

Research article

COVID-19 and household energy implications: what are the main impacts on energy use?

Ali Cheshmehzangi^{a,b,*}^a Department of Architecture and Built Environment, University of Nottingham Ningbo China, Ningbo, China^b Centre for Sustainable Energy Technologies, University of Nottingham Ningbo China, Ningbo, China

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ABSTRACT

This study explores the impacts of COVID-19 on household energy use. Some of these impacts are associated with longer-term energy demand changes and some could just be temporary. The study intends to present the results of a small pilot study conducted in China, by addressing household energy use. The samples are from 352 households and particularly focus on primary energy use in three periods of pre-pandemic (and pre-lockdown), start of COVID-19 outbreak and lockdown, and post lockdown. Each period is identified as a timeframe of 2.5 months, from November 2019 to late June 2020. The samples of this study highlight the primary implications of energy use, some that are understood as interim changes and some that may appear to be more prolonged. The results from the study highlight a variety of impacts on household energy use as well as prolonged impacts on transportation use. The primary household energy use are assessed in six fundamental elements of (1) transportation for commuting and leisure (for both private and public modes), (2) cooking, (3) entertainment, (4) heating and cooling, (5) lighting, and (6) the others. The results are summarized in three sections focused on major impacts on transportation use (comparison between private and public modes), cooking and entertainment, heating/cooling and lighting. The results could provide early suggestions for cities/regions that are experiencing longer lockdown. Furthermore, this study provides insights for larger-scale research in assessing household energy use/demand during times of health emergency and crises, such as the event of a pandemic.

1. Introduction

By now, a little introduction is needed for the ongoing pandemic outbreak that has had major impacts on societies around the globe. The COVID-19 outbreak was identified in late December 2019 in the City of Wuhan, China, and was eventually recognized as a pandemic on the 11th of March 2020. Since the start of the outbreak in January 2020, the impacts are increasingly seen on health and economies around the globe. In recent months, the COVID-19 pandemic has gained research attention mostly on primary areas of health [1, 2, 3, 4, 5], economy [6, 7, 8, 9], social well-being [10,11], resilience [12,13], and disaster management [14,15]. To date, some studies also look at other primary factors, one of which is 'energy' [16, 17, 18, 19]. The relationship between COVID-19 and energy is discussed critically as a matter of energy crisis [20], an increase in energy demand [21, 22, 23], and potential transitions [24, 25]. Nevertheless, what has been studied so far are mostly associated with the study of intersections [20], and associated with energy systems, security, and services [26]. While studies on energy and environmental

footprints [16,27, 28, 29, 30] could shed light on short-term transitions, we could argue that it is perhaps too early to see how the energy crisis [25,31] could emerge and be potentially managed any time soon. Some of the early recoveries [32, 33, 34, 35, 36], as seen in many parts of the world were just temporary. One of the early major energy demand changes were the unforeseen 20% reduction of energy use in China [37], which was mainly caused by temporary demand reductions that only lasted for less than two to three months. By April 2020, despite several spikes across the country, most operations were back to normal or towards normalization in China, which then had a reverse impact on energy use and demand [12]. It is envisaged the same pattern could appear in other countries or regions once they enter the recovery or post-recovery stages.

Of all COVID-19 energy implications, 'household energy' is not yet studied extensively. While energy security has been debated already [38, 39], also from the financial perspective for decision making [40], the impacts on the increase of household energy consumption are so far studied from the perspectives of electricity use [32,41], household

* Corresponding author.

