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ARTICLE

Aerial ropeway system — feasibility study in Doha, Qatar

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Abstract: Aerial ropeway systems, also called gondolas and aerial cable cars, are amongst driverless transportation modes, which are progressively drawing attention in promoting tourism. Aerial ropeway systems have been operated in touristic spots (e.g., over lakes, rivers, and hilly lands) in several countries. Passengers can enjoy a view from above and experience a stress-free and reliable trip. Furthermore, those systems can be exploited as public transportation in urbanized and populated regions. The objective of this article is to investigate the viability of implementing a gondola line over Doha Bay in Qatar as a tourist attraction from marketing, economic, and environmental points of view. In this study, the associated costs (capital, maintenance, and operating) of implementing a mono-cable detachable gondola technology (MDG) are estimated using international best practices. The economic analysis outcome demonstrates that the revenues generated from fares could offset the required capital investment as well as operating and maintenance costs and hence the proposed gondola could be economically attractive for investors. Moreover, no significant negative impacts and footprint on the environment are anticipated at the exploitation phase of the gondola.

Key words: aerial ropeway systems, gondola, tourism, cable car, ridership, capital costs, operating and maintenance costs, revenue.

Résumé : Les systèmes de téléphériques, aussi appelés gondoles et véhicules aériens tractés par câble, font partie des modes de transport sans conducteur, qui attirent progressivement l'attention dans le milieu de la promotion du tourisme. Des systèmes de téléphériques sont exploités dans des endroits touristiques, par exemple, au-dessus de lacs, de rivières et de régions montagneuses dans plusieurs pays. Les passagers peuvent profiter d'une vue d'en haut et faire l'expérience d'une excursion sans stress et en toute sécurité. De plus, ces systèmes peuvent être exploités comme un moyen de transport public dans les régions urbanisées et peuplées. L'objectif de cet article est d'examiner la viabilité de la mise en place d'une gondole au-dessus de la baie de Doha au Qatar en tant qu'attraction touristique du point de vue marketing, économique et environnemental. Dans la présente étude, les coûts connexes (immobilisations, entretien et fonctionnement) de la mise en œuvre d'une technologie de gondole amovible monocâble (GAM) sont estimés à l'aide des pratiques exemplaires internationales. Le résultat de l'analyse économique démontre que les revenus générés par les tarifs pourraient contrebalancer l'investissement en capital requis ainsi que les coûts de fonctionnement et d'entretien et, par conséquent, la gondole proposée pourrait être économiquement attrayante pour les investisseurs. De plus, aucun impact négatif significatif et aucune empreinte sur l'environnement ne sont prévus lors de la phase d'exploitation de la gondole. [Traduit par la Rédaction]

Mots-clés : systèmes de téléphériques, gondole, tourisme, véhicule tracté par câble, achalandage, coûts d'immobilisations, coûts de fonctionnement et d'entretien, revenu.

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1. Introduction and background

An aerial ropeway system, also called gondola lift and cable car, is a kind of passenger transportation in which the cabin (e.g., tramcar) is suspended in the air from a cable. Nonetheless, cable cars can be exploited for freight shipment as well in a limited manner. Generally, different kinds of aerial ropeway systems are available (i.e., aerial tramway, and gondola telecabins (detachable)).

Aerial ropeway systems are considered a flexible mode of transportation. They can be adapted to different terrains and thus tackle topographical challenges along a transit route. This is particularly important in areas having topographical constraints, such as valleys, where traditional urban public transport modes are difficult to operate. The capital costs, operating and maintenance costs (O&M), functionality, and capacity of cable cars, gondolas, and aerial tramways depend on the applied technology, as well as service line operational characteristics. It is worth mentioning that aerial cable cars are not a demand–responsive mode of transport, but a schedule-based mode. Irrespective of its demand, the capacity of the aerial gondola depends on parameters like cabin capacity, gondola technology, and headway.

1.1. Aerial ropeway systems specifications

Almost all cable cars consist of the following components despite differences in technology:

- cabins or tramcars,
- stations,
- pylons, and
- a ropeway conveyor.

Overall, aerial cable cars are a reliable and sustainable mode of transport. Furthermore, they are energy efficient, and gondolas and aerial tramways are a safe transportation mode. They are usually equipped with an emergency evacuation arrangement. In North America, the National Ski Areas Association stated that a gondola patron is five times and eight times more likely to suffer a fatality riding an elevator and riding in a car, respectively, than riding on an aerial cable car. The report also points out that aerial tramcars and gondolas are amongst the safest means of transportation (NSAA 2018).

Notwithstanding, gondola systems may be considered as a vulnerable transportation means because of their sensitivity to weather conditions, particularly wind (Hoffmann 2006), and also power outages, which may occasionally occur. Because power outages are troublesome for alighting and evacuation, emergency evacuation arrangements are essential for aerial cable cars. For instance, Medellín Metro resolved the issue by arranging a communication system in every cabin, which is triggered in case of emergency (Adrien 2004). Miami Metropolitan Planning Organisation points out that undertaking efficient and orderly evacuations demands advance planning (so-called Gondola Evacuation Plan), practice, training, and qualified personnel, alongside well-maintained equipment, continuous communication, and management to uphold cable cars' safety (JACOBS et al. 2016).

1.2. Available gondola technologies

Alshalalfah et al. (2012) reviewed the characteristics of existing aerial cable car technologies alongside their application and exploitation in the world with a fair evaluation. Currently, three techniques are being used for gondola systems:

- monocable-detachable gondola (MDG),
- bicable-detachable gondola (BDG), and
- tricable-detachable gondola (TDG) or 3S.

MDG is a kind of aerial lift in which the cabins are suspended from a moving ropeway conveyor and are detachable. The MDG system has two stations for each leg and may have intermediary supporting pylons in between. The capacity of MDG vehicles is usually designed to accommodate eight patrons, although some MDG systems have a lower capacity (e.g., four or greater capacity, possibly up to 15). At standard cabin capacity, MDG systems can move between 2000 and 3000 passengers per hour per direction along each leg (Bergerhoff and Perschon 2013). MDG systems are a commonly used cable car system given relatively low infrastructure capital cost compared to other systems. Several cities and agglomerations around the world have already built MDG systems, such as Medellín Metro cable in Colombia, Caracas Metrocable in Venezuela, Cable Constantine in Algeria, London Emirates Air Line cable car in England, and Complexo do Alemao (Rio) in Brazil.

BDGs use a detachable grip, which enables detaching cabins from the cable at intermediary stations as well as turns. Compared to MDG systems, which have a single cable, BDGs have twin cables for support and propulsion. Furthermore, BDGs can move faster than MDGs, albeit they are a more costly technology as well. The typical capacity of BDGs is comparable to that of MDGs. The BDG cabin capacity can reach 17 passengers per cabin, which leads to a movement capacity of up to 194 000 passengers per hour per direction. BDG systems can be seen in Hong Kong, Ngong Ping Cable Car, and formerly in Singapore before overhauling (Singapore Cable Car).

