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Every year, millions of Muslim worshippers visit Mecca in Saudi Arabia to perform Hajj which is the fifth and last pillar of Islam. In 2018, Mecca hosted more than 2,300,000 people from around 183 different countries and cultures. Based on the objective of *Vision 2030* of the Saudi Arabian government, the number of pilgrims was planned to grow to 2.5 million in 2020, and the rate of increase was projected to be 13% per year. This goal, however, has not been achieved due to Covid-19. The pandemic forced the government to severely reduce the number of pilgrims in 2020 to 10,000. Ultimately, this situation will not last forever and visitor numbers should continue to rise.

Tourism, especially religious tourism such as the Hajj, is expected to boost the economy and create new jobs for Saudi youth in the services sector. Yet, despite the many benefits of pilgrimage, the Hajj itself has adverse environmental impacts. The activities of the Hajj generate considerable solid and liquid waste, use large quantities of scarce fresh water and produce high levels of greenhouse gasses (GHGs) emissions. This paper provides an overview of the environmental impacts created by Hajj 2018 activities and estimates carbon dioxide equivalent (CO_2-e) emissions from municipal solid wastes, travel (air and land) and electricity generation (accommodation and fresh water desalination), using a range of estimation techniques based on data collected across the different Hajj activities. These findings indicate environmental impacts of the Hajj are significant, highlighting the need for action to improve environmental sustainability.

Key Words: Hajj, environmental sustainability, carbon dioxide equivalent emissions

Introduction

By the early 21st century, international tourism is a major economic driver, and its influence is evident globally. Tourism has had a profound impact on destinations around the world, and in 2018 the 1.4 billion international arrivals illustrate the scale and economic importance of global tourism activity (UNWTO, 2019a). Undoubtedly, tourism can generate employment and can greatly stimulate the macroeconomy of many destinations in developing and developed countries (Sharpley, 2009). For instance, in 2019, directly and indirectly tourism and travel contributed 10.4% of global GDP, and 334 million jobs, equivalent to 10.6% of total global employment (WTTC, 2021: 4-5). However, although tourism generates significant economic benefits to host destinations it can also have negative environmental impacts on destinations (Geneletti & Dawa, 2009; Gössling & Peeters, 2015).

Environmental sustainability is one of three pillars, along with economic and social, and is defined as

> [a] *condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity* (Morelli, 2011:5).

The relationship between tourism and environmental sustainability is complicated because tourism involves numerous activities such as transportation, accommodation, events and attractions, resulting in energy consumption (Becken & Hay, 2007) and the production of waste (Murphy *et al.*, 2018). Most importantly, these activities produce significant GHG emissions (DeLacy *et al.*, 2014). Religious tourism is one form of tourism that the literature reveals to have significant impacts on the environmental sustainability of destinations (Singh & Bisht, 2014; Abdulredha *et al.*, 2017).

Every year, millions of Muslim worshippers visit Mecca in Saudi Arabia to perform Hajj which is the fifth and last pillar of Islam. Muslims perform the rituals of the Hajj following the guidance and tradition of Mohammed, the Prophet of Islam, peace be upon him. As the fifth pillar of Islam, the Hajj is a mandatory religious duty for all adult Muslims who are physically and financially capable of undertaking the journey. The Hajj occurs annually on the 12th month of the Islamic lunar calendar. To perform the Hajj, people from around 183 different countries and cultures visit Mecca because the Hajj needs to be performed in the specific places of Mecca known as Al Mashaaer Al Mugaddassah and Al Kaaba Al Musharrafah in Al Masjed Al Haram (Parker & Gaine, 2019). The city of Mecca is the host city and according to the General Authority of Statistics in Saudi Arabia, in 2018, there were more than 2,300,000 pilgrims who performed the Hajj (Gastat, 2018:6). Based on the objectives of *Vision 2030* of the Saudi Arabian government, the number of pilgrims was planned to grow to 2.5 million in 2020, and the rate of increase was projected to be 13% per year (Arabnews, 2016). This goal, however, has not been achieved due to Covid-19. The pandemic forced the government to severely reduce the number of pilgrims in 2020 to 10,000. Muneeza and Mustapha (2021) investigated the pandemic's impact on the Hajj and found it has serious religious, economic, social and psychological effects on Hajj stakeholders. Ultimately, this situation will not last forever and visitor numbers should recover and then continue to rise.

Like other forms of religious tourism, the Hajj contributes to the Saudi Arabian economy which is particularly important in the context of dwindling oil prices and the need for Saudi to diversify its economic base. In 2017, revenue from the Hajj was between 5.3 and 6.7 billion dollars, and it is expected to reach more than $10 billion by 2030 (Gridini, 2018). From a social point of view, the Hajj gathers millions of people from different races, cultures, and languages, increasing the sense of unity and equality with others (Clingingsmith *et al.*, 2009). However, the Hajj activities cause significant impacts on the environmental sustainability of the destination (Pasha & Alharbi, 2015; Simpson *et al.*, 2014), including contributing to climate change (Hassan *et al.*, 2016).

To reduce the climate change impact of tourism, different mitigation and adaptation approaches have been proposed by tourism stakeholders and institutions. For example, the UNWTO (2015:49-67) has outlined the adaptation and mitigation strategies that have been applied by many Asian and Pacific destinations such as Nepal, Maldives, China and Sri Lanka. While interest in climate change and tourism has been growing and attracting more attentions from academics, governments, and tourism businesses (Scott & Becken, 2010; Mkiramweni *et al.*, 2016; Hoogendoorn & Fitchett, 2018), it seems that there is little effort to address climate change in Saudi Arabia (UNEP, 2019:8-9). This is specifically evident in the context of the Hajj (Simpson *et al.*, 2014; Ali *et al.*, 2020).

Interestingly, despite the notable contribution of the Hajj to climate change, there are no recent studies that have investigated and estimated GHG emissions from Hajj activities. Accordingly, this study aims to put Hajj's sustainability challenges into context by investigating the Hajj activities that contribute to impacting the environmental sustainability of the destination and providing an approximate estimation of GHG emissions from these activities.

Contextual Background

The economy of Saudi Arabia is one of the twenty largest in the world, with the economy mostly dependent on oil and related industries. However, the country's regulation system has changed since 2015 when oil prices underwent a steep decline, and with the Covid-19 pandemic, prices fell around 30% between Jan 2020 and Apr 2020, and are forecast to continue falling (Byrne, 2020). After a period of sustained oil price increases from 2000 to 2013, the rapid decline in oil income has highlighted the Kingdom's need to generate alternative fixed sources of local development. In 2016, Crown Prince of Saudi Arabia Prince Mohammed bin Salman published plans to transform his country's economy through *Vision 2030*. This outlines actions to be taken by national entities including the government sector and the private sector, to achieve the 2030 Sustainable Development Plan. The goal of the vision is to boost foreign direct investment (FDI), reduce the kingdom's reliance on oil, and increase the private sector's contribution from 40% to 65% of GDP (Vision 2030, 2016:13-53). Thus, Prince Mohammed bin Salman has set 24 goals towards this vision, one of which is to improve the tourism industry, including religious tourism such as the Hajj (Al Surf & Mostafa, 2017).

