Received 22 September 2022
Revised 26 August 2023
1 November 2023
Accepted 28 December 2023

A review of electricity consumption and CO_2 emissions in Gulf Cooperation Council households and proposed scenarios for its reduction

Tarig Zeinelabdeen Yousif Ahmed
Cambridge University, Cambridge, UK and
University of Surrey, Stag Hill Campus, Guildford, UK
Mawahib Eltayeb Ahmed
Institute of Engineering Research and Material Technology,
National Center for Research, Khartoum, Sudan, and
Quosay A. Ahmed and Asia Adlan Mohamed
University of Khartoum, Khartoum, Sudan

Abstract

Purpose – The Gulf Cooperation Council (GCC) of countries has some of the highest electricity consumptions and carbon dioxide emissions per capita in the world. This poses a direct challenge to the GCC government's ability to meet their CO_2 reduction targets. In this review paper the current household electricity consumption situation in the GCC is reviewed.

Design/methodology/approach – Three scenarios for reducing energy consumption and CO_2 emissions are proposed and evaluated using strengths, weaknesses, opportunities and threats (SWOT) as well as the political, economic, social, technical, legal and environmental (PESTLE) frameworks.

Findings – The first scenario found that using solar Photovoltaic (PV) or hybrid solar PV and wind system to power household lighting could save significant amounts of energy, based on lighting making up between 8% to 30% of electricity consumption in GCC households. The second scenario considers replacement of conventional appliances with energy-efficient ones that use around 20% less energy. The third scenario looks at influencing consumer behavior towards sustainable energy consumption.

Practical implications – Pilot trials of these scenarios are recommended for a number of households. Then the results and feedback could be used to launch the schemes GCC-wide.

Social implications – The proposed scenarios are designed to encourage responsible electricity consumption and production within households (SDG12).

Originality/value – All three proposals are found viable for policymakers to implement. However, to ensure successful implementation GCC Governments are recommended to review all the opportunities and challenges associated with these schemes as laid out in this paper.

Keywords Electricity consumption, Energy efficiency, Climate change, Emissions, Electrical load, GCC

Paper type Literature review

1. Introduction

The international community in September 2015 adopted the UN sustainable development goals (SDGs) and defined global priorities and aspiration to be achieved by 2030. One of the

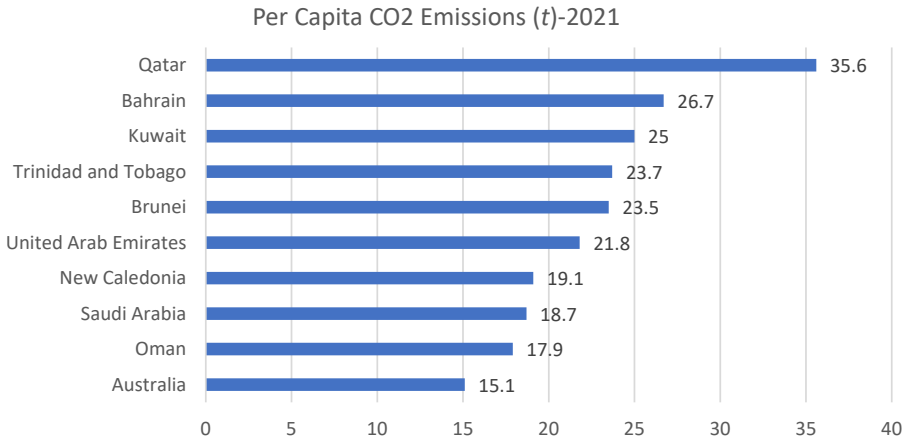
Arab Gulf Journal of Scientific Research
Vol. 42 No. 4, 2024
pp. 1882-1899
Emerald Publishing Limited
e-ISSN: 2536-0051
p-ISSN: 1985-9899
DOI 10.1108/AGJSR-09-2022-0188

fundamental objectives of the 2030 agenda is to decouple economic growth from resource use and environmental degradation. This can happen through a move towards more sustainable consumption and production patterns (Goal 12) (Bengtsson, Alfredsson, Cohen, Lorek, & Schroeder, 2018). The Paris agreement (PA) is a complementary mechanism to the SDG's (sustainability development goals) goals that tackles climate change. Energy lays at the heart of both the 2030 agenda for sustainable development and the PA on climate change (IRENA, 2019).

The six countries that comprise the Gulf Cooperation Council (GCC) for the Arab States of the Gulf (also referred to as the GCC) are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates (UAE). They together cover a total area of 2.4 Million/km^2, a population of about 58 million and a gross domestic product of $ 1.4 trillion or about $ 25,000 per capita (GCC-Stat, 2020). The GCC countries are major oil and gas producing countries. They hold approximately 30% of the world's proven oil reserves and 23.6% of the world's proven gas reserves. About 51% of the population of the GCC is national citizens and 49% non-nationals (persons bearing nationality of a foreign state other than the GCC state of residence). GCC countries have similar weather conditions and are classified as hot desert climate (BWh) according to the Koppen climate classification. Its countries share the same religion and cultural lifestyle. Since the early 1970s the GCC countries started benefiting significantly from oil and gas industry revenues.

The GCC energy system is characterized by very high dependence on conventional energy production technologies based on oil and gas. At the same time these countries are growing rapidly in most aspects of life, and they continue their path towards becoming progressively more important hub of energy production and consumption (The World Bank, 2022).

All GCC nations are classified in the world's top 50 CO_2 emitters except Bahrain (European Commission, 2021) and all are within the world's top 14 countries of CO_2 emitters per capita (Figure 1). Their emissions are concentrated in energy consumption mainly electricity and water desalination. As many other developing countries, the GCC nations are to fulfill their commitments to the PA and the SDGs (Abdel Gelil, 2009; GCC-Stat, 2020). After the Paris agreement, many countries have submitted their National determined contributions (NDCs) for adaptation and mitigation of climate change.



Source(s): Our world in data (2023)

Figure 1.
Top 10 emitters of carbon dioxide (CO_2) emissions per capita as of 2021

In the GCC the household sector is 100% electrified using mainly conventional fossil fuel energy sources (IRENA, 2019). This made household energy conservation an important issue for researchers, environmental practitioners and policy makers.

