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The transport capacity of a cable car system in public transportation

Klaus Erharter

Paul Abed

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0. Abstract

Using sustainable means of transport is a challenge that cities all over the world have to face. Here, the cable car can represent an ecologically and economically viable alternative. In order to meet this challenge, the cable car must be adapted to the needs of the local public transport system already in the planning phase.

Besides the selection of the cable car system itself, the most important planning parameter is the choice of the transport capacity of the installation. The choice of the transport capacity essentially determines the ecological and economic added value of the installation. It also determines its investment and maintenance costs as well as the acceptance of the cable car by the passengers.

A field report of the 10-passenger Ecatepec gondola lift in Mexico City, which has been in operation as an inner-city means of transport since the year 2016, will be prepared. Based on this field report, a simulation of the daily passenger flows and their impact on the required transport capacity is carried out. The possibilities of dynamic adjustment of the transport capacity to the passenger volume are analyzed.

A life cycle assessment according to ISO 14044 and ISO 14040 will be carried out for each of the different transport capacities in order to evaluate their ecological impact. Since the operation of a cable car over its service life contributes more than 90% to the life cycle assessment, these evaluations can provide valuable decision-making aids for the planning of cable cars in urban areas.

1. Statistics
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Urban cable cars have been in use for many years. However, they have not yet achieved a global breakthrough. Many city planners are still struggling with this innovative transportation system. This presentation aims to provide some basics on how an urban cable car can be optimally planned based on its most important performance parameter, the transport capacity.

Some statistics might be helpful to get an overview of the current global situation of urban cable cars.

The world map in fig. 1 shows how many urban aerial cable cars are installed per country. The installations built between 2004 and 2023 of the world's three largest cable car manufacturers were taken into account. Cable cars used purely for tourism are not included in this presentation. Cable cars with several sections are counted as one. It can clearly be seen that there is a focus on Central and South America. Urban cable cars have already been implemented in developing and emerging countries in particular and are often an elementary component of local public transport systems. In contrast, they are used less frequently in highly developed industrialized countries or very poor countries. A total of 60 urban aerial cable cars have been built in the past 20 years.

Fig 1: World map urban cable cars

The most important characteristics of urban cable cars were also analyzed. The first diagram in Fig. 2 shows the typical nominal speed. Most urban cable cars are operated at a speed between 5 and 6 m/s. Less than 10 % operate at a speed of more than 6 m/s. The nominal transport capacity is less than or equal to 3,000 passengers per hour and direction in 90% of cases. With regard to the number of cabins, almost half of the urban cable cars have fewer than 50 cabins. Nevertheless, there are a considerable number of installations with 150 or more cabins. Almost half of the installations are between 1,000 and 3,000 meters long, but some very impressive installations with a length of more than 5,000 meters have also been built.

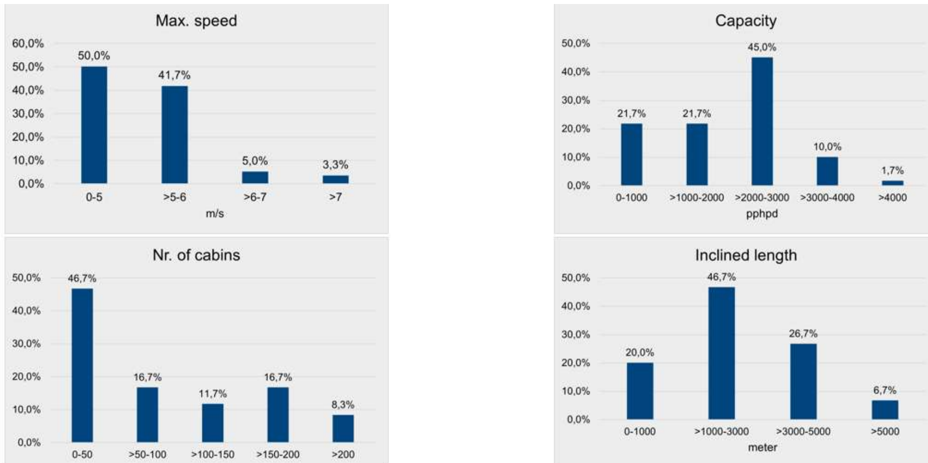


Fig 2: Statistics urban cable cars

2. Examined cable car system

Fig. 3 shows the line routing of the two urban cable cars Ecatepec Linea Roja e Linea Verde. The first line, Linea Roja, was built in 2016. The second line, Linea Verde, was inaugurated seven years later in March 2023. The second part of this presentation will provide more details about the technical and social context of the installations.