The Hajj provides an important opportunity for the Kingdom of Saudi Arabia to reduce economic dependence on oil revenues. According to the Mecca Chamber of Commerce, 25-30% of private sector income in the area surrounding Mecca and Madinah depends on the Hajj (ACCA, 2018). Currently, religious tourism contributes approximately 3% to Saudi Arabia's GDP. However, this percentage is expected to increase (Daye, 2019). Therefore, one of the pillars of the government's vision is to increase the number of pilgrims every year, to diversify and strengthen its economic status. This has led to efforts to improve Hajj services, resulting in expanding construction, improvement of transport and implementing a number of measures to control and prevent disease (Taibi & Qadi, 2016). Yet, despite the promising future benefits of pilgrimage such as improving socialisation, interaction, and international trade (Adama, 2009), the Hajj itself contributes adversely to the environment of the country. For instance, Butenhoff *et al.* (2015) noted that air pollution in Saudi Arabia becomes higher in Mecca compared to other cities due to the Hajj event. In addition, Khwaja *et al.* (2014) found that the level of air pollution during the Hajj exceeded the World Health Organization (WHO) standards. Despite the impacts on the environment, the issue has been given little attention in Saudi Arabia.

Overview of the Environmental Sustainability Problems Caused by the Hajj

Municipal solid waste generation (MSW)

The generation of municipal solid waste (MSW) is one of the more significant environmental impacts of tourism (Mateu-Sbert *et al.*, 2013). In fact, the tourism sector generates high levels of municipal solid waste when compared to other sector such as manufacturing or agriculture (Arbulú *et al.*, 2015). For instance, in 2011, UNEP estimated the generation of solid waste worldwide and found that international tourism was responsible for generating about 14% of the total MSW during that year (Muñoz & Navia, 2015).

In the context of the Hajj, managing MSW is considered one of the most complex challenges that organisers encounter (Nizami *et al.*, 2017). Every day during the Hajj period, the landfill of Mecca receives around 4.6 thousand tonnes of MSW (Nizam *et al.*, 2016). Food (50.6%) is the highest component of MSW, followed by paper and cardboard (18.6%) and plastic waste (17.4%) (Khan & Kaneesamkandi, 2013; Nizami *et al.*, 2015). However, the quantity of waste is expected to grow annually at 3%-5% (Galaly & Guido, 2017), based on the projected growth in the number of pilgrims. To illustrate, a study by Arbulu *et al.* (2017) showed that increasing 1% of arriving tourists would increase 1.25% of waste generation.

There is no waste recycling project in Mecca (Nizam *et al.*, 2015; Shahzad *et al.*, 2017), and all MSW is buried in the Mecca landfill (Alsebaei, 2014). The landfill receives on average throughout the year about 2,750 tonnes of waste per day, while during the Hajj season, these quantities increase to about 4,706 tonnes per day (Nizam *et al.*, 2015). Within 20 years, Mecca is expected to produce 44 million tonnes of MSW per day due to increased numbers of pilgrims (Osra & Kajjumba, 2019). Thus, what the government of Saudi Arabia is encountering is a very sensitive issue - the gases emitted from biological activity of MSW in landfills, mainly methane, are a vital contributor to climate change (Zhang *et al.*, 2019), and with the rapid increase of pilgrim numbers, the issue will get much worse.

Liquid waste from sewage and slaughterhouses

One of the important environmental impacts of the Hajj is the generation of liquid waste from sewage (Makkahnews, 2014a). In Mecca, there are two tertiary sewage treatment plants that are located in Uranah and Hedda valleys (Makkahnews, 2014b). Both plants can treat around 300,000 m^3 per day of sewage, while during the Hajj, sewage production is estimated to be much more than that per day, though accurate figures are not available (Al-Salman, 2018). The rest is disposed in the valley and the Red Sea with inadequate treatment (Sulyman, 2012). This discharging of untreated sewage into the valley and the sea contributes to significant environmental degradation (Whitmore & De Lacy, 2005). Alharthy (2001) and Bahabri (2011) evaluated the contamination of different components in Uranah valley such as underground water and soil. Both studies found that the level of contamination in underground water is extremely high due to untreated sewerage discharge. They also revealed that agricultural crops are polluted and are not safe for human use because they are irrigated with untreated sewage.

In addition, liquid waste from animal slaughter is a further issue (Hassan *et al.*, 2016). With more than two million Muslims performing Hajj, it is estimated that more than

1.5 million sheep, goats and camels are slaughtered during the Hajj period (Almasri *et al.*, 2019). Similar to sewage, there is an absence of data and all liquid waste from slaughtered animals is disposed without treatment (Shahzad *et al.*, 2017). One study conducted to investigate the approaches that slaughterhouses applied in disposing the waste from animals indicated that all waste, including liquid waste such as blood and cleaning water, are discharged in the Valley named 'Al-Harman', which is in the north-eastern part of Mecca, without any treatment (Hussein, 2018). This discharge has been proven to harm the quality of soil, air and water (Al-Fattly, 2013; Olayinka *et al.*, 2013; Demattê *et al.*, 2016).

Aviation

Air travel produces a significant amount of the world's GHG. This is illustrated by numerous studies that have estimated the carbon footprint in tourism destinations and revealed that air transportation is considered the major driver of GHG emissions from tourism in these destinations (Becken, 2002; Dwyer *et al.*, 2010).

Aviation is the main form of transport that foreign pilgrims use for traveling to the Hajj (Gastat, 2018:32). During the Hajj in 2018, 6,969 flights landed in Saudi Arabia from different countries, with 3,939 flights arriving to King Abdul Aziz International Airport in Jeddah and 3,030 flights landing at Prince Mohammed bin Abdul Aziz International Airport in Madinah (SPA, 2018a). While such flights increase the economy of the country and generate employment, their impact on the environment can be significant. This is especially important in that the government of Saudi Arabia plans to rapidly increase the number of aviation trips as it aims to considerably increase the number of pilgrims (CAPA, 2018).

Land transportation

Land transportation is also an important transport mode for the Hajj. For example, in the Hajj 2018, there were 32,298 vehicles (mostly cars and buses) carrying domestic pilgrims (Gastat, 2018:26). In addition, the main transport mode that transfers international pilgrims from airports to Mecca is bus. For instance, in Hajj 2018 there were more than 18,000 buses to transfer more than 1.5 million pilgrims from the airport to Mecca (SPA, 2018b). These transport activities significantly contribute to emissions (Seroji, 2011; Al-Omari, 2014).