The aim of this paper is to encourage the GCC nations to reduce their per capita electricity consumptions and CO_2 emissions by ensuring sustainable energy consumption and production. Firstly, a situation analysis of the GCC region in relation to energy use is reviewed based on previous literature. Then three scenarios are proposed and investigated looking at different energy saving measures that could be used. The three scenarios are:

(1) *First Scenario:* Proposing a PV system or hybrid energy system for household lighting.

(2) *Second Scenario:* Using efficient appliance for energy conservation.

(3) *Third Scenario:* Enhancing consumer behavior towards sustainable energy consumption.

These scenarios are evaluated for their viability and potential success in the GCC nations using two frameworks, strengths, weaknesses, opportunities and threats (SWOT) and political, economic, social, technical, legal and environmental (PESTLE). The SWOT framework investigates the strengths, weakness, opportunities and threats for each scenario in relation to certain factors. These factors are outlined in the PESTLE framework. Following this, recommendations are put forward to help GCC policymakers successfully implement these energy saving policies.

2. Background

Climate change is a global problem that requires global movement. Developed countries including the GCC are responsible for the vast majority of Green House Gas (GHG) emissions in the atmosphere (European Commission, 2021). So developed countries and the GCC are under more pressure to adopt clean developmental activities (Abdel Gelil, 2009). This clean development target is highlighted in the SDGs; mainly SDG12 which aims to ensure sustainable consumption and production. For example, target 12.1 from SDG 12 recommends developed countries take the lead on implementing a framework program on sustainable consumption and production; this refers to all energy forms including electricity. Similarly linked to energy consumption SDG 7 target 7.3 mentions the need for energy efficiency in housing (The Global Goals, n.d.). All the GCC countries are active parties in the United Nation Climate Change Convention and they submitted several related reports such as national communication reports (Abdel Gelil, 2009).

2.1 GCC energy consumption and GHG emissions

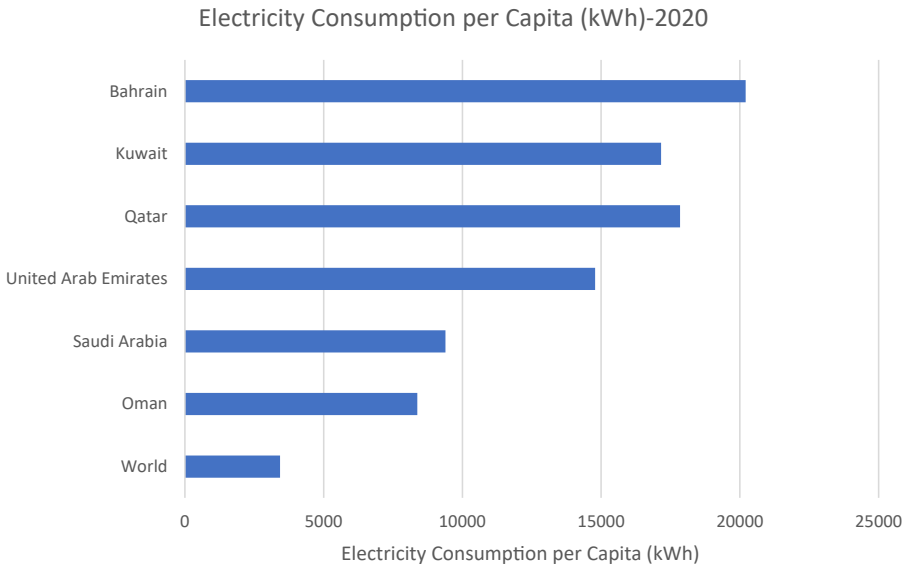
The GCC countries currently rank among the highest GHG emitting nations per capita in the world (Figure 1). Six out of the top 10 nations with the highest CO_2 emissions per capita (tonnes per person) are GCC nations. Qatar currently ranks number one in this list as of 2021 (Our World in Data, 2023).

Moreover, electricity consumption per capita is also very high in GCC nations. Four out of the top ten countries with the highest electricity consumption per capita are in the GCC (Our World in Data, 2022). According to Qader (2009) this high energy consumption is reflected in the living standards and consequently the electricity consumption of individuals and the countries. As per statistics by the World Bank, in 2014GCC countries have considerably higher electricity consumption per capita than other countries. For example, Bahrain is ranked as the third highest with a per capita consumption of 19,597 kWh per person, Kuwait

is the fourth highest with 15,591 kWh electricity consumption per person. In comparison, this is more than 60 times higher than the electricity consumption in Sudan and other sub-Saharan African countries (The World Bank, 2014). Figure 2 compares electricity consumption per capita for GCC countries with the world average per capita in the year 2020. It shows the significant electricity consumption of GCC countries compared with the result of the world. For example, the electricity consumption per capita for Oman (the lowest value of the GCC nations) is twice that of the world and for the Bahrain (the highest value of the GCC nations) is more than four times that of the world. The per capita rate of electricity consumption is also growing in the GCC due to increasing temperatures from climate change, urbanization and economic development (Al-Badi & AlMubarak, 2019).

2.2 Social norms and influence in energy consumption

Energy saving practices could be framed as communal and socially needed. This involves people adopting and encouraging energy saving practices with relatives or neighbors. Providing social approval of such practices can normalize positive "energy saving" practices and help reduce community electricity consumption consequently (Frederiks, Stenner, & Hobman, 2015). Wide research supports the efficacy of social norms information, for example, (Nolan, Schultz, Cialdini, Goldstein, & Griskevicius, 2008) found that consumers who received descriptive normative messages (e.g. information comparing a household's energy usage to that of neighbors) used significantly less energy in the short-term compared to householders who only received energy saving tips. A review of several studies (Black, Stern, & Elworth, 1985; de Young, 2016; Gardner & Stern, 1996; Stern, 1992) reflected on the role of attitude variables, such as values, worldviews, attitudes or norms for energy conservation behavior. Different modes of energy-related attitudes have been examined, such as price concern (Seligman *et al.*, 1979; Verhallen & van Raaij, 1981) energy concern, responsibility for future generations, belief that energy problems cannot be solved easily, and belief that one should



Source(s): Our world in data (2022)

Figure 2.
Average electricity consumption per capita across different GCC countries and the world for the year 2021

reduce energy consumption (Midden & Ritsema, 1983; Painter, Semenik, & Belk, 1983; Verhallen & van Raaij, 1981).

According to Black *et al.* (1985), it was found that behavioral responses related to energy, economic are affected by self-interest and internalized personal norms based on the type of energy-saving behavior. The consumer will most likely act on personal norms when there are fewer constraints on a given energy-saving action. For example, temperature settings, low-cost energy efficiency improvements and simple curtailments are impacted to a variable degree by norms, while expensive improvements are not.

