankan households are slowly and conditionally shifting toward cleaner energy for cooking and heating. However, more research is needed to strengthen the quantitative evidence base on home fuel use, household air pollution exposure, health impacts, technology adoption, and environmental impacts to allow for a more detailed assessment of transition pathways and policy options.

7. FUTURE PATHWAYS FOR CLEAN COOKING TRANSITION IN SRI LANKA

7.1 Qualitative Transition Pathways

The evidence reviewed suggests that the transition to cleaner household cooking in Sri Lanka can follow different pathways depending on the policy support, infrastructure, affordability and household uptake. A gradual pathway would involve scaling up access to LPG and electricity and upgrading biomass technologies where full fuel substitution is not possible in the near term. To move more quickly will require stronger policies, financial incentives, infrastructure, and more support for cleaner cooking technologies. Differences in household socioeconomic conditions, location, fuel availability, and cooking practices could affect the pace of transition, however. The pathways are presented as qualitative conceptual pathways and not as quantitative scenarios, as the

evidence reviewed does not provide a common baseline, technology penetration rates, energy demand projections or emissions calculations necessary for numerical modeling.

7.2 Decarbonization Potential

Transitioning to clean household energy offers substantial opportunities to reduce greenhouse gas (GHG) emissions in Sri Lanka. Traditional biomass combustion significantly increases emissions of methane (CH_4), carbon dioxide (CO_2), and black carbon, which are major contributors to climate change. By replacing these fuels with LPG, electricity, and renewable energy sources, emissions can be significantly decreased. The greatest potential for decarbonization lies in electrified cooking, particularly when powered by renewable energy sources such as solar and wind. Research demonstrates that transitioning to cleaner cooking fuels may reduce household-level emissions by over 50 percent, contingent upon the degree of adoption and the specific energy mix (Bruce et al. 2017). Therefore, integrating clean cooking transitions into national climate plans can greatly help Sri Lanka achieve its carbon-neutrality objectives.

7.3 Equity and Just Transition Considerations

Sustainability in the move towards clean cooking cannot be ensured unless it is done in an equitable manner. Low-income and rural people are always faced with many challenges, which include lack of affordability, limited access to clean energy sources, and lack of proper infrastructure. It means that unless appropriate measures are taken, disadvantaged communities will not gain from the transition to clean cooking technologies. In just transitions, there is significant emphasis on the use of policy instruments that make it possible for poor people to have access to cheap technology and subsidies. Women also suffer immensely from exposure to indoor pollution. In addition to improving health outcomes, ensuring fair access to clean cooking solutions promotes social and economic advancement (Rehfuess et al. 2014; World Health Organization 2021).

8. RECOMMENDATIONS

The study recommends the following concerns as a summary;

•The government should set up plans, policies, and programmes aimed at improving clean fuel access to nations irrespective of the family income or economic status, expansion of energy access, upgrading the development of human capital, and strengthening climate adaptation to guarantee citizens' environmental sustainability.

•There is a necessity for a well-designed policy framework to support the manufacturing of clean fuels, ICS, and heating devices for household purposes to reduce the purchase cost for end-users, especially focused on low-income households, through the introduction of subsidies, tax reductions, low-interest loans, or financial support for manufacturers.

•Government officials should carry out the execution plans towards the SDGs, especially on SDG 7, as a holistic approach with active participation of the private sector actors.

•Anticipatory measures need to be implemented by the government to enhance frameworks for climate and environmental governance, including the NDCs, while aligning SDGs with long-term development agendas.

Therefore, implementing agencies should formulate strategies or regulations to meet the air quality standards, where significant health improvements are prioritized through the transition into clean fuels and technologies.