TDG (3S) gondola systems,[1] are a speedy modern system benefiting from reversible cable car technology. Brownjohn (1998) indicates 0.5 m/s^2 as the maximum acceleration and deceleration rate for gondolas. The term 3S stands for “dreiseil”, which means tricable. TDG uses two ropeway conveyors for support, while the duty of the third one is to generate propelling force. Similar to the other two systems, the 3S cabins run in an incessant loop. The extra cable increases the stability of the gondola to sustain wind and larger weights.

Albeit TDG systems are more costly than MDGs as well as BDGs, the additional costs are offset by their higher passenger capacity and faster service. The capacity of TDG cabins can reach 38 passengers, which leads to a potential movement of 9000 passengers per hour per direction. The wind steadiness, efficiency in energy use, and flexibility in long span, (i.e., 3000 m) are other advantages of the TDG systems. Thus, the TDG system is a perfect choice for hilly areas with topographical constraints as well as in windy locations. Kitzbühel, in Austria; Whistler-Blackcomb resort in B.C., Canada; The Olympic Village of Sochi in Russia; the Hòn Thòm in Vietnam (a 7.9 km TDG system); and Matterhorn Glacier Ride in Zermatt, Switzerland, are examples of TDG systems from around the world.

As indicated before, MDG systems are widely used given the required costs for building their infrastructure. MDGs can be a plausible feeder and complement to conventional public transportation. For instance, Mi Teleférico is an aerial ropeway system that is a public transit mode in the city of La Paz in Bolivia. The MDG network in La Paz consists of 10 MDG lines differentiated by color. The 0.7 km Brown Line transports 2000 passengers in each hour of operation. The Sky Blue Line with a length of 2.6 km has a higher capacity (i.e., 4000 passengers per hour). The longest line is the Blue Line with a length of 4.7 km of the capacity to transport 4000 passengers per hour. Besides the Brown Line, the travel time of the lines varies between 10 and 16 min, depending on the line length and the cable car speed, which is on average 5 m/s.

[1]TDG was introduced by a European Company (Von Roll transport systems in Thun, Switzerland).

2. Review of the implementation of aerial ropeway systems as a means of transportation

2.1. Cable cars as public transport

In the past, gondolas were customary in mountainous areas, over lakes, rivers, and ski resorts. For the past three decades, transport authorities have started building and operating aerial tram cable cars in urbanized areas as a means of public transportation. The academic sector and the industry both have underscored and supported the advantages of urban gondolas as a public transport mode within urbanized areas since the 1980s (McLennan 1987; Neumann 1992, 1999; Fletcher 2005).

Alshalalfah et al. (2012) indicate willingness and propensity towards aerial ropeway systems as a means of public transportation, particularly in terrain-constrained urban areas. Clément-Werny et al. (2011) indicate that urban gondola capacity can compete with that of bus lines and light rail transit, which may reach 11 800 passengers per hour. Cavone et al. (2017) mention the advantages of using gondolas as public transport. Incorporating gondolas into urban areas could lead to higher accessibility and the integration of ubiquitous multi-modal networks under conflicting requirements (Cavone et al. 2018). Težak and Lep (2019) investigated a configuration of cable cars having a central exit and entry, which is suitable for use as a public transport means. Dávila and Daste (2011) and Bocarejo et al. (2014) indicate access to work and education opportunities, and social inclusion as positive consequences of implementing urban gondolas for the hilly terrains region where implementing conventional public transport is troublesome and excessively costly.

There are several real-world examples of the applicability of aerial ropeway systems, particularly in South America, such as Metrocable de Medellín in Columbia; Teleférico de Caracas in Venezuela; Sugarloaf cable car in Rio de Janeiro, Brazil; Mi Teleférico in La Paz, Bolivia; and Teleferico Santiago in Chile. The cities of Medellín, Caracas, and La Paz have already shown convincing results following the implementation of gondolas (Heinrich and Bernet 2014).

The Metrocable systems in Medellín and Caracas demonstrate multimodal transportation networks that provide access to local metro service lines. For instance, Metrocable opened in 2004 in Medellín to complement a multimodal transport service linked to Medellín's Metro. Given the Medellín topography and its steep hills, the Metrocable was designed to provide accessibility to some Medellín hilly residential districts.

As the first gondola public transit system, Line K (Linea K) of the Metrocable was inaugurated in 2004, and connects the steep hills in Comunas to the Medellín River valley. The service line is connected to the Medellín mass transit system and forms a feeder for the city multimodal transport network. The implementation of Line K in Medellín was encouragement for other South American cities, such as Caracas in Venezuela and Rio de Janeiro in Brazil, to launch similar gondola systems (Dávila and Daste 2011).

The Medellín Metrocable system has been evolving since its creation. Presently, it comprises five lines (i.e., H, J, K, L (Cable Arvi) and Line M). Brand and Dávila (2011) indicate that the Medellín Metrocable system has been heavily used by local riders, who are not predominantly high-income people and are ready to wait in the queue for even three-quarters of an hour to ride the cable car.

The Emirates Air Line cable car in London, UK, was built for the Summer Olympic Games in 2012. It shortens travel between the Greenwich Peninsula terminal and the Royal Docks terminal to 6 min. The Royal Docks is the eastern terminating point of the cable car. It is the home to the ExCeL Centre, which was the venue for several sports, such as weightlifting events and boxing, during the Olympic Games. Given its proximity to the Royal Victoria station, the Royal Docks is well-connected to trains with the nearest station reachable in 5 min on foot.

Greenwich Peninsula, which is located at the western end of the Emirates cable car line, is close to The O2 Centre. The O2 hosted artistic gymnastics and basketball events during the London Olympics. Visitors can access the Greenwich Peninsula by London Underground from the North Greenwich station. The cable line is integrated with London River Services at North Greenwich Pier as well.

The Swiss Federal Statistical Office (OFS 2020) publishes safety rankings among transit models (i.e., rail, tram, trolleybus, autobus, funicular, and gondola) in Switzerland. The statistics clearly indicate gondola as the safest transport mode amongst the aforementioned public transportation means. This is an important finding as Switzerland is a leading country in operating aerial ropeway systems in the world.

2.2. Gondola as a tourist attraction

Compared to other means of transportation, the main distinction of aerial ropeway systems from a tourism point of view is to offer scenic views to their riders. Gondola riders can enjoy a view from above the ground. This is the unique feature of gondolas. Hop-on–hop-off buses, taxies, and limousines or private cars cannot provide such an experience to their passengers. Traveling by aerial cable cars is quite safe, reliable, and unforgettable thanks to their barrier-free movement.