Most of the electricity consumed in GCC homes is in space cooling where many air conditioning systems are used. This accounts for almost 70% of peak electricity consumption (Almasri *et al.*, 2023). Lighting systems are the second highest consumers with between 8% and 30% (Mathur, Muthukumaraswamy, & Varela, 2018; Visualcapitalist, 2016; Almasri *et al.*, 2023). Some GCC countries such as Qatar and Kuwait still offer electricity free of charge for domestic use, which encourages excessive use. On the other hand, Bahrain, Saudi Arabia and Oman offer subsidized electricity prices for domestic use (Al-Badi & AlMubarak, 2019). Unlike developed countries that are enforcing taxations on energy use, GCC countries subsidize electricity and fuel price which encourage household sector to consume more electricity (Qader, 2009). Nevertheless, there is complexity of household energy consumption and conservation behavior, consumers are far from taking rational decision adopted by traditional economic models and there is always a gap between people values and materials interest and their actual behavior (Frederiks *et al.*, 2015).

2.3 Current efforts in renewable energy and energy efficiency

Renewable energy has high potential in the GCC region. Oman, Saudi Arabia and Kuwait have good wind resources (above 7.5 m/s) and all of the GCC nations have good solar irradiance (IRENA, 2019). However, as a collective only 0.6% of electricity in the GCC is generated from renewable energy (Figure 3) (Elrahmani *et al.*, 2021; IRENA, 2019). There is ambition from almost all GCC countries to increase their percentage contribution of renewable energy, however these are still well below the majority of electricity capacity. For example, by 2030 Kuwait aims to generate 15% of its electricity from renewables, Bahrain aims for 15% by 2035 and Saudi Arabia 30% by 2030 (IRENA, 2019), Table 1.

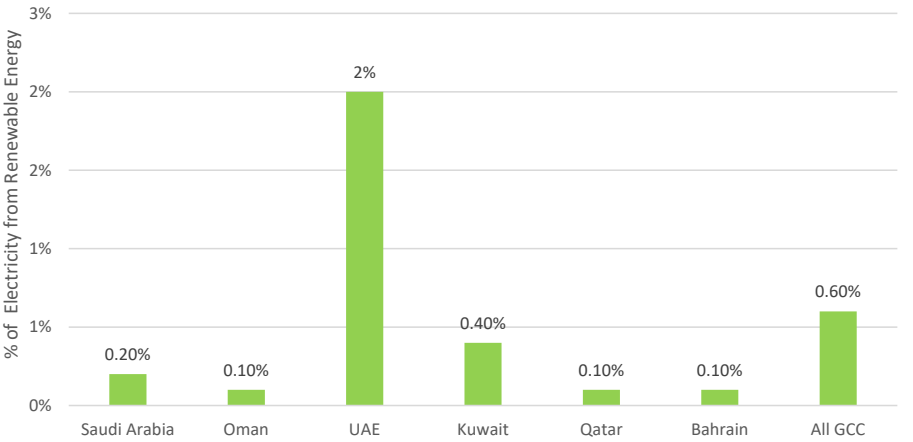


Figure 3.
Installed renewable energy capacity (%) in GCC countries

Source(s): Elrahmani *et al.* (2021) and IRENA (2019)

Solar energy was found suitable for the most of the GCC. Suitability analysis for on-grid solar PV showed most areas are over 90% suitable, despite the high temperatures (IRENA, 2019). Solar technology can be adopted by households independent of the government for those wishing to generate electricity sustainably themselves. Although this is unlikely due to the very low electricity prices from the grid and low number of power cuts, which discourages household investment in other energy sources.

The governments in each GCC country are working to limit the increasing unsustainable electricity consumption. For example, the UAE government has now commissioned various solar PV farms over the years with many more under construction. The Noor Abu Dhabi is one such project which aims to generate over 1GW of electricity from its solar panels. Such initiatives have made the UAE the current leader in the GCC with the highest share of renewable energy in its overall capacity (2%). They aim to make renewables make up 44% of their electricity capacity by 2050. Moreover, the UAE is integrating renewable electricity into new communities and cities, such as Masdar city, which is a carbon-free area in the UAE.

GCC countries also are establishing energy efficiency measures including low electricity consumptions, low energy buildings and efficient appliances (Alharbi & Csala, 2020). For example, Kuwait approved an energy conservation program and code of practice in 2014. Most other GCC countries have green building codes for new buildings.

Meaning energy efficiency can be achieved in the lighting sector by transitioning to Light Emitting Diode (LED) lights. LED lights use around 80% less energy than Incandescent lightbulbs and 30% to 40% less energy than fluorescent bulbs (Ganandran, Mahlia, Ong, Rismanchi, & Chong, 2014). Some GCC countries have made strides in this. For example, the UAE banned all sales of incandescent lamps from 2014. This is estimated to have saved them $182 million per year on energy bills as well as saving carbon emissions estimated at the equivalent of taking 165,000 cars off the street (Zissis, Bertoldi, & Serrenho, 2018), whereas in Saudi Arabia incandescent light bulbs are still widely in use and one study estimates them to make up 40% of all lights in homes in Qassim region, with LED making up only 30% of light bulbs (Almasri *et al.*, 2023).

2.4 Consumer behavior in energy consumption

Some studies have shown changes in behavior can help reduce household energy consumptions significantly. Behavioral savings potential in household is quantified in the framework of energy efficiency interventions developed in real-world contexts. In most of the studies it was found that, behavioral change interventions can generate energy savings up to 20%, but values may differ up to 100% between different studies and contexts (Lopes, Antunes, & Martins, 2012). Taking Europe as an example, the most effective interventions

Country	Renewable energy targets	Energy efficiency targets
Kuwait	2030: 15% of total electricity generation	2030: 30% reduction in energy consumption in buildings
Qatar	2022: 200 to 500 MW of Solar Energy	2022: 8% reduction in electricity consumption
Bahrain	2035: 10% of electricity from renewables	2025: 6% reduction in electricity consumption
UAE	2050: 50% clean energy(44% renewables and 6% nuclear)	2050:40% electricity consumption reduction 2030: 30% electricity consumption reduction
Saudi Arabia	2030: 30% of electricity from renewables	2021:14% reduction in peak demand
Oman	2025: 10% of electricity generation	2030:2% reduction in electricity consumption

Source(s): IRENA (2019)

Table 1.
Renewable energy and energy efficiency targets in Gulf states

included feedback, energy audits, community-based initiatives and the combination of multiple strategies, all generating savings from 5% to 20% (EEA, 2013).