Electricity generation

In Saudi Arabia, the share of renewable energy sources in primary energy supply and electricity is close to 0% (CT, 2019:27). Almost all electricity is generated in Saudi Arabia using fossil energy sources such as crude oil, diesel oil, and natural gas (Demirbas *et al.*, 2017). Since 1991, the significant increase in CO_2-e emissions due to electricity generation in Saudi Arabia is distinctly evident (Khondaker *et al.*, 2015). It has been noted that the consumption of electricity during the Hajj is equivalent to that which is consumed by two cities in Saudi Arabia at locations such as Taif, and the Northern Borders Region (Qassimnews, 2014). It has also been noted that Saudi Arabia is one of the G-20 countries with the highest per capita GHG emissions and no declining emissions trend over the past five years (CT, 2018:19).

Seawater desalination in the Hajj

Water, especially freshwater, is an essential resource and one of the most important natural resources for the tourism industry (UNWTO, 2003:45; Gössling *et al.*, 2012). The demand for water by tourism in some cases can cause problems for the local community. For instance, during a period of drought (1994-1996), the city of Tangier in Morocco suffered from a severe shortage of fresh water. That is because water supplies for tourist facilities had priority over the local water needs (De Stefano, 2004). Tourism operations in many countries may put strain on the supply of freshwater to local communities (Gössling *et al.*, 2012). This is particularly the case in developing countries as the water consumption of tourists per head is many times greater than domestic consumption (Page *et al.*, 2014).

In Mecca, extreme heat makes pilgrims use vast amounts of water for drinking, showering, and making ablutions known as 'wudu'. There are two main sources of water provided to pilgrims during the Hajj; Zamzam water and desalinated water (Amirahmadi, 2017). Zamzam is underground water that is sacred for the Muslim community and it has been mentioned in the holy book (Quran) (Khalid *et al.*, 2014). Hence, Muslims drink Zamzam water for reasons other than hydration. They believe that Zamzam has numerous benefits such as helping recovery from different types of diseases (Abu-Taweel, 2017).

During the Hajj in 2018, more than 5 million bottles of water of Zamzam were consumed by pilgrims (Alsolami, 2018). Despite the huge amount of Zamzam water that is distributed, it is still not enough to meet the quantities required by pilgrims. This has led the government to be substantially reliant on desalinated seawater during the Hajj (Malek, 2019).

Desalination has been employed in many parts of the world such as North America, North Africa, and the Middle east (Jones *et al.*, 2019). It significantly reduces pressure on freshwater resources (Shatat & Riffat, 2014). However, the operation of desalination plants requires large amounts of energy, resulting in significant amount of GHG emissions and thus, contributing to global warming (Gössling *et al.*, 2012; Pérez *et al.*, 2018).

In Saudi Arabia, seawater desalination plants are the largest providers of potable water (Demirbas *et al.*, 2017). In Mecca, desalinated water is pumped from 'Shuaiba' (140 km south of Mecca) at a rate of 670,000 m^3 per day on normal days (Arabnews, 2013). During the Hajj, the volume of water exceeds this number per day to cover the pilgrims' water demands (Malek, 2019). For example, in 2018 alone, due to the increase of pilgrims there was an increase of desalinated water of 40,000,000 m^3, with a daily consumption that exceeded 900,000 m^3 (MEWA, 2018).

Consequently, the Hajj is putting considerable pressure on the available water resources and the energy used to supply desalinated water. This pressure is expected to rise as the government aims to increase the number of pilgrims in future years (Malek, 2019).

Accommodation

Among the tourism industry sub-sectors, accommodation is considered one of the major sectors that consumes energy and produces GHG (Scott *et al.*, 2010; Huang & Wang, 2015).

The Hajj accommodation consists of services ranging from the most basic to the very sophisticated, although most pilgrims share public facilities and live in tents. According to El Hanandeh (2013), the operation of this accommodation sector contributes to GHG emissions. In this study, the calculation of GHG emissions focused on the electricity produced to serve tents in the Hajj in three areas; Mina, Arafat, and Muzdalifah, where reliable accommodation data were available. No data were available on pilgrim numbers in hotels, and hence GHG emissions from hotels was not estimated.

Methodology

A key aim of this study is to estimate GHG emissions due to Hajj activities in 2018. Secondary sources such as government reports and academic studies were used to ascertain pilgrim numbers and the GHG related emissions and/or efficiencies of related activities. The data on electricity generation of accommodation (only tents) were provided by a manager of one of the Hajj institutions. Unfortunately, no data were available for motel and hotel accommodation. Emissions produced by liquid wastes were also not estimated as there is no robust data about the quantity of liquid waste generated during the Hajj.

Measuring only CO_2 and disregarding other GHGs may underestimate the global warming potential (GWP) of emissions into the atmosphere. Therefore, the term carbon dioxide equivalent (CO_2-e) has been used as a measurement for depicting global warming potential (GWP) of all GHGs in a common unit (Brander & Davis, 2012). GWP is an indicator that provides the level of GHG causing global warming compared to CO_2 (Brander & Davis, 2012). The Kyoto Protocol is an international treaty extending from the UN conference in 1992 on Climate Change which provided a list of GHGs and their possible impacts on global warming (Table 1). For example, 1kg of nitrous oxide (N2O) emissions can be expressed as 289 kg of CO_2-e.

To estimate the GHG levels, this study will use the ***Greenhouse Gas Protocol Corporate Standard*** as it is the most relevant standard and travel and has been widely used in tourism studies (Becken & Bobes, 2016). The Greenhouse Gas Protocol Corporate Standard is divided into three scopes for estimating GHG emissions from a particular business, destination, or activity (such as the Hajj). ***Scope 1*** covers the direct emissions from

Table 1. Kyoto Gases on GHG and its GWP

Greenhouse Gas (GHG)	Global Warming Potential (GWP)
Carbon dioxide (CO2)	1
Methane (CH4)	25
Nitrous oxide (N2O)	289
Hydrofluorocarbons (HFCs)	124 – 14,800
Perfluorocarbons (PFCs)	7,390 – 12,200
Sulfur hexafluoride (SF6)	22,800
Nitrogen trifluoride (NF3)	17,200
Adopted from Brander & Davis, 2012	

controlled sources (e.g. emissions produced from burning the fuel of vehicles to transport pilgrims). ***Scope 2*** covers the indirect emissions from activities that are released into the atmosphere remote from the activity but would not occur if the activity stopped (e.g. room heating from electricity for rooms the pilgrims stay in). ***Scope 3*** covers all other indirect emissions sources that are not covered in ***Scope 2***. It encompasses the emissions from activities that would at least partly still occur if the activity stopped and are more appropriately estimated in different sectors or jurisdictions (e.g. manufacture of buses or aeroplanes that transport pilgrims) (Becken & Bobes, 2016). Hence, based on the data available, this study used ***Scope 1*** and ***Scope 2*** categories to estimate emissions resulting from Hajj 2018. Although ***Scope 1*** and ***Scope 2*** do not estimate the total direct and indirect emissions from an activity such as a major event, they do allow a comparison between similar activities (Becken & Bobes, 2016), and put the Hajj's sustainability challenges into context.