E-mail address: Ali.Cheshmehzangi@nottingham.edu.cn.

energy in the informal economy [33], household energy choice [42], and home energy management [17]. The latter is studied in correlation with the social-psychological factors that are also major drivers of energy use and demand. Because of such change, the impacts on poorer households and communities [43] are yet to be studied at a later stage. The higher energy use and energy costs would certainly have a wider impact on societies around the globe. With many countries under the widespread measures of lockdown and imposed curfew for weeks or months, the proposal for action plans to reduce energy consumption in buildings [44] may not be necessarily applicable to the residential buildings or the households. In fact, the reverse impact is expected as it has been studied by Chen et al. [17] and as is evidenced in this research study. Hence, this study aims to present the results of a small pilot study conducted in China, by addressing the so far impacts on household energy use. This is aimed to explore not only what could be the impacts on energy use exclusive to the households, but also the ones associated with daily household operations, such as the energy use that is needed for changes in transportation demand and mode. By exploring this overarching aim, the main objectives of this perspective paper are (1) to evaluate the main impacts on the primary household energy use, (2) to suggest what could become a longer-term energy implication for the households, and (3) to address what needs to be studied at a larger scale in the future research.

This pandemic cannot be simply seen as a driver for energy transition [41] but rather as a major disruption [12] that could potentially have longer impacts on household energy consumption behavior [45] and longer-term environmental impacts [46]. The study of global macro-economic impacts of COVID-19 [47] already suggests potential scenarios that indicate significant impacts on households. Hence, by studying the important topic of household energy implications, we could potentially reduce the impacts and pressure (e.g. energy costs) that seem to be overshadowing the households in the long run.

2. Method

The methodology package is designed based on a pilot study, evaluating the impacts of the COVID-19 pandemic on household energy use and consumption. This is not aimed to suggest a transitional analysis but rather to evaluate what energy implications are important for the households. This study collected on-site survey data from 500 households in the City of Ningbo, China. Based on the selection procedure, 352 of the survey respondents were qualified for this study. The survey is designed based on the overall evaluation of main household energy use and associated energy implications. This is designed based on three main dimensions, namely the general analysis of household energy consumption [48], implications for eco-environments [49], and the consideration of social emissions from energy consumption in households [50]. In doing so, we are able to have an overview of generalities that suggest differences over the select period, as well as a ground for evaluating the results against the set conditions of the pandemic at multiple stages. The study follows the household category verification [51] that provides us with a focused area of research for a better comparative analysis. Data collection procedures follow this survey design to ensure the accuracy of data for the later evaluation and suggestions of the study. The study follows an estimation procedure [52,53] to create aggregated data of households in three consecutive timelines. The timeline for the survey is selected based on three different stages in a relatively short period (see section 2.1) to have a review of impacts of the COVID-19 on energy consumption [32,38], potential financial implications [40], and energy bills [20,54]. These could then be evaluated further for potential policy interventions [55] that could lead to better socio-economic pathways [56] after the recovery stage of the pandemic. Given the increase in household consumption is inevitable [38] the study is mainly designed to verify the implications that should be addressed in a short-to-midterm.

The selection of Ningbo as the case study is due to two factors of relatively minimal COVID-19 impacts and accessibility to residential areas. The city experienced six weeks of lockdown (in February and

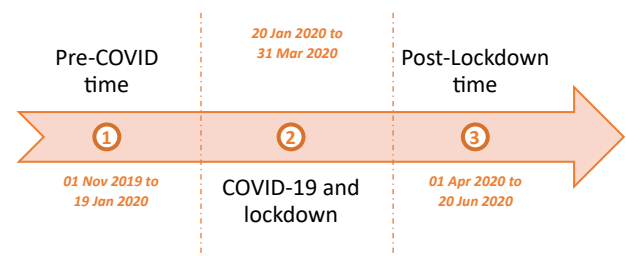


Figure 1. Three stages and timeline of the survey.

March 2020) with a maximum of 157 recorded infected cases and no fatalities (to date, as of 30th of September 2020). In compared to many other cities in China, the city has not yet experienced any new spikes or further waves of the outbreak. As a result, most operations were back to normal by mid-May 2020. The survey was conducted after the lockdown period followed by the normalization of operations in May and June 2020. The households are selected from multiple residential areas, but all qualified respondents were identified as working-class residents, with three main selection criteria of (1) living alone or with family, (2) commuting to work daily (apart from the lockdown period), and (3) having a private car. This selection is based on the mentioned category verification method [51], which is focused on specific demographic characteristics with the highest population in China. In doing so, the study focuses on current trends in household energy changes [57] by avoiding the complexities of multiple categories [58], wide-range impacts [59], and other factors such as behavioural, physical, and socio-economic attributes [60]. This is a verified approach that leads to a better analysis of data without cross-sectional variations [61] and consideration of high-consumption [62] and low-consumption categories. This study, therefore, aims to evaluate the household energy consumption behaviours [63] or changes in requirements [64] that are crucial for the users, policymakers, and developing any future action plans.