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11. REFERENCES

1. Amarasekara, R. M. (2004). Quest for sustainability: Profiles of ICS programmes in Asia: Sri Lankan ICS case 2.
2. Amegah, A. K., & Jaakkola, J. J. (2016). Household air pollution and the sustainable development goals. *Bulletin of the World Health Organization, 94*(3), 215.
3. Asian Development Bank. (2019). Sri Lanka energy sector assessment, strategy and road map (TCS190557-2). http://dx.doi.org/10.22617/TCS190557-2
4. Bagdi, T., Koley, A., Das, N., Das, S., Gayen, S., Sarkar, A., Ghosh, S., Kumar, S., Chaudhury, S., Hazral, A.K. and Ross, A.B., 2025. Health risk assessment among biogas and conventional cooking fuel users in different socioeconomic conditions of rural West Bengal. *Nature Environment and Pollution Technology*, *24*(4), pp.1-16. https://doi.org/10.46488/NEPT.2025.v24i04.B4295
5. Balakrishnan, K., Ghosh, S., Thangavel, G., Sambandam, S., Mukhopadhyay, K., Puttaswamy, N., Sadasivam, A., Ramaswamy, P., Johnson, P., Kuppuswamy, R., & Natesan, D. (2018). Exposures to fine particulate matter (PM2.5) and birthweight in a rural–urban mother–child cohort in Tamil Nadu, India. *Environmental Research, 161*, 524–531. https://doi.org/10.1016/j.envres.2017.11.050
6. Bandara, U. C., & Amarasena, T. S. M. (2020). Factors influencing solar energy technology adoption by households in Western Province Sri Lanka. *Vidyodaya Journal of Management, 6*(2).
7. Banerjee, M., Prasad, R., Rehman, I. H., & Gill, B. (2016). Induction stoves as an option for clean cooking in rural India. *Energy Policy, 88*, 159–167. https://doi.org/10.1016/j.enpol.2015.10.021
8. Benioff, R., de Coninck, H., Dhar, S., Hansen, U., McLaren, J., & Painuly, J. (2010). Strengthening clean energy technology cooperation under the UNFCCC: Steps toward implementation. https://doi.org/10.2172/988605
9. Bruce, N. G., Aunan, K., & Rehfuess, E. A. (2017). Liquefied petroleum gas as a clean cooking fuel for developing countries: Implications for climate, forests, and affordability (Materials on Development Financing No. 7). KfW Development Bank.
10. Chattopadhyay, M., Arimura, T. H., Katayama, H., Sakudo, M., & Yokoo, H. F. (2021). Subjective probabilistic expectations, household air pollution, and health: Evidence from cooking fuel use patterns in West Bengal, India. *Resource and Energy Economics, 66*, 101262. https://doi.org/10.1016/j.reseneeco.2021.101262
11. Department of Census and Statistics (DCS), & Ministry of Healthcare and Nutrition (MOH). (2009). Sri Lanka demographic and health survey 2006–07. Colombo, Sri Lanka.

12. Elledge, M. F., Phillips, M. J., Thornburg, V. E., Everett, K. H., & Nandasena, S. (2012). A profile of biomass stove use in Sri Lanka. *International Journal of Environmental Research and Public Health, 9*(4), 1097–1110. https://doi.org/10.3390/ijerph9041097
13. Fernandez, M. I., Go, Y. I., Früh, W. G., & Wong, D. M. (2025). Projection of electricity generation profiles and carbon emissions towards 2050: A Malaysia context. *Energy for Sustainable Development, 85*, 101681. https://doi.org/10.1016/j.esd.2025.101681
14. Gebreegziabher, Z., Mekonnen, A., Kassie, M., & Köhlin, G. (2012). Urban energy transition and technology adoption: The case of Tigrai, northern Ethiopia. *Energy Economics, 34*(2), 410–418. https://doi.org/10.1016/j.eneco.2011.07.017
15. Goldemberg, J., Martinez-Gomez, J., Sagar, A., & Smith, K. R. (2018). Household air pollution, health, and climate change: Cleaning the air. *Environmental Research Letters, 13*(3), 030201. https://doi.org/10.1088/1748-9326/aaa49d
16. Heltberg, R. (2005). Factors determining household fuel choice in Guatemala. *Environment and Development Economics, 10*(3), 337–361. https://doi.org/10.1017/S1355770X04001858
17. IEA – International Energy Agency - IEA (2024). *IEA – International Energy Agency - IEA*. [online] IEA. Available at: http://www.iea.org/data-and-statistics.
18. International Energy Agency (2022) *World Energy Outlook 2022*. Paris: IEA.
19. International Energy Agency, United Nations Statistics Division, World Bank, & World Health Organization. (2022). Tracking SDG 7: The energy progress report. International Renewable Energy Agency. https://www.irena.org//media/Files/IRENA/Agency/Publication/2022/Jun/SDG7_Tracking_Progress_2022.pdf
20. International Energy Agency. (2020). World energy outlook 2020. https://www.iea.org/reports/world-energy-outlook-2020
21. Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Biogas production and applications in the sustainable energy transition. *Journal of Energy, 2022*, 8750221. https://doi.org/10.1155/2022/8750221
22. Koswatte, I., Iddawala, J., Kulasekara, R., Ranaweera, P., Dasanayaka, C. H., & Abeykoon, C. (2024). Can Sri Lanka be a net-zero nation by 2050?, Current renewable energy profile, opportunities, challenges, and recommendations. *Cleaner Energy Systems, 8*, 100126. https://doi.org/10.1016/j.cles.2024.100126
23. Kypridemos, C., Puzzolo, E., Aamaas, B., Hyseni, L., Shupler, M., Aunan, K., & Pope, D. (2020). Health and climate impacts of scaling adoption of liquefied petroleum gas (LPG) for clean household cooking in Cameroon: A modeling study. *Environmental Health Perspectives, 128*(4), 047001. https://doi.org/10.1289/EHP4899
24. Maes, W. H., & Verbist, B. (2012). Increasing the sustainability of household cooking in developing countries: Policy implications. *Renewable and Sustainable Energy Reviews, 16*(6), 4204–4221. https://doi.org/10.1016/j.rser.2012.03.031
25. Mei, X., & Seo, B. K. (2024). The relationships among housing, energy poverty, and health: A scoping review. *Energy for Sustainable Development, 83*, 101568. https://doi.org/10.1016/j.esd.2024.101568
26. Mensah, J. T., & Adu, G. (2015). An empirical analysis of household energy choice in Ghana. *Renewable and Sustainable Energy Reviews, 51*, 1402–1411. https://doi.org/10.1016/j.rser.2015.07.050
27. Ministry of Environment. (2023). Nationally determined contributions implementation plan (2021–2030). Ministry of Environment, Sri Lanka.
28. Ministry of Power, Energy & Business Development. (2019). National energy policy & strategies of Sri Lanka. Government of Sri Lanka.