For estimating CO_2-e emissions produced from unsorted Municipal Solid Waste (MSW) in the Hajj, the ***National Green Emission*** (NGA) approach was applied in this study as it provides a methodology to estimate the weighted average emission factors of municipal solid waste of unknown composition (NGA, 2017:77). The NGA approach is designed by the Department of the Environment and Energy in Australia for individuals and firms to estimate their GHG from different components including MSW. The NGA follow the International Panel on Climate Change (IPCC) guidelines and have set default emission factors for MSW of unknown composition. The emission factor of unknown composition can be estimated, as each tonne of unknown composition of MSW generates 1.4 tonne of CO_2-e.

For estimating the CO_2-e emissions from transportation (aviation and land) this research applied factors derived by the UNWTO (2019b:36) which provides the average estimation of CO_2-e emissions per passenger per kilometre. The number of pilgrims in each flight and the breakdown of each flight is confidential in Saudi Arabia. Hence, the data used in the study were derived from the El Hanandeh (2013) study which provides the number of pilgrims from each country in 2011 - in this study numbers from 2011 were extrapolated to the 2018 data.

CO_2-e emissions from electricity generation for seawater desalination and accommodation was estimated by identifying the quantity of CO_2-e produced per kWh. According to the ***Clean Development Mechanism Designated National Authority*** (CDMDNA) (2011:4), the electricity grid mix in Saudi Arabia produces 0.654 kgCO_2-e per kWh).

Nevertheless, it should be noted that there are different technologies that have been applied to desalination such as multi-effect distillation (MED), electrodialysis (ED), multi-stage flash (MSF), reverse Osmosis (RO), hybrid, and others. The most common type used in Saudi Arabia is multi-stage flash (Napoli & Rioux, 2015). The simple basic principle of MSF is to heat the water to produce as much steam as possible at low pressure and temperature in a series of many successive stages (Shatat & Riffat, 2014). The process of seawater desalination via MSF consumes typically 2.5 to 3.5 kWh of electricity per m^3 of water (IRENA, 2012). Therefore, this study estimated the average which is 2.5+3.5/2=3. Based on this assumption this study estimated the CO_2-e emissions of electricity generation due to desalinating of seawater that was consumed in the Hajj 2018.

Results

CO_2-e emissions produced from Municipal Solid Waste

Based on data from the Department of Municipal and Rural Affairs of the Kingdom of Saudi Arabia, in 2018 there were around 120,860 tonnes (120,860,000 kg) of municipal solid waste produced in the five days of the Hajj season (SPA, 2018c). To estimate the CO_2-e emissions of MSW produced, the formula will be as follow:

CO_2-e MWS = Qt x EF.

Where

CO_2-e MWS = CO_2-e emitted from MSW.

Qt = quantity of MSW by tonne.

EF = the emission factor (t CO_2-e/t waste) of mixed MSW which is 1.4 (NGA, 2017).

Accordingly

CO_2-e MWS = 120,860,000 * 1.4 = 169,204 t CO_2-e which is 169,204,000 kgCO_2-e.

CO_2-e emissions produced from aviation

To estimate the CO_2-e emission produced due to aviation related to the Hajj in 2018, this research applied UNWTO (2019b:36) estimations of CO_2-e emissions per passenger per kilometre (Table 2).

CO_2-e = 0.1042 kg/p-km.

Where

p = passenger.

km = kilometre which is the unit of distance.

CO_2-e emissions produced from land transportation - Cars

To estimate the CO_2-e produced from cars, calculations were made based on UNWTO (2019b:36) data which indicate that each car passenger emits around 0.1135 kg of CO_2-e per km in a tourism context. The CO_2-e emissions were estimated based on multiplying the number of pilgrims who travelled by car from their cities to Mecca with the distance and the default emission factor that was proposed by UNWTO (2019b:36). The estimation of CO_2-e emissions from vehicles used by internal pilgrims is provided in Table 3.

Buses

To estimate the CO_2-e emissions of buses that transport both domestic and international pilgrims, the estimation of UNWTO (2019b:36) about the CO_2-e emissions from

Table 2: CO_2-e Emissions from Aviation

Country	Number of pilgrims in 2011 (as per allocated quota)	Distance travelled round trip (km)	Number of estimated pilgrims in 2018 (22%)	CO_2-e = 0.1042 kg/p-km
Afghanistan	29,047.00	6,488.00	35,437	23,957,169.68
Albania	2,601.00	6,256.00	3,173	2,068,400.01
Algeria	34,780.00	7,732.00	42,432	34,186,376.14
Angola	195.00	15,240.00	238	377,945.90
Argentina	1,000.00	31,066.00	1,220	3,949,234.18
Australia	399.00	27,464.00	487	1,393,671.67
Austria	475.00	7,294.00	580	440,820.18
Bahrain	655.00	2,504.00	799	208,472.52
Bangladesh	148,607.00	10,454.00	181,301	197,492,412.15
Belgium	638.00	8,840.00	778	716,637.58
Benin	2,259.00	11,632.00	2,756	3,340,421.93
Bosnia-Herzegovina	1,564.00	6,572.00	1,908	1,306,602.98
Brazil	204.00	27,136.00	249	704,065.23
Brunei	211.00	16,650.00	257	445,877.01
Bulgaria	1,002.00	5,720.00	1,222	728,341.33
Burkina Faso	9,600.00	12,462.00	11,712	15,208,505.16
Burma (Myanmar)	1,900.00	17,460.00	2,318	4,217,211.58
Burundi	184.00	6,226.00	224	145,319.82
Cameroon	3,276.00	10,842.00	3,997	4,515,556.39
Canada	623.00	20,908.00	760	1,655,746.34
Central African Republic	570.00	7,354.00	695	532,569.33
Chad	5,011.00	5,536.00	6,113	3,526,291.39
China	37,230.00	16,308.00	45,421	77,183,614.61
Cocos (Keeling) Islands	1.00	6,904.00	1	719.40
Comoros	658.00	7,702.00	803	644,446.37
Democratic Republic of the Congo	6,009.00	8,764.00	7,331	6,694,733.71
Republic of the Congo	61.00	8,762.00	74	67,562.03
Cote d'Ivoire	6,487.00	14,124.00	7,914	11,647,198.41
Croatia	58.00	7,058.00	71	52,216.50
Cyprus	140.00	15,540.00	171	276,894.83
Denmark	109.00	8,884.00	133	123,119.80
Djibouti	448.00	2,366.00	547	134,855.85
Eritrea	2,190.00	1,378.00	2,672	383,666.07
Ethiopia	34,700.00	2,778.00	42,334	12,254,321.38
Fiji	71.00	33,802.00	87	306,428.65
France	4,549.00	8,884.00	5,550	5,137,706.04