The survey is conducted through the consideration of the above-mentioned factors, and by defining multiple uses in and associated with the households. Section 2.2 summarises the main parameters of the survey study for the households. Finally, 352 respondents were qualified for this pilot study. It is important to note that as of May 2020, most daily operations in Ningbo are back to normal and nearly all jobs require on-site operations (apart from some entertainment industries such as cinemas and theatres, and some public buildings, such as museums and libraries). Therefore, the survey could only be conducted during a time when most industries were operational. The survey could not be conducted in separate timelines as the pandemic could not be predicted, the lockdown period was not fixed, and post-lockdown time was under high-level safety and security measures. The following two sub-sections explain the details of the survey and the parameters of the data collection and analysis.

2.1. Survey of household pilot studies

The household cases were selected only if access was permitted. Hence, the research was conducted based on the survey of multiple residential compounds across the city. The survey consisted of four parts. First, the survey started with explaining the aims and objectives of the study as well as the use of the data, to ensure all respondents are aware of the importance and accuracy of the studied areas. In this regard, the participants were asked about their knowledge of household energy use as well as daily activities and operations. Second, the participants were requested to answer three questions to ensure they meet the selection criteria (as shown in section 2 above); and finally, 352 results were qualified. Third, if qualified, the survey included a range of questions on household size, household type, household income, and demographic distribution. Fourth, the participants were asked about household energy

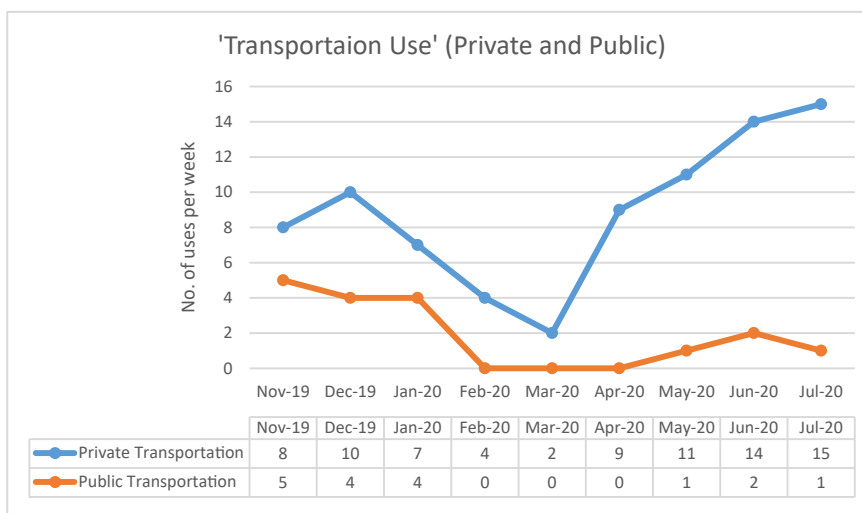


Figure 2. The results for transportation use (private and public) from Nov 2019 to 20 June 2020 (shown as July 2020).

use in three stages of pre-pandemic (and pre-lockdown), the start of COVID-19 outbreak and lockdown, and post lockdown. Each period is identified as a timeframe of approximately 2.5 months, from November 2019 to late June 2020 (i.e. period 1: 01 Nov 2019 to 19 Jan 2020; Period 2: 20 Jan 2020 to 31 Mar 2020; and Period 3: 01 Apr 2020 to 20 Jun 2020) (Figure 1).