29. Mitchell, C. S., Zhang, J., Sigsgaard, T., Jantunen, M., Lioy, P. J., Samson, R., & Karol, M. H. (2007). Current state of the science: Health effects and indoor environmental quality. *Environmental Health Perspectives, 115*(6), 958–964. https://doi.org/10.1289/ehp.8987
30. Muller, C., & Yan, H. (2018). Household fuel use in developing countries: Review of theory and evidence. *Energy Economics, 70*, 429–439. https://doi.org/10.1016/j.eneco.2018.01.024
31. Musafer, N. (2020). Biomass energy policy perspectives of Sri Lanka: A review. *International Journal of Scientific Research and Publications, 10*(12), 674–681.
32. Nandasena, S., Wickremasinghe, A. R., & Sathiakumar, N. (2012). Biomass fuel use for cooking in Sri Lanka: Analysis of data from national demographic health surveys. *American Journal of Industrial Medicine, 55*(12), 1122–1128. https://doi.org/10.1002/ajim.21023
33. Ozoh, O.B., Okwor, T.J., Adetona, O., Akinkugbe, A.O., Amadi, C.E., Esezobor, C., Adeyeye, O.O., Ojo, O., Nwude, V.N. and Mortimer, K., 2018. Cooking fuels in Lagos, Nigeria: factors associated with household choice of kerosene or liquefied petroleum gas (LPG). *International journal of environmental research and public health*, *15*(4), p.641.https://doi.org/10.3390/ijerph15040641
34. Pallegedara, A., & Mottaleb, K. A. (2021). Exploring choice and expenditure on energy for domestic works by the Sri Lankan households: Implications for policy. *Energy, 222*, 119899. https://doi.org/10.1016/j.energy.2021.119899
35. Perera, K. K. C. K., & Sugathapala, A. G. T. (2002). Fuelwood-fired cookstoves in Sri Lanka and related issues. *Energy for Sustainable Development, 6*(1), 85–94. https://doi.org/10.1016/S0973-0826(08)60302-6
36. Puzzolo, E., & Pope, D. (2017). Clean fuels for cooking in developing countries. In *Encyclopedia of sustainable technologies* (Vol. 4, pp. 289–297).
37. Rehfuess, E.A., Puzzolo, E., Stanistreet, D., Pope, D. and Bruce, N.G., 2013. Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environmental health perspectives*, *122*(2), p.120. https://doi.org/10.1289/ehp.1306639
38. Rosenthal, J., Quinn, A., Grieshop, A. P., Pillarisetti, A., & Glass, R. I. (2018). Clean cooking and the SDGs: Integrated analytical approaches to guide energy interventions for health and environment goals. *Energy for Sustainable Development, 42*, 152-159. https://doi.org/10.1016/j.esd.2017.11.003
39. Sawin, J. L., Martinot, E., Sonntag-O'Brien, V., McCrone, A., Roussell, J., Barnes, D., Flavin, C., Mastny, L., Kraft, D., Wang, S., & Ellenbeck, S. (2010). Renewables 2010 global status report.
40. Shi, X., Chen, H., Yu, Y., & Wen, F. (2018). Development of variable renewable energy policy in developing countries: A case study of Sri Lanka. *International Journal of Public Policy, 14*(1–2), 10–29. https://doi.org/10.1504/IJPP.2018.090682
41. Shupler, M., Godwin, W., Frostad, J., Gustafson, P., Arku, R. E., and Brauer, M. (2018). Global estimation of exposure to fine particulate matter (PM2.5) from household air pollution. *Environment International, 120*, 354–363. https://doi.org/10.1016/j.envint.2018.08.026
42. Smith, K. R. (1994). Health, energy, and greenhouse-gas impacts of biomass combustion in household stoves. *Energy for Sustainable Development, 1*(4), 23–29. https://doi.org/10.1016/S0973-0826(08)60067-8
43. Smith, K.R. and Mehta, S., 2003. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International journal of hygiene and environmental health*, *206*(4-5), pp.279-289.https://doi.org/10.1078/1438-4639-00224
44. Sri Lanka Sustainable Energy Authority. (2022). Sri Lanka energy balance 2022. Colombo, Sri Lanka: SLSEA, 2022. ISSN: 2386-172X
45. Sri Lanka Sustainable Energy Authority. (2025). About us. https://www.energy.gov.lk/en/about-us/inception