Table 2 (cont.): CO_2-e Emissions from Aviation				
Country	**Number of pilgrims in 2011 (as per allocated quota)**	**Distance travelled round trip (km)**	**Number of estimated pilgrims in 2018 (22%)**	**CO_2-e = 0.1042 kg/p-km**
Gambia, The	1,434.00	13,030.00	1,749	2,374,662.77
Georgia	463.00	7,508.00	565	442,018.48
Germany	3,050.00	8,294.00	3,721	3,215,817.69
Ghana	3,365.00	11,002.00	4,105	4,706,006.48
Greece	139.00	4,668.00	170	82,688.95
Guinea	8,048.00	11,964.00	9,819	12,240,844.57
Guinea-Bissau	637.00	14,556.00	777	1,178,503.25
Guyana	77.00	28,604.00	94	280,170.46
India	129,632.00	7,760.00	158,151	127,879,633.39
Indonesia	212,937.00	15,916.00	259,783	430,836,388.96
Iran	66,658.00	3,866.00	81,323	32,759,929.62
Italy	581.00	6,757.00	709	499,192.29
Japan	127.00	19,330.00	155	312,198.83
Kenya	3,383.00	5,096.00	4,127	2,191,450.21
Lebanon	2,284.00	2,832.00	2,786	822,133.00
Liberia	696.00	12,554.00	849	1,110,599.65
Libya	5,593.00	5,952.00	6,823	4,231,613.68
Macedonia	346.00	5,990.00	422	263,394.68
Madagascar	1,263.00	9,640.00	1,541	1,547,916.01
Malawi	2,432.00	7,996.00	2,967	2,472,054.55
Malaysia	22,600.00	14,100.00	27,572	40,509,333.84
Maldives	349.00	8,330.00	426	369,762.04
Mali	11,062.00	13,030.00	13,496	18,323,870.10
Mauritania	3,087.00	13,128.00	3,766	5,151,653.00
Mauritius	204.00	11,244.00	249	291,734.58
Mayotte	188.00	82,400.00	229	1,966,212.32
Mongolia	112.00	17,450.00	137	249,105.73
Morocco	32,300.00	9,510.00	39,406	39,049,060.45
Mozambique	3,881.00	11,762.00	4,735	5,803,217.89
Nepal	1,052.00	9,432.00	1,283	1,260,950.88
Netherlands	722.00	9,156.00	881	840,522.63
Niger	9,333.00	14,348.00	11,386	17,022,771.38
Nigeria	64,386.00	9,290.00	78,551	76,038,781.92
Pakistan	157,547.00	5,748.00	192,207	115,120,768.11
Philippines	4,393.00	17,174.00	5,359	9,590,095.56
Romania	179.00	5,648.00	218	128,297.71
Russia	20,079.00	7,628.00	24,496	19,470,341.85
Rwanda	388.00	16,290.00	473	802,878.71
Senegal	10,459.00	13,390.00	12,760	17,803,236.88
Serbia and Montenegro	2,058.00	6,080.00	2,511	1,590,808.90
Sierra Leone	3,611.00	11,736.00	4,405	5,386,835.74
Singapore	664.00	14,670.00	810	1,238,177.34
Slovenia	48.00	7,306.00	59	44,915.83
Somalia	8,592.00	4,528.00	10,482	4,945,592.08
South Africa	887.00	10,876.00	1,082	1,226,208.09
Sri Lanka	1,405.00	9,282.00	1,714	1,657,754.06
Sudan	28,131.00	1,916.00	34,320	6,851,891.90
Suriname	86.00	26,786.00	105	293,065.63

Table 2 (cont.): CO_2-e Emissions from Aviation

Country	Number of pilgrims in 2011 (as per allocated quota)	Distance travelled round trip (km)	Number of estimated pilgrims in 2018 (22%)	CO_2-e = 0.1042 kg/p-km
Swaziland	117.00	11,056.00	143	164,741.03
Sweden	270.00	10,740.00	329	368,186.53
Switzerland	322.00	8,110.00	393	332,109.37
Tanzania	12,868.00	6,788.00	15,699	11,104,053.41
Togo	1,136.00	11,066.00	1,386	1,598,165.00
Trinidad and Tobago	63.00	23,682.00	77	190,010.16
Tunisia	9,873.00	6,534.00	12,045	8,200,751.53
Turkey	69,521.00	4,744.00	84,816	41,926,652.24
Uganda	4,363.00	9,148.00	5,323	5,073,998.58
United Kingdom	1,632.00	9,524.00	1,991	1,975,869.99
United States	7,393.00	22,372.00	9,019	21,024,753.69
Vietnam	67.00	14,646.00	82	125,141.28
Western Sahara	273.00	11,260.00	333	390,706.24
Zambia	2,815.00	8,672.00	3,434	3,103,039.32
Zimbabwe	127.00	12,816.00	155	206,991.22
Egypt	72,855.00	2,467.00	88,883	22,848,388.42
Kuwait	2,636.00	2,468.00	3,216	827,044.57
Qatar	1,168.00	2,656.00	1,425	394,376.16
Oman	2,547.00	3,992.00	3,107	1,292,407.60
United Arab Emirates	3,577.00	3,392.00	4,364	1,542,440.09
Total	**1,362,083.00**	**1,186,776.00**	**1,661,741**	**1,561,190,021.20**

buses = 0.0300 kg/p-km is applied in this study. Because the government data does not provide the number of pilgrims in each bus that travelled to Mecca, this study adopts the assumption of El Hanandeh (2013) that each bus in the Hajj holds approximately 40 passengers. For the Hajj in 2018, 3,685 buses travelled from Madinah to Mecca. Based on the assumption that each bus holds 40 passengers, around 147,400 travelled from Madinah to Mecca by bus.

The CO_2-e emissions were estimated based on multiplying the number of pilgrims who travelled by bus from their cities to Mecca by the distance and the default emission factor that was proposed by the UNWTO (2019b:36). The estimation of CO_2-e emissions from buses that transported domestic pilgrims is provided in Table 4 and international pilgrims in Tables 5, 6 and 7.