2.2. Parameters and participants of the survey

Among the 500 participants, 352 were selected for the analysis. All qualified participants are employed or have their own businesses, have to commute to their workplace on a daily basis, and have a private car. 41.2% of participants indicated an annual household income of less than 500,000 RMB, 45.7% between 500,000 to 999,999 RMB, and 13.1% above 1,000,000 RMB. Regarding ethnic background, more than half of the participants were locally from Ningbo (54.5%), followed by other Chinese but not local (41.8%), non-Chinese or foreign nationals (2.3%), and Chinese minority ethnics (1.4%). More than third of the participants live with a family with one child (34.1%), followed by couples only (29.8%), family with two children (19.3%), and larger families (16.8%). Single-living participants were intentionally disqualified in this survey. Of all 352 participants, the majority live in mid-to-highrise apartments (76.4%) followed by low-to-midrise apartments/houses (18.8%), and villa housing or individual houses (4.8%), which is the factual representation of the Chinese housing market.

The parameters of the study were the primary energy use in six fundamental elements of (1) transportation for commuting and leisure (for both private and public modes), (2) cooking, (3) entertainment, (4) heating and cooling, (5) lighting, and (6) the others. The survey is divided in four packages, that includes (1) the number of uses per week for transportation, both for private and public modes, (2) the number of times per day for cooking and household entertainment activities that require energy use for preparation or operations, (3) the estimated number of hours per day for indoor ‘cooling and heating’ and ‘lighting’. To verify the latter, data for energy costs were also assessed. The data is then aggregated with the average figures amongst all 352 participants, and in three phases as indicated in section 2.1. The monthly average figures are then assessed to indicate changes in household energy use across all three phases.

3. Results

The results of this paper are presented across three combined areas, based on their energy use and daily/regular energy demand. First, the

results of ‘transportation use’ indicate the changes over the total period of 7.5 months in three phases. The correlation between the decline in public transportation use and the increase in private car use is a primary result. Second, the results of ‘cooking’ and ‘household entertainment activities’ are summarized together to indicate the changes between different phases and the correlation between these two daily needs that require energy use for preparation and operations. Third, the results for two major household energy sources are summarized, namely indoor ‘cooling and heating’ and ‘lighting’. These two categories account for the majority of our household energy use and represent the daily comfort needs of our indoor environments. The estimated energy use of these two fundamental elements are cross-checked with energy bills from the same time in 2019. For this analysis, 38.9% of the participants (137 of the total of 352) could verify the difference from their energy bills in both years. This is used only for the verification of energy demand changes during the time of this study. The results indicate no significant changes for the category of ‘the others’, which includes refrigeration, water heating, other household appliances, etc. Hence, the results for this category is not presented. Integrated across all three areas, the following sub-sections present the data followed by further analysis.

3.1. Main impacts on transportation use

The main implication here is the significant change in transportation use that may last longer than expected. The decline in public transportation use, as has been seen from the early days of the lockdown, is based on four main factors, (1) early closure of public transportation systems as also indicated by [12,17], (2) social distancing measures that are used for safety and prevention procedures [65,66], (3) the general perception that rightly suggests public facilities are not safe during the pandemic [12,67], and (4) accessibility to public transportation systems [68,69] that requires decision making to walk outdoor to reach public transport. However, the main energy implication is that public transportation remains ostracized even after the lockdown. Although Ningbo has had no new cases since early March 2020, the use of public transportation is minimized significantly. While the frequency of operations are back to normal since late April 2020, the use of such systems are not even close to half of what they used to be. While public transport systems are managed by the government in China, the pressure would be on the provision of daily energy and operational management. In countries where public transportation is privatized, owners may face even further difficulties in managing the daily operations. The results from the survey indicate 40% increase in private car use with added traffic and energy demand in this sector. Meanwhile, public transportation is facing an