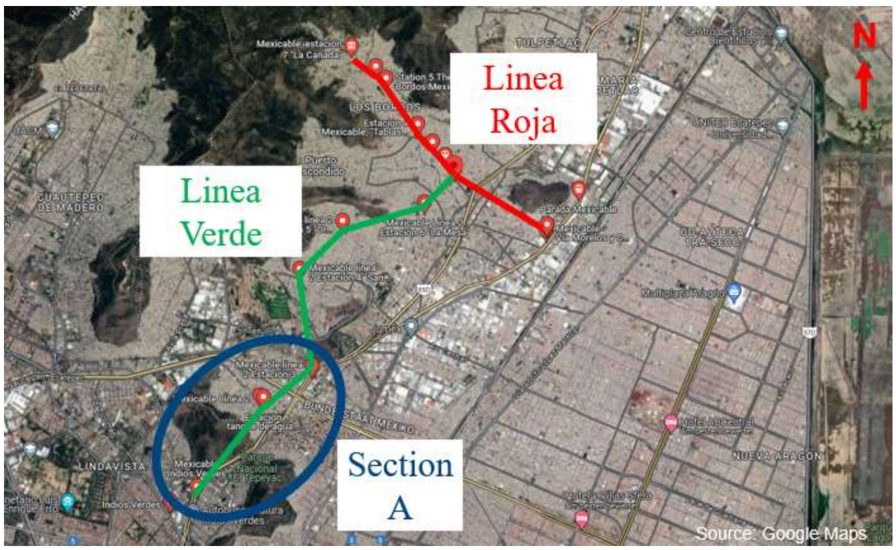


Fig 3: GD10 Ecatepec Linea Roja e Linea Verde

The following technical considerations were made on the basis of section A of the Linea Verde. This section consists of a 10-passenger gondola lift with a middle station with a nominal capacity of 3,000 pphpd and a nominal speed of 6 m/s.

Fig. 4: GD10 Ecatepec Linea Verde, section A

The diagram in fig. 5 shows, normalized to 100%, the distribution of the daily public transport demand for the Linea Verde. The diagram was created by analyzing the actual entries to the stations, which are registered by the operator via the access gates present at all stations.

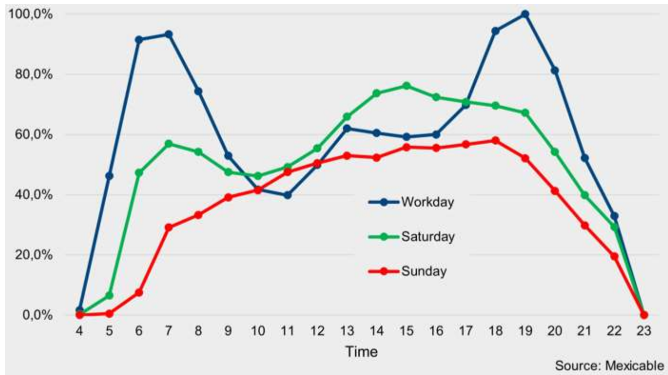


Fig. 5: Daily passenger distribution Ecatepec Linea Verde

The diagram is very interesting and could be of general application for urban cable cars connecting suburbs with transportation hubs in large cities.

- There is a first peak in the early morning when people move from home to their workplaces. A second peak is visible in the late afternoon when people go back home from work.

- There are significant differences between the working days and Saturday and Sunday. The transport demand is much more equilibrated and at a lower level in the weekends.

- The cable car transports 36,000 passengers per working day with an average availability of 99.88%. At peak times, there are waiting times of 5 – 10 min during which the cable car with a nominal capacity of 3,000 p/h reaches its limits. In practise, the capacity of the cable car is less than 3,000 as some cabins leave the first station empty at regular intervals to allow passengers to board the cabins at the following intermediate stations.