Albeit, there are dozens of urban aerial ropeway systems around the world, most of these systems are found in tourist attraction spots to serve specific tourist destinations. For instance, the Sugarloaf cable car in Rio de Janeiro was inaugurated in 1912 and considered a pioneer of its kind in Latin America. According to SouthAmerica.travel (2017), it has carried 37 million visitors since its opening. Sugarloaf cable car offers a wonderful view of Rio within a 3 min ride to the peak of Sugarloaf Mountain. The peak sits 1299 ft above the city. The cable cars, with a headway of 30 min, operate from 0800 to 2200 (Blore and Vries 2006) and offer a capacity of about 65 people.

In South America, Sistema Teleférico Warairarepano is a gondola lift that climbs El Ávila Mountain via El Ávila National Park in Venezuela. The system contains 70 cars moving 3.5 km in a quarter of an hour and provides a great view of the Venezuelan capital. The cable car fare is $20 per ride as the tourist rate. Nevertheless, the fare is significantly less for locals (about one quarter). Upon arriving at the top, visitors can hire an SUV to go down the other side of the mountain, called Galipan, and enjoy Venezuelan cuisines.

In North America, Disney Skyliner at Walt Disney World opened in September 2019. It is a cable car manufactured by Doppelmayr Garaventa Group and flies over Bay Lake, Fla., USA. The gondola serves five stations, which are located in resorts and theme parks. A full route journey time (one-way) is 11 min. The Skyliner has been welcomed by an enormous number of users. The main advantages that the Skyliner users have indicated are (*i*) ease of use, (*ii*) convenience, (*iii*) quick access to Epcot and Hollywood Studios unlike traditional buses, (*iv*) punctuality, and (*v*) the placement of the stations at the resort (TripAdvisor 2020*b*). Along the border of The United States and Canada in the region of Niagara Falls, Healy (2006) mentioned the 12 min ride that can be made by gondola, and underscores that it would be an attractive adventure and excitement for tourists.

In Oceania, Horn and Simmons (2002) number the Skyline gondola among the top tourism attractions in Rotorua, a town with a population of 58 000 in the northern part of New Zealand.

In Europe, Teleférico de Gaia is an aerial cable car that reveals outstanding scenery to its riders over the Douro River and the city of Porto. Given the average speed of 2 m/s of the gondola and the distance of 600 m between the two sides of the Douro River, the trip takes approximately 5 min. Funivia del Renon in Bolzano, Italy; Matterhorn Glacier Ride in Zermatt, Switzerland; and Koblenz Rheinseilbahn in Koblenz, Germany, are other examples of the tourist-oriented applicability of cable cars in Europe.

Similarly, in Asia, Sentosa Island Cable Car in Sentosa Island, Singapore, and Ngong Ping 360 in Hong Kong are two other demonstrations of the implementation of gondolas as a tourist attraction.

3. Review of the economic justifications of aerial ropeway systems from around the world

Several studies demonstrate the viability of implementing aerial ropeway systems from an economic point of view. For instance, Healy (2006) forecasted the net revenue from the New Table Rock Gondola in Niagara Falls would have reached $1.8 million.

The feasibility study of the implementation of a cable car in the holy city of Mecca in the Kingdom ofSaudi Arabia demonstrated the potential to resolve Mecca's transportation problems (Alshalalfah et al. 2011).

The study results showed that depending on the applied technology and corridors' geographical characteristics, the capital costs of the proposed gondola would range from $18.5 million to $84.5 million. Similarly, base year annual O&M cost estimates range from $1.85 million to $11 million. The cost–benefit analysis showed that the benefit over cost ratio (BCR) depends on the line alignment as well as the technology used, and could vary between 1.04 and 4.26. The aforementioned study also showed that TDG systems could bring about higher impacts in terms of savings in travel time and operating costs and cuts in greenhouse gas emissions, as well as air pollution reduction. Nevertheless, these benefits could not counterbalance the large capital and O&M costs of a TDG (Alshalalfah et al. 2011).

Tahmasseby and Kattan (2015) conducted a feasibility study on gondola systems to connect the main campus of the University of Calgary to adjacent areas including a medical center, a shopping center, and a light rail transit station. Their findings showed that operating a gondola line would enhance mobility and accessibility in the University of Calgary campus neighborhood. The same study also looked into the operator's perspective and demonstrated that all costs would be recovered, if such a gondola system was implemented.

Translink[2] undertook a feasibility study for a cable car line, which could connect the University station of Simon Fraser University to Burnaby Mountain (CH2M HILL Canada Limited 2018). The implementation of the aforementioned cable car could lead to the elimination of the existing bus lines in the area and result in bus O&M cost savings of $89.3 million alongside capital costs savings ($34.5 million). It was estimated that the cable car operating costs would be approximately $54.2 million. The cost–benefit analysis showed a BCR of 1.8 and thus demonstrated that the aerial cable car project would outweigh the project costs.

4. Economic feasibility study approach — aerial ropeway MDG in Doha, Qatar

4.1. The state of Qatar and motivation for implementing an aerial ropeway system

Qatar, the small Middle Eastern country, repeatedly ranks as one of the wealthiest countries on the globe per capita. The 2020 population of Qatar was estimated at 2 684 329 according to the latest Qatar Planning and Statistics Authority (2020) census. Qatar's domestic product per capita was reported to be $69 687 according to the International Monetary Fund and it is estimated to reach $72 000 in 2021 (IMF 2020). This trend has placed the country among the nations with the highest GDP per capita in the world. Qatar welcomed

[2]Transit operator in Vancouver, B.C., Canada.

1.819 million visitors in 2018 according to Qatar National Tourism Council (2018) report. Foreign touristic arrivals in Qatar have been forecast to reach 2.9 million by the year 2022 according to Alpen Capital (GCC Hospitality Industry Report 2018).[3]

The same report indicates that leisure tourism increased by 8.66% and reached revenue of $8.6 billion in 2017 in the country. This tourist influx promotes the implementation of an aerial cable car as a tourist attraction in Doha, Qatar, which will be the host of the FIFA World cup Games 2022 in the months of November and December 2022. According to Alpen Capital, the country will need 60 000 hotel rooms by 2022. This requirement is according to FIFA guidelines and instructions. Qatar planned to open some 21 new hotels, predominantly five-star and four-star, by 2021. Such figures demonstrate the economic viability of implementing an aerial cable car in the city for investors.

Because of the scarcity of sights and landmarks, natural parks, waterfalls, mountains and hiking trails, wildlife areas, and scenic landscapes in the country, a gondola flying over Doha Bay could draw considerable tourist attention. Currently, a half-day safari with camel ride and inland sea boat rides are the most popular outdoor activities and entertainment among tourists and country visitors according to TripAdvisor (2020*a*). Riding an aerial cable car over Doha Bay would be an attractive outdoor activity in Qatar given the country's climate and Doha Bay's unique landscape.