Energy efficiency from behavioral interferences can be improved by working on energy-related practices that can simply and smoothly be applied using default appliance settings. Household consumers can be encouraged to make one-off actions in setting a dishwasher or washing machine's default program to "short-cycle" and/or to "cold" water. Evidence from field studies and experimental trials found that strategies that encourage people to shift from the status quo (e.g. offering "free trial" periods or "try-before-you-buy" offers) should exploit on salient "trigger points" in peoples' lives, that is, significant life events such as moving house, marriage or the birth of a child, when automatic, routine and habitual behavior patterns are disrupted and people are more amenable to change (Frederiks *et al*., 2015).

Energy-saving messages can be framed to maximize their impact and help reduce household energy consumption. Different results can be gained by framing a choice between gain or loss (Lopes *et al*., 2012). Loss framed message emphasize the negative outcome of a decision; whereas gain framed messages emphasize the positive outcome. Both can influence consumer decisions (Kim, 2018; Leoniak & Cwalina, 2017; Lopes *et al*., 2012). Although, a study by Frederiks *et al*. (2015) suggests people view loss of something as far greater than an equivalent size gain. For example,instead of considering the payouts (gains) of saving energy, focus could be on the costs associated with energy-cooling practices and show how energy conservation activities and green-environmental behavior will stop forthcoming losses and costs. Another example is a message saying "You are currently losing $10 per billing quarter by not switching off your conditioners" can be more inspiring than saying, "You could save $10 per billing by turning off your conditioners".

A recent review of electricity consumption in the GCC identified energy efficiency as one of the best measures that can be taken to save energy (Almasri & Alshitawi, 2022). In particular improving the efficiency of air conditioners and adding thermal insulation to walls. However, there is currently a research gap on consumer behavior analyzes for energy conservation in the GCC. Any energy saving in the GCC would need to be done with growth and economy in mind, as increase in electricity consumption has closely followed economic growth in GCC countries (Osman, Gachino, & Hoque, 2016).

2.5 Solar resources in the GCC region

The review demonstrates that the GCC region is characterized by abundant solar energy resources. The northwestern, southeastern and western mountains of the region are highlighted as locations for solar energy application. Oman displays the highest onshore wind speed range, 3–6.3 m $s^{-}1$, and has the highest annual solar radiation of up to 2500 kWh/m2. The UAE has the second highest annual solar radiation, 2285 kWh/m2, while Saudi Arabia and the state of Kuwait have equal annual solar radiation at 2200 kWh/m^2 (Shawon, Chaar, & Lamont, 2011).

3. Approach and methodology

The methodology adopted in this research paper based on situation analysis and proposing scenarios that supports household energy consumption reduction in the Gulf region. Many reports and research papers were reviewed mainly climate change reports like the National Communications Reports and other mitigation efforts reports and there search papers that highlighted household energy consumption issue were well studied. Most references are taken from high end journal websites such as www.sciencedirect.com.Research papers are mostly from the past 10 years to reflect the current state of society, however in some occasions older papers are referenced when required.

There are various analytical tools that can be used to assess electricity consumption in the GCC. The various tools including simulation tools, scenario tools and bottom-up tools among

others are investigated by AlKhars (2019) for electricity research in the GCC between 1983 to 2018. In this paper the scenario method is utilized, which was found to be lacking in literature for the GCC region (AlKhars, 2019). The scenario method combines a series of years, periods or conditions into scenarios or case studies for analysis.

Secondary data and graphs were used to explain energy consumption and GHG emission in the GCC region compared with developed and developing countries. Three energy consumption scenarios were analyzed to evaluate their potential to reduce energy consumption in the GCC countries. Solar energy utilization was proposed as the first scenario, while using efficient appliances was the second scenario. Consumer behavior was addressed as the third scenario.

The discussion section evaluates the scenario proposals using the SWOT framework. This looks at each proposal's SWOT. Thereafter recommendations are made to policy makers. Also, the PESTLE analysis is used to further analyze the techno-economic and social impact of these proposals. PESTLE stands for political, economic, social, technical, legal and environment. Both the SWOT and PESTLE frameworks have been applied previously in literature to evaluate renewable energy potential in certain countries (Madurai Elavarasan, Afridhis, Vijayaraghavan, Subramaniam, & Nurunnabi, 2020; Zalengera *et al.*, 2014).

4. Proposed scenarios

Policy measures and instruments play an important role in promoting energy efficiency and conservation. There are several types of these measures and instruments including market instruments such as taxes, charges, tradable permits and credits, and nonmarket ones such as subsidies, voluntary agreements and administrative regulations.

Nevertheless, it was found that in market economies the behavior of producers and consumers always determined the final effect on energy consumption (Frederiks *et al.*, 2015). Therefore, for effective energy consumption reduction both the consumer and government play an important role.

Since GCC countries have some of the highest electricity consumptions and CO_2 emissions per capita in the world,this paper discusses and presents the following scenarios for household energy consumption reduction:

(1) *Scenario One:* proposing solar energy for lighting,

(2) *Scenario Two:* Using energy efficient appliances,

(3) *Scenario Three:* Promoting energy efficient consumer behavior.

4.1 First scenario: proposing a solar PV system for household lighting

The GCC countries all have high solar irradiance and are considered suitable for solar PV despite the high temperatures (IRENA, 2019). Solar PV systems can therefore be utilized to help power some of the high energy consuming appliances. Although air conditioning is the largest energy consumer in GCC households, lighting systems closely follow. It may be unrealistic at first to power air conditioning with solar PV due to the large amount of solar panels required and high costs. Therefore, solar PV can be used to power lighting loads which will require fewer solar panels. With battery storage then night-time appliances such as lighting can be powered. The energy consumed by lighting in household varies, but studies estimate this from 12% to 30% per household (Mathur *et al.*, 2018; Visualcapitalist, 2016), whereas air conditioning makes up around 70% of residential electricity consumption in some GCC countries [24].

For this scenario households in Qatar are used as an example in the GCC, most of the households in the Gulf region is divided into three categories; flat, house and villa. These are shown in Table 2 alongside their average energy consumption for Doha, Qatar.

The energy consumption of lighting is estimated and presented on Table 3 based on low estimate (12%) and high estimate (30%) of usage.