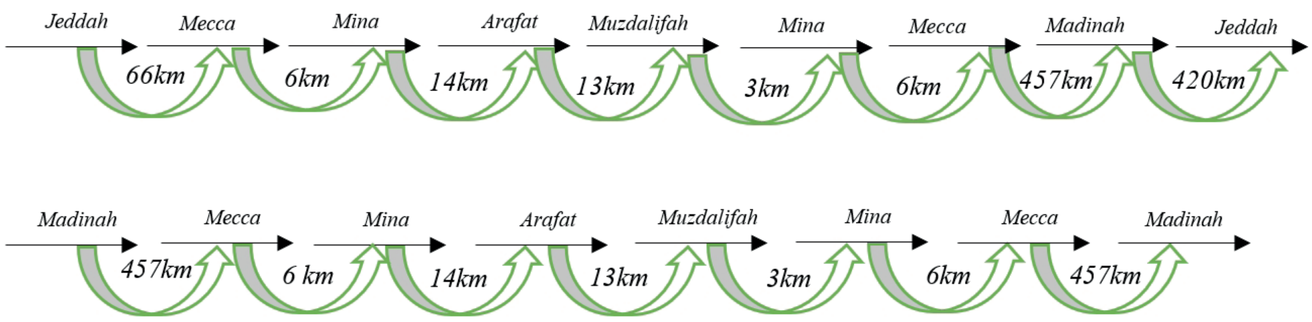
According to the Deputy Minister of the Hajj and Umrah, 17,000 buses transported foreign pilgrims inside the Hajj areas (Arabnews, 2018). There are two places that most international pilgrims visit - Jeddah and Madinah - as these have the two main airports. In addition, Madinah is considered the second most important place for Muslims

Table 3: CO_2-e Emissions of Vehicles Used by Internal Pilgrims (round trip).

Destination	*Sharae'a-Mecca (32 km)*	**South-Mecca (1307.4 km)*	*Madinah-Mecca (914 km)*	*Taif-Mecca (180.2 km)*	*Jeddah-Mecca (132 km)*	*Jeddah-Mecca (old road) (132 km)*
Number of pilgrims (total)	70,600	21,304	42,775	10,014	91,678	3,591
CO_2-e emissions (0.1135 kg/p-km)	256,419.20	3,161,298.43	4,437,435.73	204,813.34	1,373,519.80	53,800.36
Total	**9,487,286.86 kgCO_2-e**					

Adapted from (Gastat, 2018). Abbrev (kg =kilogram). *There are three main cities in the South (Jazan 707.3 km – Aseer 404 km – Najran 850 km). Thus, the average distance of the three cities was considered in this study which is (707.3+ 404+ 850)/3= 653.7 km (one round).

Figure 1: International Pilgrim Journey (before, during, and after) Performing the Hajj Rituals



Abbreviation - km= kilometre

Table 4: Bus Transportation for Domestic Pilgrims (round trip)

Destination	Sharae'a-Mecca (32 Km)	South-Mecca (1,425.2 km)	Madinah-Mecca (914 km)	Taif-Mecca (130 km)	Jeddah-Mecca (132 km)
Bus	5,436	2,582	3,685	2,356	5,729
Passenger (Number of buses*40)	217,440	103,280	147,400	94,240	229,160
CO_2-e Emissions (0.0300 kg/p-km)	208,742.40	4,415,839.68	4,041,708.00	367,536.00	907,473.60
Total	**9,941,299.68 kgCO_2-e**				
Adapted from (Gastat, 2018). Abbrev (p= passenger, km= kilometre, kg =kilogram)					

as it the location of the mosque of prophet Mohammed, peace be upon him. Thus, many pilgrims visit the mosque either before or after performing the Hajj rituals. This study estimated the CO_2-e emissions from the movement of buses from the airports in Jeddah and Madinah Figure 1.

As indicated, 57% of flights (3,939) landed at King Abdul Aziz International Airport in Jeddah, and 43% (3,030) arrived at Prince Mohammed bin Abdul Aziz International Airport in Madinah. Therefore, this study assumes that the number of buses was equally divided based on the number of flights that landed in Saudi Arabia. Based on the assumption, the number of buses (17,000) that transport international pilgrims from Jeddah and Madinah is 9,690 (57%) and 7,310 (43%) respectively.

International pilgrims travel to Mecca by bus

Despite aviation being the main transport mode that international pilgrims use to arrive to Saudi Arabia, some pilgrims arrive by bus (Table 7) (El Hanandeh, 2013). Similar to aviation data, robust data on the number of buses that travel to Mecca are not available / published.

Table 5: Bus Transportation for Foreign Pilgrims During the Hajj - Starting from Jeddah (round trip)

Destination	Jeddah-Mecca (66 km)	Mecca-Mina (6 Km)	Mina-Arafat (14 km)	Arafat-Muzdalifah (13 km)	Muzdalifah - Mina (3 km)	Mina-Mecca (6 km)	Mecca-Madinah (457km)	Madinah-Jeddah (420km)
Number of buses	9,690 (57%)							
***Passenger* (Number of buses*40).**	387,600							
CO_2-e emissions (0.0300 kg/p-km)	767,448	69,768	162,792	151,164	34,884	69,768	5,313,996	4,883,760
Total	**11,453,580 kgCO_2-e**							
Abbrev (p= passenger, km= kilometre, kg=kilogram)								

Table 6: Bus Transportation for Foreign Pilgrims During the Hajj Starting from Madinah (one trip)							
Destination	**Madinah-Mecca (457 km)**	**Mecca-Mina (6 km)**	**Mina-Arafat (14 km)**	**Arafat-Muzdalifah (13 km)**	**Muzdalifah - Mina (3 km)**	**Mina-Mecca (6 km)**	**Mecca-Madinah (457km)**
Number of buses	7,310 (43%)						
Passenger (Number of buses*40).	292,400						
CO_2-e emissions (0.0300 kg/p-km)	4,008,804	52,632	122,808	114,036	26,316	52,632	4,008,804
Total	**8,386,032 kgCO_2-e**						
Abbrev (p= passenger, km= kilometre, kg= kilogram)							

Therefore, El Hanandeh's (2013) figures for pilgrims who arrived by bus for the Hajj (110,924) are used in this study with an assumption that the number of pilgrims using bus transport decreased by approximately -23% - applying an equal reduction for each country. To illustrate, the pilgrims who arrived by bus for performing the Hajj in 2018 were 85,623 (Gastat, 2018: 32), which is 77% of the pilgrims who arrived in 2011 (110,924). The decrease of the percentage occurred because in 2012 the government started to improve the infrastructure of Mecca (Jadwa, 2018: 30).

It should be noted that pilgrims who arrived by bus from Yemen were excluded from the ration allocated due to the war that was underway. Still, 25,000 pilgrims from Yemen arrived by bus to Saudi Arabia to perform the Hajj rituals in 2018 (Alarabiya, 2018).