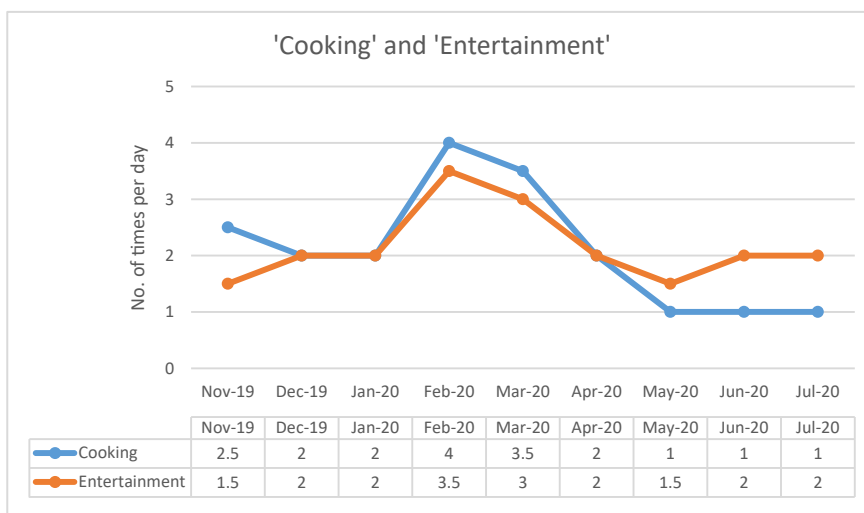


Figure 3. The results for household cooking and entertainment from Nov 2019 to 20 June 2020 (shown as July 2020).

estimated 80% decline in use, which has become prolonged with many empty buses, metro systems, and less demand for regular uses. The correlation between the increase and decline as shown in Figure 2 suggests a much larger energy demand in this sector.

3.2. Main impacts on household 'cooking' and 'entertainment'

Food and entertainment are part of our daily needs but are partially associated with outdoor activities. In China, the culture of eating outdoor [70] is a major part of socializing activities and urban life. The growing outdoor entertainment [71] also indicates the increasing popularity amongst Chinese society. Our survey results suggest an interesting correlation between the two, particularly during the lockdown and post-lockdown periods. The main impact on household cooking is the 40% increase during the lockdown in comparison to the pre-lockdown time. Nevertheless, the trend did not keep up and our results indicate a significant decline in household cooking after the lockdown period. This indicates that household cooking is not returned to normal but instead lower than before. While larger demand for eating outdoor is economically viable for the post-recovery phase of the outbreak, it seems that people generally prefer to recover from several months of constantly cooking and eating inside their households. The same pattern is also seen for household entertainment [72,73] that constitutes a relationship

between indoor stay and activities. For instance, household entertainment was almost tripled during the lockdown period but is reduced to its normal figures after the lockdown. The limited availability and closure of outdoor entertainment activities have enabled people to look for alternatives within the boundary of their households. This also means a short-term increase in household energy use. However, the sudden surge on computing entertainment could lead to longer-term impacts. The results do not suggest longer-term impacts but indicate a partial surge in household energy use and demand (Figure 3). Although no statistically significant results were found that could suggest longer-term transitions, the relatively high increase of household energy demand (for household cooking and entertainment) in the lockdown period challenged assumptions and expectations.

3.3. Main impacts on household 'heating and cooling' and 'lighting'

The results here touch on two main areas of human comfort for the indoor environments, namely 'heating and cooling' and 'lighting', which are both main energy consumption of households [74, 75, 76, 77, 78]. Considering the apparent impact of seasonal changes on energy demand, the results suggest an estimated 60% increase in cooling and heating, and 40% in lighting, just between January and February 2020. This comparison is in the same season and indicates two different times of shorter