To mitigate the lighting energy consumption then solar panels can be used. These can be installed in homes to provide each home sufficient electricity to cover its lighting load. Since lighting is used at night, a battery storage system would be required to store the electricity generated from the solar PV system. Alternatively, the solar panels can be connected to the grid and the equivalent electricity can be exported to the grid. Similarly, air conditioning electricity consumption can be offset by increasing the size of the solar panels to cover air conditioning consumption. However, the size of the solar panels would increase and therefore the cost.

For example, in Qatar the average daily electricity generation from solar PV is 4.6 kWh per 1 kW (peak) of solar panels (SolarGIS, 2022). Using this value with the numbers in Table 3 (divided by 30 days) then the mean solar panels required are shown on Table 4. Solar panels required for a house and villa to cover 30% of the lighting load is estimated at 15 kW and 14.6 kW, respectively. These values are quite high and would require large rooftop areas. However, for solar panel sizes for covering lighting at 12% is within average rooftop solar PV sizes.

A business model that could work well in Qatar and other GCC countries is the roof rental model. In this, the residential homeowner rents out their rooftop space to a solar PV developer

Table 2. Average monthly electricity consumption in Qatar, kWh, at different residential units

Flat (kWh)	House (kWh)	Villa (kWh)
992	6,045	10,017
2,223	6,637	5,767
2,489	9,588	8,830
1,551	8,224	9,055
959	4,908	3,978
2,116	7,646	5,125
1,456	5,571	4,160

Source(s): Kahramaa (2017)

Table 3. Average monthly energy consumption, lighting (12%) and lighting (30%) consumption, in KWh, in Qatar

	Flat	House	Villa
Average	1,684	6,946	6,705
Lighting (12%)	202	833	805
Lighting (30%)	505	2,084	2,011

Source(s): Author's own calculations and data from Table 2 (Kahramaa, 2017)

Table 4. Estimated solar PV size to power lighting consumption in Qatar

	Flat	House	Villa
Lighting (12%)	1.5 kW	6 kW	5.8 kW
Lighting (30%)	3.6 kW	15 kW	14.6 kW

Source(s): Author's own calculations and data from Table 3

to install solar PV panels. The panels will be connected to the main grid. The developer will then benefit from any electricity produced by the solar panels and exported to the grid through a feed-in tariff scheme. The resident will benefit by taking rental payments from the developer or profit sharing from the feed-in tariff scheme. This model was suggested by Alhaj (2017) and has the advantage of significantly reducing upfront solar PV costs for residents since the developer would purchase the system.

If the rooftop space is limited to install solar panels then a hybrid renewable energy system can be utilized. This would use small wind turbines installed on the roof of the home or courtyard. Wind and solar energy are complementary and this may help ensure more continuous electricity generation. However, a wind turbine may not work for some homes in the GCC region, particularly those that are in urban areas and overshadowed by tall buildings. Therefore, further investigations on the feasibility of the small wind turbine would be required for each geographic area.

4.2 Second scenario: using efficient appliance for energy conservation

Many efforts are in the pipeline to mainstreaming mitigation action in the GCC and one of the proposed actions is to develop mitigation measures. After the Paris agreement, there was pressure on the GCC as fossil fuel producers to submit their NDC. Energy consumption reduction targets through energy efficiency are one of the best scenarios for Gulf region in the residential sector. In some of the GCC countries energy star appliances are used which are certified by the energy department in USA. In general, energy star certified appliances can save the following:

(1) Refrigerators and freezers – 15% more efficient.

(2) Dehumidifiers −15% more efficient.

(3) Room air cleaners and purifiers – up to 20% more efficient.

In addition to energy star rated appliances one of the easiest energy reduction measures is replacing lighting systems to efficient LED types. Some GCC countries have made strides in this such as the UAE banning incandescent lamps from 2014 (Zissis *et al.*, 2018). However, others are lagging (Almasri *et al.*, 2023). Since LED lights use around 80% less energy than incandescent lightbulbs and up to 40% less energy than fluorescent bulbs it is recommended to transition all existing lighting systems to this technology sooner rather than later. Policymakers can conduct house surveys to investigate the rate of inefficient appliances in homes and act accordingly.

4.3 Third scenario: enhancing consumer behavior towards sustainable energy consumption

In this scenario, we discuss consumer behavior and social norms, with emphasis on practical solution based on cost effectiveness and sustainable energy. Three norms are proposed that can be applicable for consumers in the GCC. These situations can be promoted by policymakers in the government or utility companies:

(1) Effectiveness of behavioral interventions improving energy related practices in using default systems by encouraging households to perform one-off actions. For example, setting washing machines (dish and cloth) for short-cycle/cold water fora full cycle and when hot water is not needed for dishes and clothes or closing doors and windows while air conditioners are on. Consumers in the GCC can positively respond and improve their energy practice if there is an active participation process.

(2) Energy saving messages the message should focus on minimizing the losses and costs; to prevent future losses in terms of time, effort and money and this is called loss-framed message. Some of the literature reviewed suggests loss-framed message may be more

effective for the consumers than gain-framed messages. So, the statement can be"you are going to lose$20 per bill by not switching off your lights while you are at home" instead of saying "you are going to save $20 by turning off the lights". Gulf consumer culture is not much affected by the saving issue, but no one likes to lose money.

(3) Social influence where possible promote good examples of energy saving practices of neighbors, others in the community or people in other countries to households. By doing so such good practices can then appear acceptable and "normal" to households. This can then motivate households to do similar good practices in energy saving and consequently reduce their consumption.

5. Discussion and recommendations

Understanding sustainable consumption and production in the GCC brings to light the linkage and cross cutting issues with other SDGs goals. Namely SDG goal 12 (responsible consumption and production) and SDG goal 13 (climate action). On the other hand, comprehensive understanding of climate action makes it important to develop a policy framework as well as an institutional framework to consider mitigation and adaptation. The implementation and coordination process of which requires different actors; ministries, private sector and organizations in the GCC. Ensuring information sharing and awareness raising will help in enabling sustainability plans in the GCC. Household energy is considered as one of the challenging issues globally in the fight for climate change and it is an opportunity for researchers, practitioners and policy makers to work together on.