Since pilgrims from different countries use buses to travel to Saudi Arabia and there is absence of robust data, this study estimated the CO_2-e emissions following the assumptions of the UNWTO (2019b:36) which indicate that each bus passenger emits 0.0300 CO_2-e kg per km.

Table 7: International Pilgrims Arriving to Mecca by Bus - Hajj 2018 (round trip)							
Country	Distance to Mecca (km)	Number of passengers (2011)	Number of buses (2011)	Approx. passenger number per bus (2011)	Assumption of number of passengers (2018). (-23 %).	Assumption of number of buses (2018)	CO_2-e emissions = (0.0300kg/p-km)
Jordan	2,700	5,299	132	40	4,080	102	330,480.00
Syria	3,120	16,604	415	40	12,785	320	1,196,676.00
Tajikistan	10,980	6,447	161	40	4,964	124	1,635,141.60
Kyrgyzstan	12,320	3,860	96	40	2,972	74	1,098,451.20
Kazakhstan	13,400	7,137	178	40	5,495	137	2,208,990.00
Azerbaijan	8,920	8,795	220	40	6,772	169	1,812,187.20
Turkmenistan	7,978	4,407	110	40	3,393	85	812,080.62
Uzbekistan	9,346	23,629	591	40	18,194	455	5,101,233.72
Yemen	3,140	20,520	513	40	25,000*	625	2,355,000.00
Palestinian territory	2,700	4,298	107	40	7,478	83	605,718.00
Kuwait	2,468	2,636	66	40	3,309	51	244,998.36
Qatar	2,656	1,168	30	40	2,030	22	161,750.40
Oman	3,992	2,547	64	40	899	49	107,664.24
United Arab Emirates	3,392	3,577	90	40	1,961	69	199,551.36
Total	**17,869,922.70 kgCO_2-e**						
Adapted from (El Hanandeh, 2013). * The number of Yemenis pilgrims was not decreased by the assumed percentage (-23%). Abbrev (km = kilometre, P= passenger, kg= kilogram).							

CO_2-e Emissions Produced from Electricity Generation

Seawater desalination

To estimate the CO_2-e emissions from seawater desalination, the following formula was applied:

EC = WC* ECMSF.

Where

(EC) = electricity consumed of desalinating seawater by using multi-stage flash technique.

(WC) = water consumed in the Hajj was 40,000,000 m^3 (MEWA, 2018).

(ECMSF) = electricity consumed of seawater desalination of the multi-stage flash technique (3 kWh per m^3) of water.

Thus

EC = 40,000,000 * 3 = 120,000,000 kWh.

According to CDMDNA (2011:4) each kWh of electricity generated in Saudi Arabia will produce 0.654 $kgCO_2$-e .

Accordingly

CO_2-e of electricity =

EC* 0.654 =

120,000,000* 0.654 = 78,480,000 $kgCO_2$-e .

Accommodation (Tent)

This study estimated the CO_2-e emissions of electricity produced to serve accommodation (tents) in the Hajj in three areas; Mina, Arafat, and Muzdalifah.

Mina (3-4 days)

Mina is a valley surrounded by mountains, and is located about 6 kilometres to the east of Mecca. A large portion of the Hajj is performed in Mina, thus, pilgrims spend 3-4 days there.

In Mina the electricity consumed in 2018 was 556 Megawatts. Based on CDMDNA (2011:4) each kWh of electricity in Saudi Arabia produces 0.654 $kgCO_2$-e.

556 MWh = 556,000 kWh.

Accordingly

556,000 kWh * 0.654 = 363,624 $kgCO_2$-e produced in Mina.

Arafat (approx. 12 hours)

The day of Arafat is an Islamic day that falls on the ninth day of Dhu al-Hijjah of the lunar Islamic calendar. This is the second day of the Hajj. Muslim pilgrims will travel from Mina to Arafa and will remain until the sunset. Arafat is about 14 kilometres southeast of Mina.

In Arafat the electricity consumed in 2018 was 75 Megawatts. According to CDMDNA (2011:4) each kWh of electricity produces 0.654 $kgCO_2$-e.

75 MWh = 75,000 kWh.

Accordingly

75000 * 0.654 = 49,050 $kgCO_2$-e produced in the day of Arafat.

Muzdalifah (approx. 12 hours)

After sunset of the ninth day of the Islamic month of Dhu al-Hijjah, Muslim pilgrims travel to Muzdalifah. This is an open area located about 3 km southeast of Mina. Pilgrims will remain there until the dawn of the next day.

In 2018, the electricity consumed in Muzdalifah was 40 Megawatts. According to CDMDNA (2011:4) each kWh of electricity in Saudi Arabia produces 0.654 $kgCO_2$-e.

40 MWh = 40,000 kWh.

Accordingly

40000 * 0.654 = 26,160 ($kgCO_2$-e /kWh). produced in the day of Muzdalifah.

The total emissions of CO_2-e produced via electricity generation in the Hajj event 2018 was

363,624,000 + 49,050,000 + 26,160,000 = 438,834,000 $kgCO_2$-e.

Table 8 presents the CO_2-e emissions produced during Hajj 2018 from each activity.

Discussion

Table 8 clearly illustrates that the Hajj activities contribute significant GHG emissions and hence harm the environmental sustainability of the destination. This is evident despite the approximate estimation of GHGs undertaken by this study by applying only ***Scope 1*** and ***Scope 2*** methods. ***Scope 3*** methods have not been undertaken. The emissions produced from liquid waste from hotels and motels is also excluded due to the lack of available data. If these activities were included,

Table 8: Approximation of CO_2-e Emissions During Hajj 2018		
Activity	**kgCO_2-e emissions**	**%**
Aviation	1,561,190,021.20	87
Municipal solid waste (MSW)	169,204,000.00	9
Electricity generation (water desalination and accommodation)	78,918,834.00	4
Land transportation (car and bus)	57,138,121.20	3
Total	**1,866,450,976.40**	**100**

the estimation of total emission would be increased. However, despite these limitations, the significant GHG emissions revealed by this study are sufficient to show substantial environmental impacts of the Hajj.

The estimated GHG emissions arising from the 2018 Hajj indicated that aviation contributes the largest percentage (87%). This result is consistent with Kumar's (2015) study which found that air travel is the largest producer of GHG in Shri Mata Vaishno Devi Shrine religious event in Katra, Jammu and Kashmir. In fact, globally, it is well documented that aviation produces the largest amounts of GHG in international events (Higham *et al.*, 2019). Hence, with the anticipation that air travel will increase as the numbers of pilgrims increase, emissions will continue to rise. This is unless there is action to reduce the aviation production of GHG. For instance, one of the initiatives is setting taxes for CO_2 production. This step has been taken by many governments such as Sweden, UK, and Germany to obligate airlines to use more efficient aircraft (Becken & Pant, 2019). The government could also financially support international initiatives for airlines, especially Middle-Eastern owned airlines, to become more carbon efficient by improving technology to be able to use low-carbon fuels such as hydrogen.