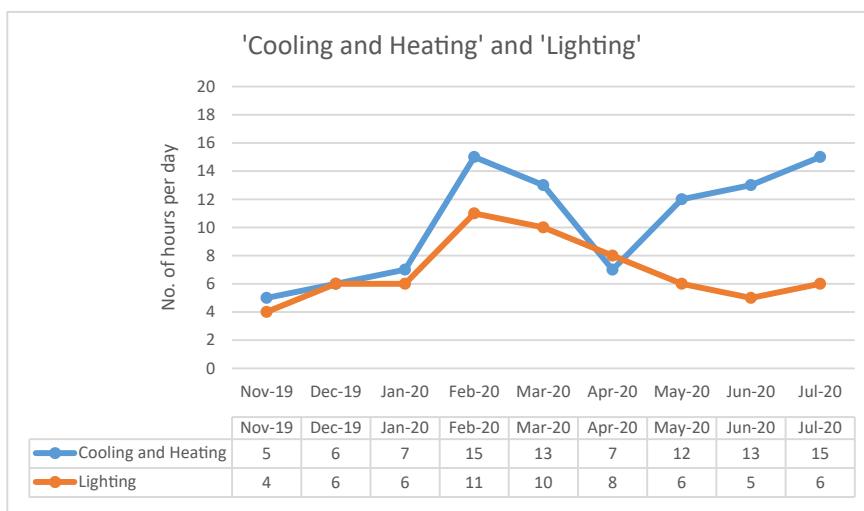


Figure 4. The results for cooling and heating and lighting from Nov 2019 to 20 June 2020 (shown as July 2020).

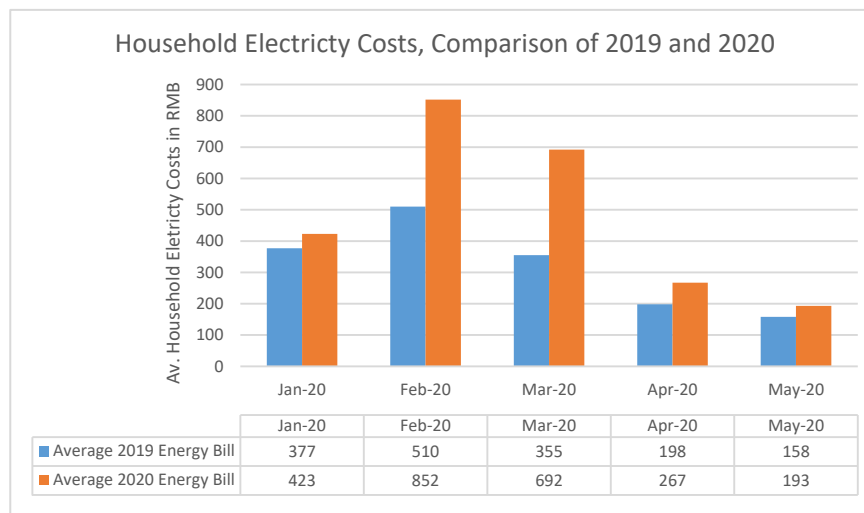


Figure 5. The results for household energy bill comparisons for electricity costs only, comparison of 2019 and 2020 figures for months of Jan–May.

indoor stay (pre-COVID) and the lockdown period that stretched over most of February 2020 (Figure 4).

To verify the energy impacts, 38.9% of the participants (137 of the total of 352) provided the information on their energy bills from Jan–May 2020 and the same time in 2019. The comparison indicates a significant increase in energy bills (i.e. by comparing 2019 and 2020 data) suggesting an average of 67% increase in electricity energy costs in February 2020 (in compared to February 2019), 95% in March 2020, 35% in April, and 22% in May (Figure 5). The unit price for both years have been the same. This verification adds to our concerns that household energy has been significantly affected, and could continue with a similar pattern of at least 20% increase. Future research should aim to look at a much longer period to see if these could be identified as potential transitions in the household energy increase due to longer indoor stay.