In general, appropriate safety arrangements are needed to enable aerial cable car systems to cope with wind gusts. According to the World Weather Online (2020), the average gust in Qatar does not exceed 40 km/h and predominantly falls around 25 km/h. Such figures make the implementation of an aerial ropeway system in Qatar feasible.

4.2. Tourism viewpoint

A day trip and associated package of outdoor activities for the proposed gondola at the points of departure and arrival could promote riding the gondola and increase ridership for residents and particularly visitors and tourists.

The idea of a day trip originates from combining the activities being offered by the previously mentioned facilities on either side of the Corniche and making unforgettable memories for residents, tourists, and visitors. A day tour would start by visiting Al Dafna garden and engaging in some outdoor activities. The City Center shopping mall, Sheraton Hotel, Four Seasons Hotel, Marriott Marquis Hotel, and Doha Exhibition and Convention Center are all located within walking distance of the garden. The tour would continue in the afternoon by riding the gondola and crossing over the Corniche while enjoying a fresh breeze from Doha Bay. Following arrival at the Mia Park gondola station, people might take a visit to the Islamic Museum for a couple of hours. Thereafter the tour would continue with an evening snack at one of the Mia park cafes with a view of the bay adjacent to the Islamic Museum. Outdoor activities would continue by recording memories and taking photos with the Doha skyline in the background, illuminated strikingly following the sunset. When it comes to dinner and nightlife activities, visiting Souq Waqif would be inevitable. The Souq is a well-known Doha tourist attraction (Avon 2010). The Souq is a marketplace selling traditional garments, spices, handicrafts, and souvenirs. Besides its traditional markets and bazaars, the Souq hosts several art galleries, events, and local concerts and it is home to several restaurants, cafes, and Shisha lounges. On weekends and particularly from October to March, it attracts tens of thousands of visitors. For instance, a fresh dates festival attracted 54 000 visitors to the Souq in 2018, according to the Head of Agricultural Affairs Department in Qatar (Ataullah 2019).

[3]It should be noted that the projection and forecast made were before the COVID-19 pandemic crisis.

The tour would complete at the Souq in the evening and visitors could return to their residential place easily by taking a cab or riding the Doha Metro.

4.3. Line alignment

For the case of Doha, Qatar, the MDG system seems to be appropriate based on the Doha Bay topography, the steady weather conditions predominantly existing in Qatar, the number of annual tourists and visitors to the country, its trends in the next 10 years, and thus the anticipated patronage. Given the Doha Beaufort wind force scale, which shows the rarity if high or strong winds, it is concluded that an MDG system could function well. Furthermore, it is not expected that the demand for a gondola system in Doha would exceed 3600 passengers per hour at any time. Meanwhile, the topography and the terrain of Doha Bay permits the implementation of an MDG system without requiring a long span. The implementation of other gondola technologies, such as BGD and TDG systems, would be more costly, while no additional tangible benefits anticipated.

In this study, the proposed cable car is a MDG line with a capacity of 10 passengers per cabin and a proposed headway of 2 min. Thus, the line capacity would be 300 passengers per hour per direction, which could potentially be increased up to 2400 passengers per hour per direction by shortening the headway to 15 s.

The Corniche encompasses Doha Bay. Along the Corniche, there are a couple of parks, a hotel, and a museum. Furthermore, the West Bay district, where business and government offices are located, is close by.

The Corniche Promenade and Park (Al Dafna garden, and Hotel Park in the West Bay area and Mia Park next to the Dhow Harbour) located on the other sides of Al Corniche St., are popular destinations for joggers, bicyclists, skaters, and others who are used to having an active lifestyle and doing outdoor activities. The Doha Corniche is a waterfront promenade in Doha, Qatar, that stretches 7 km along Doha Bay. Some recurring events, such as Qatar National Day, are held along the Doha Corniche (Varghese 2017) every year. Doha Corniche is a favorite tourist and leisure spot in Doha, Qatar (Qatar Tourism Authority 2018).

Al Dafna garden, located within walking distance to the south of the Sheraton Hotel, is a popular public garden in Doha, Qatar. The garden was established in 1990 on an area of 93 297 m^2. It is prominent given its delightful view of Doha Bay. It is also considered one of the most attractive gardens to visitors, particularly for fans of walking, cycling, skating, scootering, and social activities.

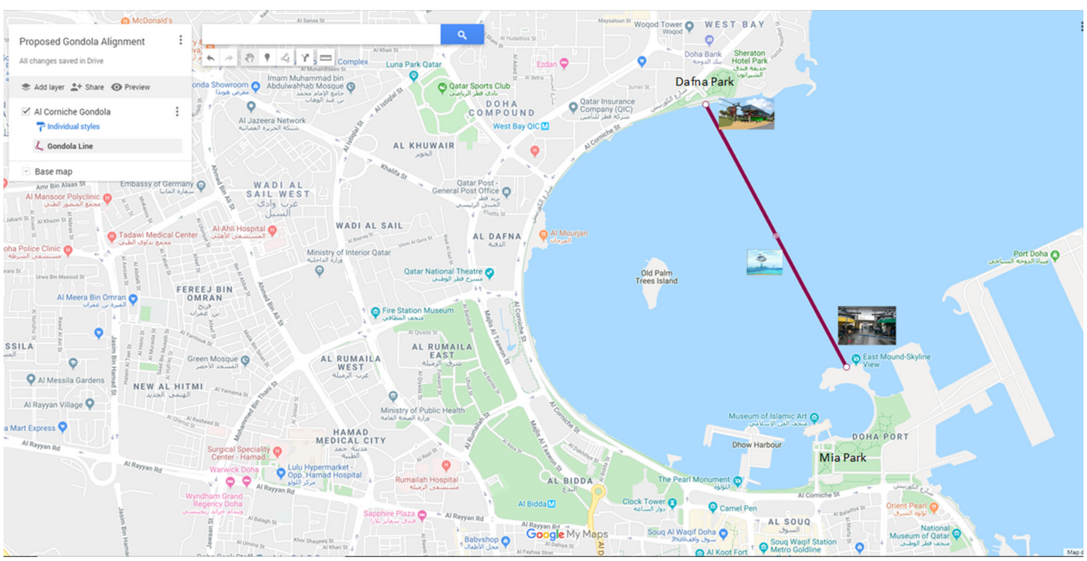
Mia Park, located on the east side of Dhow Harbour and adjacent to the Qatar Islamic Museum, is an exceptionally pleasant green spot in Doha. It offers a greenery promenade to Doha Corniche as well as a view of the Doha skyline. Park visitors can take advantage of such a view and stare at the Doha skyline from the best vantage point in the city, particularly at dusk and night. Visitors may stroll or partake in social activities, have a picnic, or even complement their stay by visiting the Islamic Museum located within walking distance of the park.