This practical experience gives a good indication of the number of passengers that could actually be transported by an urban cable car. Rule of thumb: 40,000 per day with a transport capacity of 3,000 per hour.

A very important aspect for a public transport system is its ecological footprint. The concept of the ecological footprint and the methodology for carrying out a life cycle assessment in accordance with ISO 14044 and ISO 14040 were already explained at the OITAF Congress 2017. The presentation is still available on the OITAF website.

- The Ecatepec Linea Verde ropeway transports 12.000.000 people per year
- A diesel bus line could also be operated instead of a ropeway
- Calculation tool (presented at OITAF congress 2017) can determine the CO_2 footprint over the service life of a ropeway of 35 years (complete Life Cycle Assessment according to ISO 14044 and ISO 14040)
- A CO_2 equivalent of 300 g CO_2/kWh is calculated for electricity production (Climate Transparency Report 2022). This value is reduced by 10 % every 10 years, as an increase in renewable energies is assumed
- The cable car pays for itself after just 1 year (from an environmental point of view)

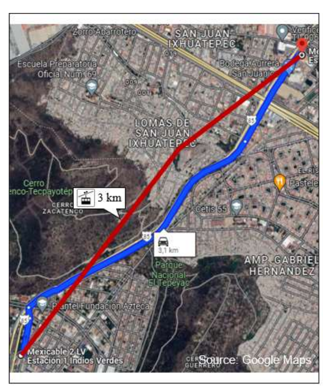
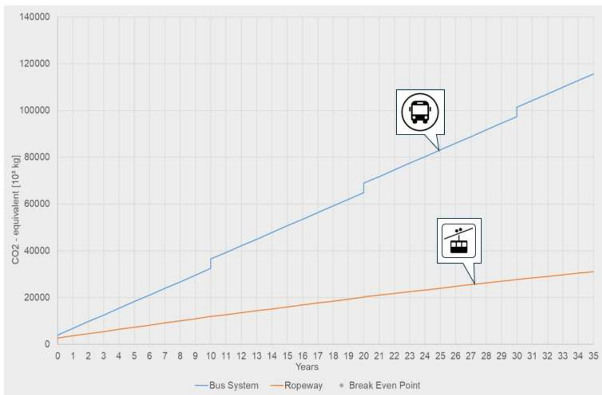


Fig. 6: LCA calculation hypotheses

Fig. 6 shows the route profile of the cable car in red and an alternative bus route in blue. The highway runs almost parallel to the cable car, so the length of the tracks is almost the same. The life cycle assessment provides a method for comparing the CO_2 emissions of the cable car and the bus over their entire service life using the “cradle-to-grave” approach. The most important emission factor for the cable car is its electrical energy consumption. According to the database “Climate Transparency Report 2022” an equivalent of 300 g CO_2 per kWh of electricity production is generated in Mexico. With this data and knowing the real transport volume of 12 million passengers per year, it is possible to compare the different means of transport according to a standardized method.



In 35 years of operation:

420.000.000 passengers

\- 84.000 t CO_2 (-72%)

$C0_2$eq = 24,5 g / p km

(p km = passenger kilometer)

Fig. 7: LCA comparison cable car – diesel bus

The result of the calculation over a service life of 35 years is shown in fig. 7. The cable car will transport 420 million passengers over a period of 35 years. The CO_2 savings amount to 84,000 tons or 72% less than the comparative bus system.

Fig. 8 shows a table from the British government of 2022 in which the CO_2 intensity of various means of transport is listed. The intensity is expressed in CO_2 equivalents emitted per passenger and per kilometer. Due to the excellent acceptance of the Ecatepec LV cable car and the right choice of the nominal transport capacity, the carbon footprint of 24.5 g CO_2 / p km is almost unrivalled.