3.4. In-depth analysis: potential policy implications and actions

The results of the study cannot verify transitional changes. There are, however, temporary energy implications that are identified as part of this all-inclusive study on household energy consumption behaviour. The increasing demand for household energy use means higher consumption patterns, an increase in the use of household appliances, and longer energy use for cooling/heating and lighting. Therefore, the main policy implications are on measures against the potentially increasing environmental footprint during and after the crisis [79], as well as policy implications for energy supply chain and decline in economic activities and energy consumption [80]. Give the reduction in CO₂ emissions only happened for a temporary period [21,81,82], the study verifies what has been associated with such reduction during that period. One example is the significant change in the selection of transportation mode, which lacks policy support and interventions. This requires action plans that could be responsive to the prolonged decline of public transportation use. The continuity of such a decline would have long term impacts on the industry and could encourage people to opt for private cars. Apart from the already known long-lasting economic effects [83], there are growing concerns regarding short-term effects on behavioural changes that could potentially lead to longer-term behavioural patterns. For instance, the significant increase of household or in-house entertainment could have an adverse impact on outdoor entertainment or create an imbalance in some industries or sectors. For instance, the longer the public libraries remain closed, the more people may question the need for such buildings in their communities. Thus, there is an obvious demand for new digital gadgets and tools that could put pressure on conventional methods of

outdoor activities and functionalities. This study, however, does not delve into such arguments as it can only verify the household energy implications. Nevertheless, there is enough evidence to indicate the need for future actions that could deal with potential transitions or changes that may change our day-to-day activities.

As the pandemic continues, we could identify areas for policy interventions, some of which that could navigate the clean energy transition in the transportations sector [31], provide measures for energy sector responses [55], or create better energy governance [25,84]. Moreover, issues of energy access [54] may seem just about fine for the working class, as it is evidenced in this pilot study. However, this is unlikely to be the case for the people of lower income or deprived communities that have become more vulnerable [12] due to the socio-economic impacts of the pandemic. The more self-sustained development patterns are the ones that could eventually help the better redevelopment of the communities, such as the development of actions for energy access [54], community-focused institutions [84], better investments that include stronger polices [85], and advocating methods of transitioning energy systems [86]. As suggested by [87] “instability makes the ability to adopt and implement...policy options more”. Therefore, we see an opportunity to enhance policies and actions that could lead to positive new normals [12], such as further investment in public facilities, public transportation, energy access, environmental policies, and policy interventions at the community level.

In summary, policy implications and actions are essential in a long term and after the pandemic. These actions are essential to reflect on the losses in the progress of implementing and achieving the United Nation’s sustainable development goals (SDGs), such as the sustainable energy for all initiative [48]. The current disruption in the patterns of household energy consumption could potentially impact the major initiatives of energy management and energy control, which then require to be carefully assessed and supported. Therefore, active policies are needed to reflect on the conditions responsibly [12] and by taking into consideration the long term effects of the COVID-19 pandemic on households, household energy, energy consumption behaviour, and energy demand. Altogether, the household energy implications should not be neglected as part of transitional opportunities or behavioural changes that may have occurred due to the pandemic. This study sheds light only a few examples on a small scale, but future research should evaluate larger datasets and potentially at multiple locales. It is important to note that the current variations in energy use, even if in specific sectors, could have significant implications for national-level or local-level policy initiatives. Therefore, policy interventions should be carefully crafted to reflect on the socio-economic conditions as well as potential behavioural changes. By