The proposed gondola line will connect Al Dafna Park in West Bay, Doha, to East Mound Skyline View at Mia Park. Photos recently taken and exhibited in Fig. 1 show East Mound Skyline View and Mia Park. On the left side, the West Bay business district, as well as the Sheraton Hotel (pyramid-shaped), are visible.

Figure 2 illustrates the proposed line alignment connecting the two sides of Doha Bay. The gondola line will be 2.15 km long over Doha Bay. There will be no significant land acquisition costs applicable as it flies over public land and Doha Bay. The gondola speed is proposed to be between 3 m/s (10.8 km/h) and 4 m/s (14.4 km/h), which ensures at least a 12 min leisure ride over the bay for passengers. This is almost as fast as the gondola lift in

Fig. 1. East Mound Skyline View, Mia Park, Doha Bay, Hotel Sheraton, and West Bay District (photos were taken on 10 February 2020).

Fig. 2. Proposed gondola alignment over Doha Bay, Doha, Qatar. Map data: © 2021 Google.



Medellín, Columbia, and the journey time is similar to that of the Disney Skyliner at Walt Disney World in Lake Buena Vista, Fla.

The proposed line will have a minimal visual intrusion impact and more importantly, it does not fly over residential and built-up areas, which means it never affects the privacy of Doha residents.

4.4. Operational characteristics

In Doha, Qatar, the hot season encompasses more than three months: from mid-May to the beginning of autumn. Based on the weighted average of the individual contributions from Hamad International Airport and Bahrain International Airport, the average daily high temperature in Doha exceeds 37 °C in the summertime. In the month of July, the average high reaches 42 °C, while the average low hovers around 31 °C.

Given the hot summer months in Doha, it is proposed that the cable car be operational for 9 months of the year (starting the month of September and terminating in May). The cabins require air-conditioned facilities given the average temperature particularly in the months of April, May, September, and October. The Disney Skyliner is an aerial ropeway system connecting a couple of parks and hotels in the middle of the Caribbean Beach resort in Lake Buena Vista, Fla. (Niles 2019). In addition to the air-conditioned stations, the gondola cabins (manufactured by Doppelmayr) themselves are equipped with several air ventilation systems to make the cabins' inside pleasant and comfortable for patrons.

The operating hours are proposed to be from 0800 to 2200. In case of special events, extended hours of operation can be considered as well.

4.5. The capital costs

The gondola capital costs are estimated according to the quotes obtained from the major cable car vendors in the world (e.g., Leitner Ropeways and Doppelmayr-Garaventa Group). Marginal cost variation needs to be taken into consideration for the best capital costs estimation. As a reference, Težak et al. (2016) indicate US$11 million as the gondola capital cost with a capacity of transporting 3000 passengers per hour, having 20 pylons and 100 cabins without any intermediary stations. For this case study, the gondola capital cost components are summarised below.

- Propulsion: The costs associated with propulsion represent a significant cost component. There is a significant difference between drive motor costs and return motor costs. The breakdown of the propulsion customary capital costs for the MDG technology is outlined as follows:
    - Drive (terminal): QR 4.4 million
    - Return (terminal): QR 3.1 million
- Terminals: The costs associated with building the required basic infrastructure; architectural as well as civil works. It is worth mentioning that terminal capital costs do not significantly depend on the applied gondola technology. For instance, in both techniques (MDG and TDG), the basic capital costs (excluding amenities such as shops, restaurants, toilets, etc.) for building a terminal are estimated at approximately QR 2.8 million.
- Equipment: The equipment costs of the gondola line comprise the costs of pylons, cabins, ropeway conveyors, as well as energy supply, air-conditioning facilities, the cabin carriage, and telecommunication equipment. The aforementioned costs for MDG system equipment are estimated at around QR 9.4 million per kilometre. The costs would be 2.1 times higher in the case of a TDG system.

- Required civil works. The infrastructure civil works cost consists of the following cost components:
    - foundations,
    - piling,
    - cupping, and
    - soil tests.
- The infrastructure civil works costs can be estimated accurately once the design of the gondola is completed and finalized. As a preliminary estimation, the infrastructure civil works costs may hover around QR 2.8 million per kilometre for the MDG technology. The aforementioned costs would increase to QR 4.2 million in the case of the TDG technology.
- Reserved generator: In case of an outage, backup generators, which are commonly diesel driven, will automatically come into operation to resume service runs. The cost of a backup generator is not significant compared to that of the other components. The backup generator cost is estimated at around QR 600 thousand and is the same for both MDG and TDG techniques.
- Duty: Duty on equipment is considered to be 10% of the electro-mechanical constituents (including propulsion and line infrastructure). The figure is based on experiences from other gondola installations around the world.
- Contingency plan: Contingency costs are considered to cover any unforeseen capital costs that may happen. It is assumed to be 20% of the total capital cost.
- Land: The cost of land acquisition, which is not applicable in this study.

Table 1 summarizes the capital cost components for the proposed MDG line in Qatari riyal.

4.6. The operating and maintenance (O&M) costs

The O&M cost comprises energy consumption costs, personnel costs, maintenance costs, and capital reserve funds (Tupper 2009; Alshalalfah et al. 2011; JACOBS et al. 2016).

- The cost of energy consumption, which expresses the associated costs of the energy consumed for propulsion (often generated by either electric power or a diesel engine). The consumed energy is also used for operating the required facilities, such as air conditioning, lights, lifts, escalators, and so on. The energy consumption cost is usually calculated according to the duration of line operation and consistent with the current energy tariff in the region. The average power consumption per kilometre for a typical MDG gondola system ranges between 125 and 150 kWh/km. It is worth mentioning an increase in the capacity of gondola lines by adding cabins would contribute slightly to energy consumption because of the gondola centralized power source configuration. In this case study, because air-conditioned cabins will be used, the energy consumption will be relatively higher. Given the proposed headway of 2 min and air-conditioned cabins with a capacity of 10 riders, it is estimated that the gondola will consume 350 kWh per hour of operation. Based on the energy tariff in Qatar quoted by Kahramaa,[4] QR 0.32/kWh (flat-rate) is assumed as the relevant tariff for the gondola.
- Personnel cost covers the wage of two personnel (e.g., a mechanic) who are assigned to the stations during daily operation. Assuming QR 20 000 ($5500) per month per mechanic including all associated costs incurred by the operating company (e.g., insurance, mobilization,

[4]Qatar General Electricity & Water Corporation.

Table 1. Capital cost estimation of the MDG line in Doha.