In this study, the literature was reviewed to understand the current situation with regards to household energy consumption in the GCC. Across several reports the GCC countries consistently ranked among the top energy consumers per capita in the world, with many of its countries being in the top 10. This was highlighted as being unsustainable and contrary to the requirements of the SDG goals. However, the literature also highlighted many targets already in place by GCC countries to reduce electricity consumption and to increase the share of renewable energy in the next years. Several papers also highlighted the benefit of specific behavioral messages to help encourage sustainable consumption in households. With this background three scenarios were put forward to help with reducing energy consumption and emissions in GCC households. These proposals are analyzed against the SWOT framework to evaluate their SWOT within the GCC countries alongside the PESTLE Framework.

The review of the literature, the proposed scenarios and their evaluation highlights many areas that need to be addressed by GCC governments when developing energy policy or programs. The areas that need to be considered and recommendations are detailed below:

(1) General policy

- Align any new energy policy with SDGs mainly SDG12, sustainable consumption and production concept and actions for the household sector.
- Develop policy approaches include information, communication measures, regulations and market-based actions to support sustainable consumption and production.
- Support public-private partnerships to encourage innovation in cleaner production and consumption.
- Encourage technology research related to low energy household cooling and this should consider design and materials.
- Support research in developing energy efficiency measures in the Gulf region.

(2) Policy for household consumption

- Establish an energy efficient appliances program with a focus on replacing older appliances with new efficient types (such as those certified with energy Star rating). Also, include the replacement of incandescent and fluorescent light bulbs with LED types.
- Subsidies are required for renewable energy technologies to be used in household, such as the incorporation of solar panels to reduce carbon emissions.
- Adopting effective measures in buildings include appliance standards, building codes, demands-side management programs, public benefit charges and eco-labeling.

(3) Consumer behavior recommendations

- Developing public awareness program in energy saving and efficiency in household to affect consumer behavior. Including school and community awareness programs.
- Introducing incentives for consumers who succeeded in achieving agreed, saving target in energy consumption.
- Extensive research that supports the efficacy of social norms and developing models that supports motivation actions towards energy saving.

6. Conclusion

A review of the household energy consumption in the GCC countries from the literature showed that urgent action is required to help GCC countries reach net zero targets. One source indicated that 4 out of the top 5 countries for emitters of CO_2 per capita in the world were in the GCC. Moreover, 4 out of the top 10 countries for consumption of electricity per capita in the world were also in the GCC.

Three energy saving scenarios were proposed to help GCC countries reduce their electricity consumption and CO_2 emissions. SWOT and PESTLE frameworks were used to evaluate these scenarios, including their strengths, weakness, opportunity and threats across these factors: political, economic, social, technical, legal and environmental. The results of these findings are presented in Tables 5–7. In summary, the main conclusions drawn are:

(1) Proposal 1 investigated adopting PV systems or renewable hybrid energy system (solar PV + wind turbine) to power lighting. This was estimated to help reduce carbon-based electricity emissions from 8% to 30%, which is the approximate lighting electricity consumption levels residentially. Although air conditioning is a higher consumer, this was not considered due to the due to the large size solar PV or hybrid system required which could put many households or developers off due to costs or space requirements.

(2) Proposal 2 investigated the use of efficient electrical appliances. Replacing old appliances such as clothe dryers, washing machines and refrigerators with more efficient energy star rated versions can save around 20% of energy consumed in household and support sustainable consumption and production. Also swapping incandescent bulbs with LED bulbs can save up to 80% of the lighting energy. However, a major concern would be the sustainable disposal of old appliances which needs to be planned carefully by the government.

	Strengths	Weakness	Opportunities	Threats
Political	Increasing solar and wind PV installations will better alignment with UN SDG Goals and the Climate Change Targets	Since the system is only sized to cover lighting loads it may not make a big dent on climate change targets	If the scheme is successful it can be expanded to cover more household energy demand	Low political will from governmental leaders will mean a low uptake of the system
Economic	Solar panels for lighting use would be much less in number and cost compared for the whole house	The high initial cost of solar PV systems and wind turbines may put many developers or homeowners off	Opportunity to engage solar PV developers, create job opportunities and grow the economy. Also, households can lend their roofs to solar PV developers to reduce the upfront cost. The developers can benefit from Feed-in tariff payments	There needs to be a strong financial incentives
Social	It will make homes more sustainable and increase awareness of clean energy	There is low awareness and uptake currently of rooftop solar PV systems in the GCC	If some households participate then this can motivate others to do so	Low interest from residents could make uptake poor
Technical	There is strong solar irradiance in the GCC which will ensure strong and reliable solar PV output	Wind conditions are not as reliable for small wind turbines	Opportunity to engage research and development organizations to innovate and provide solutions for integrated solar PV and wind system	The high temperatures during the summer and dust storms could reduce efficiency of the solar panels
Legal	In alignment with climate change goals and targets	Laws and regulations will need drafting to accompany the scheme which can slow down implementation	New laws and regulations can be introduced to boost uptake of this scheme	Current laws may conflict with elements of this scheme, making it even harder to administer properly
Environmental	Reduced carbon emissions with no need for reduced lighting consumption	The scheme only covers the lighting loads meaning around 10% of CO_2 reduction	There is opportunity to increase contribution of the solar PV and wind turbine to cover more household electricity consumption	The reduction in CO_2 emissions and use of renewable energy may make people compromise and use more electricity

Source(s): Author's own assessment

Table 5.
PESTLE and SWOT analysis for scenario 1 proposing a solar PV or hybrid renewable energy system for household lighting

	Strengths	Weakness	Opportunities	Threats
Political	This scheme will be in alignment with many GCC government schemes to reduce electricity consumption	Needs to be well planned and organized, which will consume government resources	If successful, can save government money as will reduce electricity consumption without requiring new power plants. Also, discounts can be offered by the government for more efficient appliances	The large number of households and old appliances may make it difficult to monitor progress
Economic	Can save households money in the long term from reduced electricity bills	More efficient appliances will have a high upfront cost to start with	Increased economic activity in the sale of efficient electrical appliances which can open opportunities for more jobs and innovations	The cost of efficient appliances might people off from switching
Social	Households will benefit with new appliances	Some households might be put off with the extra spending required	Word of mouth from those who changed to more efficient appliances can encourage others to follow suite	Lack of understanding and the importance of energy efficiency may reduce the success of this scheme
Technical	Can save around 20% in energy consumption just by changing to more efficient appliances	It may be difficult to distinguish which appliances are more efficient	Opportunity to increase Energy Star certified appliances to the market or create a new certification system	Many households may not understand power ratings and efficiency
Legal	Many policies and targets are already in place relating to energy efficiency in the GCC (Table 1)	Implementation of this scheme successfully will require a lot of effort legally and politically	There is opportunity to provide legal incentives such as banning of inefficient appliances	Some laws may require changing to implement this scheme successfully which could delay the scheme
Environmental	With increased appliance efficiencies less electricity is consumed and therefore less CO_2 footprint	Old appliances will require careful measures to ensure they are disposed of or recycled sustainably to reduce impact on the environment	There is opportunity to introduce a new recycling scheme to encourage sustainable disposal of old appliances	The amount of old appliances that are disposed could be significant which could cause harm to environment through pollution