46. Thanthirige, T. R. M., Galappaththi, U. I. K., Kadabadu, J. C. K., Busawon, K., and Wedage, T. D. G. (2022). Life cycle analysis of solar photovoltaic and coal-based electricity generation: Case study refers to Sri Lanka's domestic energy consumption. In *Proceedings of the 7th International Conference on Environment Friendly Energies and Applications (EFEA)* (pp. 1–6). https://doi.org/10.1109/EFEA56675.2022.10063822
47. Theiventhran, G. (2022). Emerging frontiers of energy transition in Sri Lanka. In *Energy policy advancement* (pp. 185–210). Springer. https://doi.org/10.1007/978-3-030-84993-1_9
48. Vakalopoulos, A., Dharmage, S. C., Dharmaratne, S., Jayasinghe, P., Lall, O., Ambrose, I., Weerasooriya, R., Bui, D. S., Yasaratne, D., Heyworth, J., & Bowatte, G. (2021). Household air pollution from biomass fuel for cooking and adverse fetal growth outcomes in rural Sri Lanka. *International Journal of Environmental Research and Public Health, 18*(4), 1878. https://doi.org/10.3390/ijerph18041878
49. Verma, P., Kumari, T., and Raghubanshi, A. S. (2021). Energy emissions, consumption and impact of urban households: A review. *Renewable and Sustainable Energy Reviews, 147*, 111210. https://doi.org/10.1016/j.rser.2021.111210
50. Waleed, K. and Mirza, F.M., 2023. Examining fuel choice patterns through household energy transition index: an alternative to traditional energy ladder and stacking models. *Environment, development and sustainability*, *25*(7), pp.6449-6501.https://doi.org/10.1007/s10668-022-02312-8
51. World Bank. (2023). Access to clean fuels and technologies for cooking (% of population) – Sri Lanka. https://tradingeconomics.com/sri-lanka/access-to-clean-fuels-and-technologies-for-cooking-percent-of-population-wb-data.html
52. World Health Organization. (2021). WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. WHO.
53. World Health Organization. (2024). World health statistics 2024: Monitoring health for the sustainable development goals. WHO
54. Yadav, P., Davies, P.J. and Asumadu-Sarkodie, S., 2021. Fuel choice and tradition: Why fuel stacking and the energy ladder are out of step?. *Solar Energy*, *214*, pp.491-501. https://doi.org/10.1016/j.solener.2020.11.077

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