Capital cost component	Remarks	Cost in QR* (M)
Propulsion at terminals	Drive (terminal) + return (terminal)	7.5
Propulsion at intermediate stations	Not applicable	0.0
Terminals capital costs	Skyline View Terminal + Al Dafna Terminal	5.6
Intermediate stations capital	Not applicable	0.0
Infrastructure (lines)	QR9.4 M/km	20.7
Infrastructure civil works	Approximately QR 2.8 M/km	6.2
Backup generator	—	0.6
Duty on equipment	Estimated as 10% of the electro-mechanical parts associated costs	2.9
Contingency	One-fifth of the total capital costs (20%)	8.7
Total capital costs		52.2

*The Qatari riyal ties with the US dollar and approximately 3.65 QRs equal to $1.

training, etc.), and a 9 month operation, the personnel wage will be estimated at QR 2.4 million per annum in the first year.

- Recurring maintenance and service costs may vary between QR 250 and QR 550 per hour of operation (Warren 2011). In this study, an average figure of QR 400 per hour, which is the median of the above-mentioned ranges, has been assumed.
- Insurance cost is estimated because of the lack of availability of such a system in Qatar; the figure from the Burnaby Mountain study in British Columbia (Tupper 2009) is taken into consideration. The average insurance in the Canadian case was quoted as CAD 200 thousand, which is equivalent to QR 575 thousand.
- Capital reserve fund costs representing a capital reserve fund accrual for forthcoming capital expenses with the purpose of system rehabilitation over its lifetime. In this regard, replacing sheave assemblies and cabin carriages will likely occur two times in the project lifespan. The foremost cost components (e.g., replacing cabins and track ropes) occur once. Given the project lifetime and the assumed interest rate of 2%, the capital reserve fund cost is forecasted to be QR 526 thousand per year.

The total O&M costs of the proposed MDG line (operated annually for 9 months from September to May, and for 14 h of operation) are summarized in Table 2.

In line with the current inflation rate, a 2% increase in the O&M cost components has been taken into consideration. Thus, the total O&M costs are estimated to reach QR 8.03 million at the end of the project lifetime.

5. Discussion: revenue analysis and investment return

Forecasting the ridership of the proposed gondola line in Doha would pave the way for calculation of the anticipated revenue over the lifetime of the gondola for potential investors. Depending on the preferred business model, the investor and operator of the proposed cable car can be either two different companies or a single entity.

The main source of revenue will originate from tickets. In general, the fare system in an urban gondola context could be distance-based, surcharge-based, flat, zone-based, time-based, demand-based, or a combination of these parameters, such as distance and demand-based. For the case of Doha, a flat-rate system would be appropriate because there will be no intermediate stations along the proposed line and the gondola is going to be used as a recreational mode of transport. It is worth mentioning that all traditional public transport services (e.g., metro, buses, as well as Hop-On Hop-Off tours, etc.) in Doha are operated under flat-rate systems presently. However, ridesharing and paratransit services, and boat rides, which are demand-responsive, apply floating tariffs.

Table 2. Estimation of operating and maintenance costs for the proposed cable car.

Cost component	Remarks	Annual cost in QR (M)
Energy consumption	Power: 3822 h, 350 kWh per hour of consumption, and QR 0.32/kWh	0.43
Personnel wage	Assumed QR 20 thousand for each mechanic per month, which increases by 2% per year; two mechanics per station; two work shifts; two stations; 9 months operation	1.44
Maintenance cost	Assumed QR 400/h	1.53
Insurance cost	Based on the case study in Burnaby, B.C., Canada	0.57
Capital reserve fund	QR 11 M to QR 16 M will be spent to overhaul or change major parts of the gondola	0.52[5]
Total operating and maintenance costs in the first year		4.50

Based on the Hop-On Hop-Off tour tickets and activities in Doha (Marhaba.qa; Qatar Tourism Authority Entertainment 2014), and given the current economic conditions in Qatar and the world, a ticket may be offered for QR 50 (almost $15) for a round trip. For a single ride, QR 35 (almost $10) is proposed. Seasonal and discount tickets may also be offered, such as 100 QR (almost $30) for a family of four for a round trip, 25 QR for children under a certain age, and QR 350 for a seasonal pass of 3 months.

In the absence of a stated preference (SP) survey, two scenarios are accounted for to forecast ridership: scenario 1: pessimistic, in which it is assumed that 5% of visitors to Qatar would ride the cable car at least once; and scenario 2, optimistic, in which it is assumed that 10% of visitors to Qatar would ride the cable car at least once. The scenarios are defined based on the recent figures of similar cases. For instance, O'Sullivan (2016) mentions that despite a potential capacity of 2500 passengers per hour in the London Emirates cable car, the actual patronage is 4000 passengers per day. This indicates approximately 13% utilization of the potential gondola capacity and thus 1.5 million passengers per year as the realized ridership of the London Emirates cable car. Similarly, the San Francisco cable car experienced 17 511 rides per day in 2017, mainly because of the waiting lines, which can be long during high tourism seasons (Barmann 2017). For the case of the Ngong Ping gondola in Hong Kong, the ridership hovers around 5200 passengers per day in 2018 (Hui 2018). Nonetheless, demand increased in October's Golden Week and the year-end Christmas season tremendously. During the lunar year festivities, extended hours and various promotions may be offered to tourists as well.

In the calculation of economic factors, it is presumed that the lifetime of the proposed gondola is 30 years, and the discount rate is 5%. Moreover, a similar rate has been considered to incorporate an increase in the anticipated revenue due to growth in ridership as well as in ticket prices.