Source(s): Author's own assessment

Table 6. PESTLE and SWOT analysis for scenario 2 using efficient appliance for energy conservation

	Strengths	Weakness	Opportunities	Threats
Political	Reducing electricity consumption through behavior is cheap and effective	Political support is required to ensure success of this scheme. This could take a long time	Opportunity for politicians to lead by example and influence households to reduce energy usage through social media channels	Reducing electricity consumption could be seen by politicians as a low priority item and therefore not given care or attention
Economic	This would a very low-cost scheme to implement for households	There will be other costs for governments associated with marketing the scheme	There is opportunity to significantly reduce energy consumption and CO_2 without adding costly new power plants	The marketing costs could be significant with low implementation from households
Social	Word of mouth could help spread the word regarding reducing energy consumption	The cheap cost of grid electricity may be a demotivator for consumers to change behavior	There is opportunity to put messages related to financial savings for households if they reduce their energy use	Low attention to the scheme is a threat as many can afford to live with high electricity consumption and may not care much for sustainability
Technical	There is low technical knowledge required as it will be simply reducing energy use	Can be difficult to measure the impact of each messages as consumption is linked to several factors	There is opportunity for messages to focus on the highest energy consumers such as air conditioning	The messages and marketing campaign may be poorly communicated or technically confusing for households to understand
Legal	Sustainability and reduction in electricity is planned by several GCC countries and could be drafted in law	Low awareness of legal implications from citizens with regards to electricity consumption	Legal penalties and incentives can be given to households to change their habits and reduce their electricity consumption	Laws relating to this scheme could be vague which would render the ineffective
Environmental	Reducing electricity consumption is cheap and fast way to reduce CO_2 emissions	The reduction in CO_2 emissions is not guaranteed as it will depend on the response of households	Focusing on the highest consumers of electricity and CO_2 emissions such as air conditioning could yield the best results	Just focusing on households may mean reduced environmental impact from them but not from other sectors such as industry, transport and commercial buildings

Source(s): Author's own assessment

Table 7.
PESTLE and SWOT analysis for scenario 3 enhancing consumer behavior towards sustainable energy consumption

(3) Proposal 3 investigated consumer behavior. complexity of household energy consumption and conservation behavior can be tackled by proposing scenarios for GCC consumers to change their behavior towards effective use of energy, energy

saving messages (loss framed) and social influence. An effective marketing campaign would be required to make this a success, with strong support from politicians and influencers.

To ensure the best results with the most CO_2 emissions and electricity consumption reduction then all three scenarios are proposed to be applied. These can be applied through a pilot scheme at first to monitor and evaluate their success. The feedback from the pilot schemes can be used to roll out the schemes nationwide. Further research and development of these scenarios is encouraged to identify the best method of implementation.

References

Abdel Gelil, I. (2009). Arab environment climate change. Available from: https://www.preventionweb.net/files/12741_FullEnglishReport1.pdf#page=36

Al-Badi, A., & AlMubarak, I. (2019). Growing energy demand in the GCC countries. *Arab Journal of Basic and Applied Sciences*, *26*(1), 488–496. doi: 10.1080/25765299.2019.1687396.

Alhaj, M. (2017). Implementation of rooftop solar PV in Qatar through the roof rental business model. *Modern Environmental Science and Engineering*, *3*(2), 115–122. doi:10.15341/mese(2333-2581)/02.03.2017/006.

Alharbi, F. R., & Csala, D. (2020). GCC countries' renewable energy penetration and the progress of their energy sector projects. *IEEE Access*, *8*, 211986–212002. doi: 10.1109/ACCESS.2020.3039936.

AlKhars, M. A. (2019). Survey and analysis of the quantitative methods used in electricity research on GCC countries: 1983–2018. *Heliyon*, *5*(10), e02634. doi: 10.1016/J.HELIYON.2019.E02634.

Almasri, R. A., & Alshitawi, M. S. (2022). Electricity consumption indicators and energy efficiency in residential buildings in GCC countries: Extensive review. *Energy and Buildings*, *255*, 111664. doi: 10.1016/J.ENBUILD.2021.111664.

Almasri, R. A., Akram, R., Almarshoud, A. F., Omar, H. M., Alshitawi, M. S., & Khodary Esmaeil, K. (2023). Evaluation of the total exergy and energy consumptions in residential sector in Qassim Region, Saudi Arabia. *Alexandria Engineering Journal*, *62*, 455–473. doi: 10.1016/J.AEJ.2022.07.041.

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S., & Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: Moving beyond efficiency. *Sustainability Science*, *13*(6), 1533–1547. doi: 10.1007/S11625-018-0582-1.

Black, J. S., Stern, P. C., & Elworth, J. T. (1985). Personal and contextual influences on household energy adaptations. *Journal of Applied Psychology*, *70*(1), 3–21. doi: 10.1037/0021-9010.70.1.3.

de Young, R. (2016). Changing behavior and making it stick: The conceptualization and management of conservation behavior. *Environment and Behavior*, *25*(3), 485–505. doi: 10.1177/0013916593253003.

EEA (2013). Achieving energy efficiency through behavior change: What does it take?, (EEA Technical report No 5/2013). doi: 10.2800/49941.

Elrahmani, A., Hannun, J., Eljack, F., & Kazi, M. K. (2021). Status of renewable energy in the GCC region and future opportunities. *Current Opinion in Chemical Engineering*, *31*, 100664. doi:10.1016/J.COCHE.2020.100664.

European Commission (2021). GHG emissions of all world - publications Office of the EU. Available from: https://op.europa.eu/en/publication-detail/-/publication/45c88a84-2d65-11ec-bd8e-01aa75ed71a1/language-en

Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, *41*, 1385–1394. doi: 10.1016/J.RSER.2014.09.026.