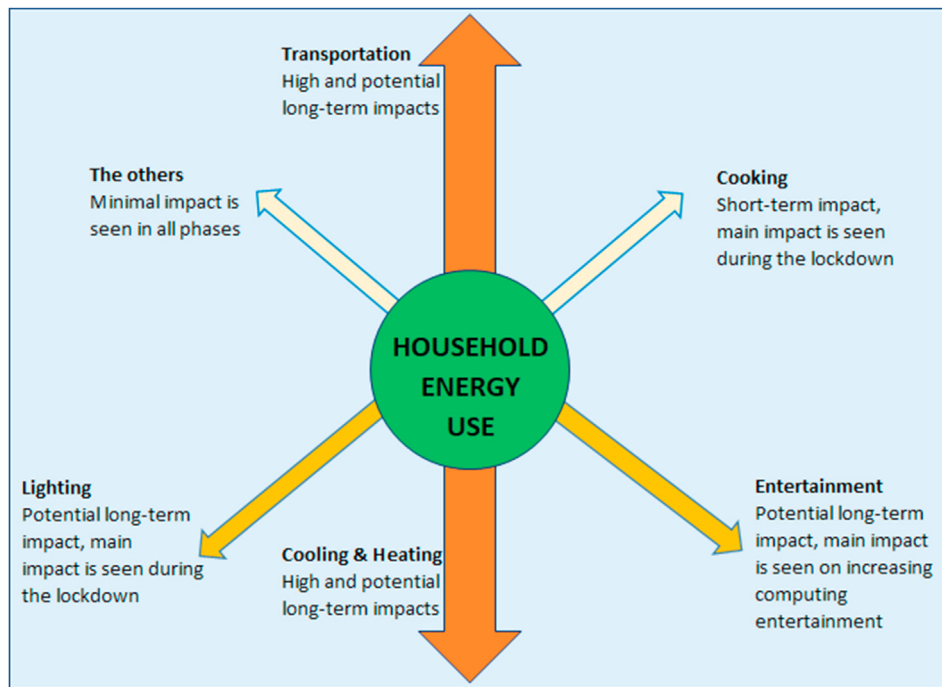


Figure 6. The summary of energy use impacts due to COVID-19. (Legend: the long and thick arrow indicates high impact and long term effects, the short and think arrow represents short-term changes or insignificant impacts).

formulating these, the aim should be to establish long term action plans on major initiatives that are likely to be affected the most. In the following section, we summarise the findings of the study and highlight what could be a crisis and what could be an opportunity. These are highlighted as part of the conclusions of the study.

4. Conclusions

This study is placed in the light of the ongoing COVID-19 pandemic event and its focus is on household energy implications that suggest energy impacts on transportation, cooking, entertainment, cooling and heating, and lighting. It mainly investigates the changes that could suggest major impacts on the household energy use because of the COVID-19, and some that could potentially last longer than these few months of the pandemic. In light of this investigation, the main findings of this research are summarized in the followings:

- (1) The impacts on transportation use, specifically from the household use perspective, is twofold: first, there is an inevitable increase in private transportation for commuting and leisure, and second, there is a significant decline in public transportation use that could lead into unforeseen pressures on public transportation suppliers/companies or even longer-term impacts;
- (2) The impact on energy consumption related to household cooking is likely to be temporary with reverse impacts after the lockdown period;
- (3) The impact on household entertainment is likely to increase in the longer term, with a potential increase in computing entertainment that became more popular in recent months. Hence, we anticipate steady and higher energy consumption for household entertainment activities
- (4) The impacts on household electricity costs associated with heating and cooling will largely depend on potential transitions for work-from-home initiatives and longer indoor stays. It is likely to see longer impacts that could lead to more indoor stays in the future.
- (5) The impacts on household lighting are similar to cooling and heating and mainly depend on forthcoming transitions. It is likely

the indoor stays could be temporary during the COVID-19 pandemic but could remain as longer-term norms even when the pandemic ends. Hence, we could anticipate longer-term transitions should more people opt for work-from-home in the future.

- (6) The impacts on other household energy use are unchanged and appear to have minimal impacts on the short-term.

Figure 6 summarizes these impacts indicating how they would be seen from the household energy use perspective.

The energy crises resulted from the impacts of COVID-19 on daily operations/use suggest both long-term and short-term changes. Through a pilot study, this research paper briefly assessed changes in household energy use in different phases before and during the pandemic (to date). The results could provide early suggestions for cities or regions that are experiencing longer lockdown or may face the new waves of the outbreak. As this study serves only as a pilot study, the findings indicate the need for larger-scale research in assessing household energy use and energy demand in the event of a pandemic. Finally, we emphasize the importance of energy implications that could lead to better evaluation of potential transitions and the impacts on energy suppliers and the decision making of energy managers, policymakers, and end-users. If not properly planned, energy impacts could become adversities of the lower-income communities and could lead to potential conflicts in a phase in which the society needs more support than ever.

Declarations

Author contribution statement

A. Cheshmehzangi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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