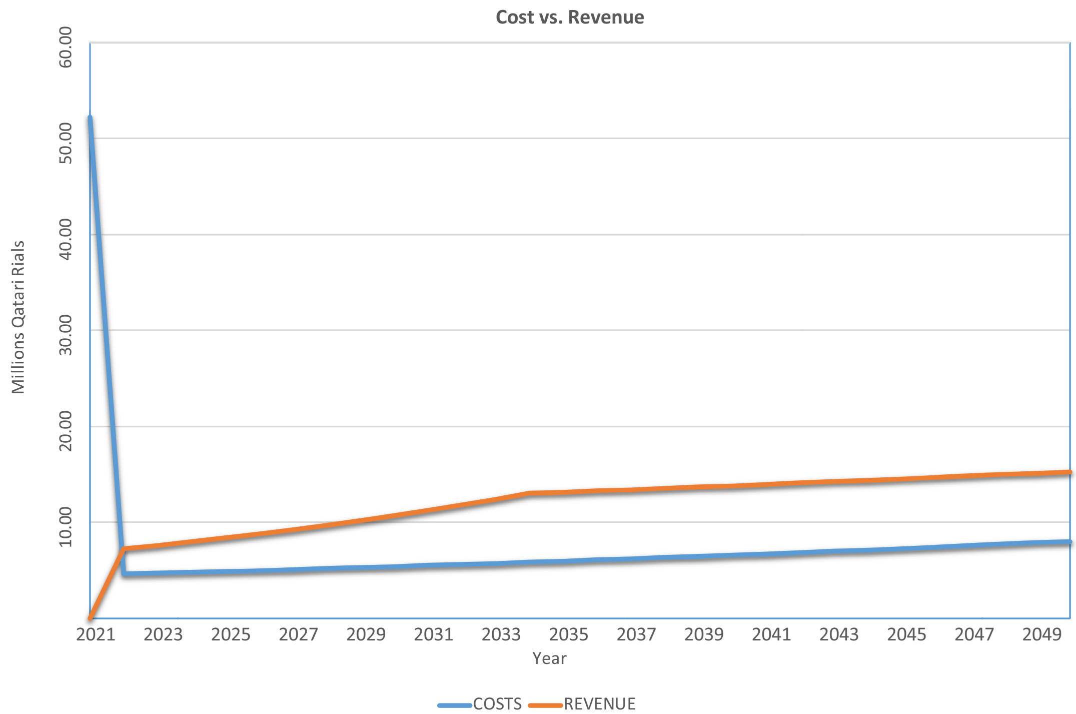
5.1. Scenario 1 — pessimistic scenario

In this scenario, it is assumed that 5% of Doha visitors, estimated at around 2.9 million visitors per year, will ride the gondola once. In other words, 145 000 riders for the first year are forecasted. Furthermore, a 5% increase per year in ridership is projected.

Based on the cash-flow analysis, the rate of return is calculated at 9%, which is higher than the minimum attractive rate of return of the current market. The BCR will be approximately 1.22 (applying the conventional method of BCR and considering no disbenefit to the public or environment). Both economic metrics are promising to investors. In other words,

[5]The CRF is approximately QR 521 K/year due to a built up QR 17 million over 30 years of operation. Two percent interest rate has been assumed. Furthermore, no spending for the first 8–10 years has been considered to ensure the accumulation of QR 5.6 million to QR 7.0 million to cover rehabilitation costs afterwards.

Fig. 3. Cost versus revenue in scenario 1 (pessimistic) for the proposed gondola.



the revenue generated from gondola fares may offset the investment costs completely in the initial years of operation and thus the system becomes profitable. This is apart from other revenue sources, such as advertisement. Moreover, tourists' influx to nearby recreational facilities, such as museums, boat rides, and restaurants, can be an incentive to those facilities' owners to partake in gondola investment.

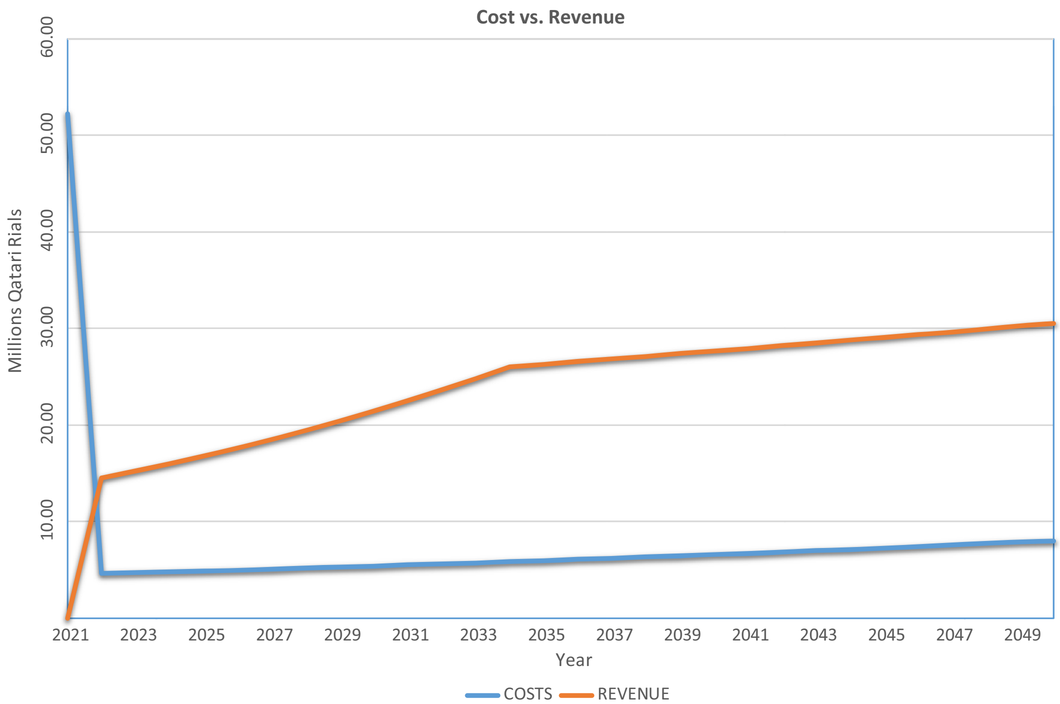
It is estimated that by the year 2050 (the end of the gondola lifetime) when the number of tourists and visitors reaches 6 million persons per year in Doha, 305 000 visitors will ride the gondola, which can be completely accommodated by the gondola given its capacity. Figure 3 illustrates the costs versus revenue of the proposed gondola in the pessimistic perspective.

5.2. Scenario 2 — optimistic scenario

In the optimistic scenario, it is assumed 10% of Doha visitors will ride the gondola once. In other words, 290 000 riders for the first year is forecasted. As in the pessimistic scenario, it has been assumed that the ridership will increase steadily at the rate of 5% per year.

The rate of return in this scenario may reach 24% and the BCR will be approximately 2.44 (applying the conventional method of BCR and considering no disbenefit to the public or environment). Both indicators are promising and attractive to investors. It is estimated that by the year 2050 over 600 000 visitors will ride the gondola, which can be completely accommodated by the gondola given its capacity. Figure 4 shows the costs versus revenue of the proposed gondola for Scenario 2.

Fig. 4. Cost vs. revenue in scenario 2 (optimistic) for the proposed gondola.



6. Environmental analysis

Generally, aerial ropeway systems are considered a sustainable mode of transport given their relatively low emissions. This is because of the electric propulsion system used at their terminal and intermediary stations (if applicable), which brings about less pollution. Furthermore, aerial ropeway systems generate negligible noise along their route and therefore cause an insignificant disturbance. In fact, aerial ropeway systems are one of the quietest public transport systems.

For instance, the implementation of Medellín Cable Car in Colombia helps cut CO_2 emissions while improving sustainability in the region as well. At the local level, it was estimated that the cable car project could reduce 121 029 tonnes of CO_2 in the first 7 years of operation by reducing the usage of old buses, cars, and taxies and thus resulted in less emission (myclimate; The Climate Protection Partnership 2012). The project has resulted in greenhouse gas reductions too.