Ganandran, G. S. B., Mahlia, T. M. I., Ong, H. C., Rismanchi, B., & Chong, W. T. (2014). Cost-benefit analysis and emission reduction of energy efficient lighting at the Universiti Tenaga Nasional. *The Scientific World Journal*, *2014*, 1–11. doi: 10.1155/2014/745894.

Gardner, G., & Stern, P. (1996). Environmental problems and human behavior. - PsycNET. Available from: https://psycnet.apa.org/record/1996-97587-000

GCC-Stat (2020). Atlas of GCC statistics. Available from: https://www.gccstat.org/ar/center/docs/publications/2112-gcc-atlas-2021/file

IRENA (2019). Renewable energy market analysis: Gcc 2019. Available from: publications/2019/Jan/Renewable-Energy-Market-Analysis-GCC-2019

Kahramaa (2017). Qatar general electricity and water corporation. Raw data collected from Survey in Doha, Qatar, in 2017, from Kahramaa database.

Kim, H. J. (2018). The effects of gain versus loss framing and issue involvement on publics' responses to nuclear energy messages in South Korea. *Asian Journal of Communication*, *28*(5), 541–558. doi: 10.1080/01292986.2018.1491057.

Leoniak, K., & Cwalina, W. (2017). The effect of message goal framing on the effectiveness of pro-environmental signs promoting energy conservation behavior. Available from: https://www.researchgate.net/publication/325286144_The_effect_of_message_goal_framing_on_the_effectiveness_of_pro-environmental_signs_promoting_energy_conservation_behavior?channel=doi&linkId=5b03f41d0f7e9be94bdb2415&showFulltext=true

Lopes, M. A. R., Antunes, C. H., & Martins, N. (2012). Energy behaviours as promoters of energy efficiency: A 21st century review. *Renewable and Sustainable Energy Reviews*, *16*(6), 4095–4104. doi: 10.1016/J.RSER.2012.03.034.

Madurai Elavarasan, R., Afridhis, S., Vijayaraghavan, R. R., Subramaniam, U., & Nurunnabi, M. (2020). SWOT analysis: A framework for comprehensive evaluation of drivers and barriers for renewable energy development in significant countries. *Energy Reports*, *6*, 1838–1864. doi: 10.1016/J.EGYR.2020.07.007.

Mathur, A., Muthukumaraswamy, S. A., & Varela, L. (2018). Investigation and analyses of energy-efficient technologies for HVAC and lighting systems via energy auditing processes. In *2018 International Conference on Smart Grid and Clean Energy Technologies, ICSGCE*, 2018 (pp. 186–190). doi: 10.1109/ICSGCE.2018.8556644.

Midden, C. J. H., & Ritsema, B. S. M. (1983). The meaning of normative processes for energy conservation. *Journal of Economic Psychology*, *4*(1-2), 37–55. doi: 10.1016/0167-4870(83)90044-2.

Nolan, J. M., Schultz, P. W., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2008). Normative social influence is underdetected. *Personality and Social Psychology Bulletin*, *34*(7), 913–923. doi: 10.1177/0146167208316691.

Osman, M., Gachino, G., & Hoque, A. (2016). Electricity consumption and economic growth in the GCC countries: Panel data analysis. *Energy Policy*, *98*, 318–327. doi: 10.1016/J.ENPOL.2016.07.050.

Our World in Data (2022). Per capita electricity generation, 2021. Available from: https://ourworldindata.org/grapher/per-capita-electricity-generation

Our World in Data (2023). Per capita CO2 emissions, 2021. Available from: https://ourworldindata.org/grapher/co-emissions-per-capita?tab=table

Painter, J., Semenik, R., & Belk, R. (1983). Is there a generalized energy conservation ethic? A comparison of the determinants of gasoline and home heating energy conservation. *Journal of Economic Psychology*, *3*(3-4), 317–331. doi: 10.1016/0167-4870(83)90009-0.

Qader, M. R. (2009). Electricity consumption and GHG emissions in GCC countries. *Energies*, *2*(4), 1201–1213. doi: 10.3390/EN20401201.

Seligman, C., Kriss, M., Darley, J. M., Fazio, R. H., Becker, L. J., & Pryor, J. B. (1979). Predicting summer energy consumption from homeowners' Attitudes1. *Journal of Applied Social Psychology*, *9*(1), 70–90. doi: 10.1111/J.1559-1816.1979.TB00795.X.

Shawon, M. J., Chaar, L. el, & Lamont, L. A. (2011). The GCC: Wind technology deployment potential. In *2011 IEEE GCC Conference and Exhibition, GCC*, 2011 (pp. 174–177). doi: 10.1109/IEEEGCC.2011.5752483.

SolarGIS (2022). Solar resource maps and GIS data for 200+ countries | Solargis. Available from: https://solargis.com/maps-and-gis-data/download/qatar

Stern, P. C. (1992). What psychology knows about energy conservation. *American Psychologist*, *47*(10), 1224–1232. doi: 10.1037/0003-066X.47.10.1224.

The Global Goals (n.d.). Goal 7: Affordable and clean energy - the global goals. Available from: https://www.globalgoals.org/goals/7-affordable-and-clean-energy/ (accessed 14 August 2022).

The World Bank (2014). Electric power consumption (kWh per capita) | Data. Available from: https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

The World Bank (2022). Middle East and North Africa region Gulf economic update with a special focus achieving climate change pledges. Available from: www.worldbank.org

Verhallen, T. M. M., & van Raaij, W. F. (1981). Household behavior and energy use. In Claxton, J. D. (Ed.), *Consumers and energy conservation* (pp. 32–45).

Visualcapitalist (2016). Infographic: What uses the most energy in your home?. Available from: https://www.visualcapitalist.com/what-uses-the-most-energy-home/

Zalengera, C., Blanchard, R. E., Eames, P. C., Juma, A. M., Chitawo, M. L., & Gondwe, K. T. (2014). Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy. *Renewable and Sustainable Energy Reviews*, *38*, 335–347. doi: 10.1016/J.RSER.2014.05.050.

Zissis, G., Bertoldi, P., & Serrenho, T. (2018). *Update on the Status of LED-Lighting world market since 2018* (Vol. 2021). Luxembourg: EUR 30500 EN, Publications Office of the European Union. ISBN 978-92-76-27244-1, JRC122760. doi: 10.2760/759859.

Corresponding author
Tarig Zeinelabdeen Yousif Ahmed can be contacted at: tariq90@hotmail.co.uk