Although this current research only estimates the CO_2-e emissions of MSW, this study confirms that the emissions of MSW contributes notably in producing GHG with around 9% of the total emission. Thus, the government needs to improve their waste management practices. This is because disposing all MSW in landfill without proper treatment generates GHG - mainly methane and carbon dioxide (Hardy, 2003) - both of which have high global warming potential (Chalvatzaki & Lazaridis, 2010). Accordingly, effective strategy such as adopting recycling methods or converting the waste to energy would mitigate the GHG from landfill. For instance, Nizami *et al.* (2017) indicate that if the government of Saudi Arabia developed a waste-based biorefinery or waste to energy facilities they could treat around 87% of total MSW. The remaining could be recycled. The same study revealed that both strategies would reduce GWP by 1.15 million Mt.CO_2-e and would aid the government to increase the sustainability of its economy. In fact, the country has great opportunity to reduce the GHG from MSW in the context of the Hajj because it has been found that Hajj pilgrims have high intention to sort and recycle waste if recycling bins were available in Hajj sites (Alsebaei, 2014).

Generating electricity for seawater desalination and accommodation also contributed significantly to the production of GHG (4% of total), although this study only estimated an approximate average. In regard to seawater desalination, this study revealed that approximately 78,480,000 kgCO_2-e were produced due to using non-renewable energy for the operation of seawater desalination. The result is in line with other studies that indicated the significant impact of desalinating seawater on the environment using non-renewable energy in the tourism context (Xu *et al.*, 2003; Sadhwani & De Ilurdoz, 2019).

Similarly, it has been revealed that using non-renewable resources for generating electricity for accommodation in tourism contributes significantly to producing GHG (Abeydeera & Karunasena, 2019). The results of this study show that the generation of electricity produced around 438,834 kgCO_2-e. It should be noted that the estimation of GHG emissions from accommodation in this study only counted accommodation from tents and excluded more than 100 hotels and motels in Mecca (SPA, 2011), due to the lack of data availability. The exclusion has impacted the result of this study, underestimating emissions from accommodation. However, despite the exclusion, the quantity of GHG that this study found provides an indication that the generation of electricity for accommodation and seawater desalination for the Hajj pilgrims releases significant amount of GHG. In fact, it was indicated that compared to all cities in Saudi Arabia Mecca is the highest city for electricity consumption due to the pilgrimage (Makkahnews, 2015), and is expected to increase in the next years if the same approach is applied. Thus, to mitigate the GHG from electricity generation, using renewable energy such as solar energy instead of conventional generation of energy could be an effective approach (Daly *et al.*, 2010), particularly in a country like Saudi Arabia where its geographical location falls in a sun belt so suitable for solar (Almasoud & Gandayh, 2015). In fact, Faqeha *et al.* (2018) indicated that if the government applied solar energy in all the tents in the Hajj, approximately 1280 mega-volt ampere (MVA) of low emission energy would be produced.

Land transportation was the last GHG emitter in the Hajj with 3% of the total calculated. This is because this study only estimated the GHG produced from each pilgrim per km and excluded other factors that can considerably increase the results such as fuel consumption, vehicle type, and fuel emission factors (Grizane & Jurgelane-Kaldava, 2019), due to the lack of availability of the data. Yet, despite the exclusion and applying only basic methods to estimate the GHG from land transportation, the result of this study illustrated that 57,138,121.20 kg of CO_2-e were emitted. This result provides a clear indication that land transportation contributes significantly in impacting the environmental sustainability of the destination.

The quantity of GHG released by land transportation can be reduced if both short- and long-term mitigation policies and strategies are introducing such as increasing vehicles that use electric and hybrid engines (UNWTO, 2019b: 47), enhancing bus engine performance and using lightweight materials to decrease the energy intensity per km per pilgrim (Fischedick *et al.*, 2014). For instance, for the 2008 summer Olympic games in Beijing, the government changed the traditional buses to more than 100 natural gas public buses. This step of promoting clean energy aided in reducing around 20,000 tonnes of GHG emissions (Wu *et al.*, 2011). Furthermore, the world expo 2010 that was held in Shanghai, succeeded in reducing the GHG emissions from 1.66 kg/trip to 1.55 kg/trip through improving the transport infrastructure, introducing clean energy vehicles, and imposing policies to restrict the use of cars (Zeng & Li, 2014).

Conclusion

This study investigated the components that contribute to the environmental impacts of the Hajj on Mecca, Saudi Arabia and the planet more generally. In particular, it provided an estimation of the CO_2-e produced during the Hajj from MSW, air and land transportation, and electricity generation for accommodation and water desalination (Table 8). The results estimate that, at a minimum, the Hajj activities in 2018 produced approximately 1,866,450,976.40 kgCO_2-e.

The government of Saudi Arabia has set various strategies and policies to mitigate the impact of the Hajj activities on the environmental sustainability - such as the *Green Hajj* project, the *Prepared Meal* project, and an *Environmental Charter* (Almadina, 2010; Al-Rajhi, 2018; SPA, 2019). Yet, the result shows that these measures have either not been implemented or have been insufficient to significantly improve the Hajj's sustainability. Given the scale of pollution generated by the Hajj, there is an urgent need to set strategies and implement more exacting measures. In fact, although COVID-19 has negatively impacted the Hajj, it can also offer an opportunity for the stakeholders to address their issues (Seraphin, 2021). Hence, restrictions on the number of pilgrims may give Hajj stakeholders an opportunity to put more effort into developing more efficient strategies and plans to mitigate the impact of Hajj activities on the sustainability of the destination. For example, one of the issues that contributes to harming the environmental sustainability of the destination is the lack of collaboration between key stakeholders from public and private sectors in implementing environmental projects such as *Green Hajj* and *Prepared Meal* (Al-Hakim, 2019; Hossain, 2019). Such an issue has been proven to hinder moves towards sustainability in tourism destinations (Hatipoglu *et al.*, 2016; Wondirad *et al.*, 2020). In contrast, enhancing collaborative networks is proven to lead stakeholders to innovative actopms which result in improving the sustainability in a destination (Graci, 2013). Therefore, hopfully this issue is addressed by the stakeholders before the Hajj event starts in earnest again.

Finally, it is important that the Saudi Government implement a process to regularly estimate (more accurately than we have been able to in this paper) the GHG emissions of the Hajj activities as a basis for benchmarking and continually reducing these emissions going forward.

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