6.1. Preliminary environmental impact assessment (EIA) for the proposed Doha gondola

The preliminary EIA in this study deals with the identification, prediction, and qualitative evaluation of environmental impacts of the proposed gondola line at the two phases of construction and operation separately. It should be noted that the EIA in this study has been limited to the physical environment. Socio-economic, cultural, and biological environment impact assessments have not been taken into consideration because the neighborhoods of the proposed gondola line on both sides of Doha Bay are all well-developed urbanized areas. Furthermore, there are no religious, archeological heritage sites, or protected land(s) in the proposed area.

6.2. Construction phase

The EIA at the construction phase considers adverse impacts a well as beneficial impacts of constructing the proposed gondola line in Doha.

6.2.1. *Adverse impacts*

The gondola adverse impact is investigated from the following aspects:

- landslide;
- water pollution;
- waste;
- solid waste production;
- water pollution;
- noise pollution;
- air pollution;
- landuse pattern;
- spoil disposal;
- land erosion and slope stability; and
- impacts on the operation of recreational, cultural sites, and mosques.

6.2.2. *Beneficial impacts*

No tangible beneficial impacts are anticipated during the construction phase of the gondola line. Table 3 summarises the qualitative EIA of the proposed gondola during the construction phase.

As indicated before, the noise pollution generated by the construction site as well as construction wastes will have a considerable impact on the environment, although those impacts are temporary and will diminish following the completion of the gondola construction.

6.3. Operation phase

Like the EIA during the construction phase, the EIA at the operation phase considers adverse impacts a well as beneficial impacts of operating the proposed gondola line in Doha.

6.3.1. *Adverse impacts*

During this phase, the adverse impact is evaluated by looking into the following points:

- solid waste management;
- drainage management;
- water pollution;
- noise pollution; and
- air pollution.

6.3.2. *Beneficial impacts*

The beneficial impacts of operating the gondola are limited to

- Development of sustainable infrastructure with recreational and tourism purposes following the completion of the project.

Table 4 summarises the qualitative EIA of the proposed gondola at the operational phase.

Table 3. Qualitative EIA of the proposed gondola — construction stage.

EIA aspect	Impact area	Impact form	Range	Extent	Scale	Score
Landslide	Negligible	—	—	—	—	—
Water pollution	Direct impact area	Direct	Local (4)	Short term (2)	Moderate (4)	10
Wastes	Indirect impact	Direct	Site-specific (2)	Short term (2)	High (12)	16
Solid waste production	Direct impact	Direct	Site-specific (2)	Long term (4)	Moderate (4)	10
Water pollution	Direct impact	Indirect	Local (4)	Short term (2)	Moderate (4)	10
Noise pollution	Direct impact	Direct	Site-specific (2)	Short term (2)	High (12)	16
Air pollution	Direct impact	Direct	Local (4)	Short term (2)	Medium (4)	10
Land-use pattern	Direct impact	Direct	Site-specific (2)	Long term (4)	Low (2)	8
Spoil disposal	Indirect impact	Direct	Site-specific (2)	Short term (2)	Low (2)	6
Land erosion and slope stability	Negligible	—	—	—	—	—
Impacts on the operation of recreational, cultural sites and mosques	Direct impact	Direct	Site-specific (2)	Long term (4)	Moderate (4)	10

Table 4. Qualitative EIA of the proposed gondola — operational stage.

EIA aspect	Impact area	Impact form	Range	Extent	Scale	Score
Solid waste management	Direct impact	Direct	Local (4)	Long term (4)	Moderate (4)	12
Drainage management	Direct impact	Direct	Local (4)	Long term (4)	Moderate (4)	12
Water pollution	Indirect impact	Direct	Local (4)	Long term (4)	Low (2)	10
Noise pollution	Direct impact	Direct	Site-specific (2)	Long term (4)	Low (2)	8
Air pollution	Direct impact	Direct	Local (4)	Long term (4)	Low (2)	10
Development of a sustainable recreational infrastructure	Direct impact	Direct	Local (4)	Long term (4)	Moderate (4)	12

7. Conclusions and final remarks

This paper investigated the applicability of implementing an aerial ropeway system, also called a gondola, from a tourism point of view. The proposed gondola line flies over Doha Bay in Qatar and connects the two sides of the bay. Given the lack of adequate outdoor and natural attractions in the Gulf state, there is an opportunity for implementing an aerial cable car in Qatar. The proposed gondola flies over a non-built-up area that connects two sides of Al Corniche in Doha while providing a sea view to its riders.

From the economic point of view, the cable car associated expenses (i.e., O&M costs as well as capital costs) were estimated. Furthermore, the anticipated revenue for two different scenarios: (*i*) pessimistic ridership and (*ii*) optimistic ridership, were taken into consideration. An economic analysis was carried out by calculating the cash-flow, internal rate of return, and the BCR over a 30 year time window. The analysis outcomes in both aforementioned scenarios demonstrated that a gondola system in Doha could be an attractive, viable, and profitable investment in the long term, because the revenue generated from selling tickets as well as from other sources may outweigh the investment costs gradually, and thereafter the system would become profitable. Furthermore, a qualitative EIA was undertaken for both phases of construction and exploitation. The EIA showed promising results. Apart from noise pollution, and construction wastes during the construction stage, the other EIA measures were satisfactory and showed relatively low impacts and footprints on the environment.

The scope of the study may be extended by incorporating qualitative factors, such as convenience, accessibility, and business development indices. It should be mentioned that the feasibility study was conducted at the ex-ante stage based on ridership estimation in two defined scenarios. The actual ridership of the proposed gondola line plays an important role in evaluating the economic viability of the gondola because the estimated revenue directly depends on the ridership. Such ridership can be estimated based on a combination of revealed preference and stated preference survey results. The project's performance should be re-assessed at the ex-post stage following the gondola line implementation and operation and once again in the mid-term when better judgment and accurate figures in ridership, service performance, operating, and maintenance costs are available.

8. Management implications

This study can be considered as a decision support, marketing, and feasibility study tool for investors and government communications office to evaluate the viability of implementing emerging transit technologies, such as gondola and cable cars, as a recreational facility in countries having limited outdoor activities. The study quantitatively considers both (*i*) technological as well as (*ii*) marketing and economic points of view. Furthermore, the study is enriched with a qualitative EIA for construction as well as exploitation stages.

The study outcomes will be the basis for evaluating the potential benefits of the implementation of unmanned vehicle systems to encourage tourism and recreation for residents and visitors of cities with a lack of adequate outdoor and natural attractions, particularly located in the Gulf region. The case study is the booming city of Doha in the State of Qatar. The country will host the 2022 FIFA World Cup for the first time in the Middle East and aim to promote tourism and sporting events in the region.

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