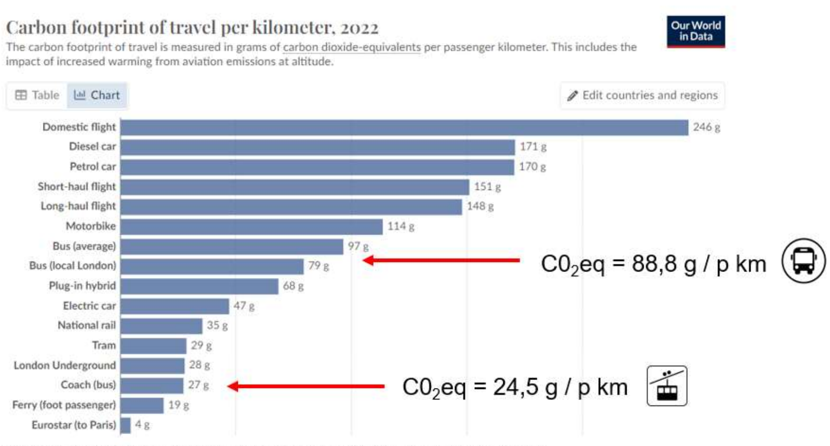


Fig. 8: Carbon footprint of travel per passenger kilometer

3. Measures to increase efficiency during periods of low-capacity utilization

A cable car is designed for a nominal capacity at a nominal speed. In this configuration, all cabins are fully loaded in one direction and empty in the other. The Ecatepec Linea Verde, for example, has a nominal power of 491 kW. At low capacity - with only partially occupied cabins - the power consumption of the system remains high, not even 10 % of the energy consumption depends on the capacity utilization (Fig. 9).

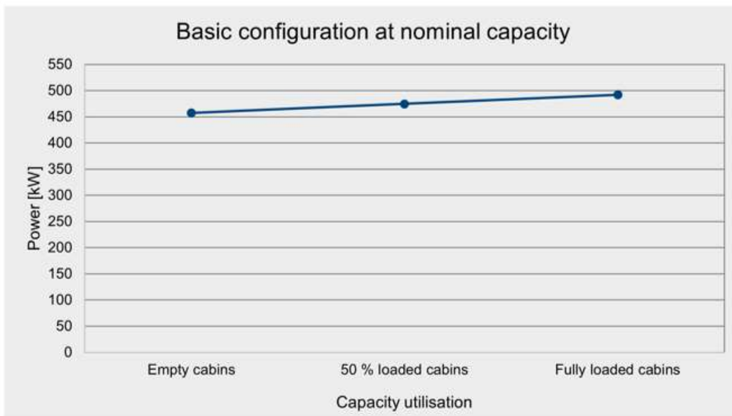


Fig. 9: Power vs. capacity utilization

A strategy for reducing the energy consumption of a cable car could be to reduce the number of cabins in periods of low frequency by removing them from the line through fast gates and parking them in the garage (Fig. 10). This must be done during passenger transport, is technically demanding and has only a limited impact on energy consumption. On the other hand, an oversized installation with too many circulating cabins is not energy efficient.

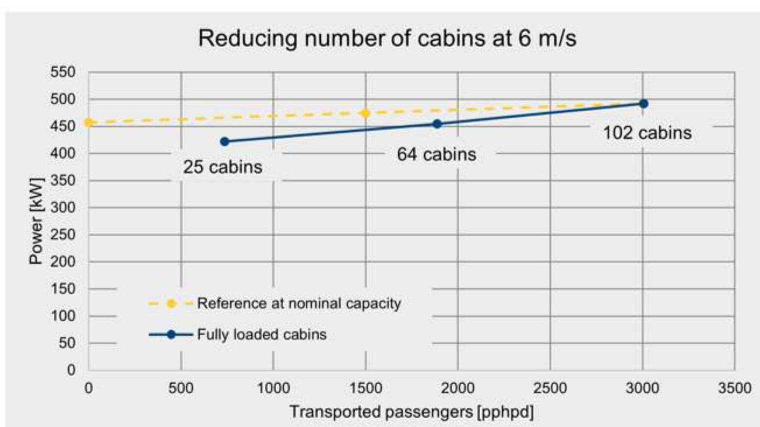


Fig. 10: Power vs. number of cabins

The simplest and best strategy for reducing the energy consumption is to reduce speed in periods of low frequency (Fig. 11). This has a major impact on energy consumption at the expense of increased travel time. There are already systems available that automatically adjust the installation speed to the actual passenger volume.

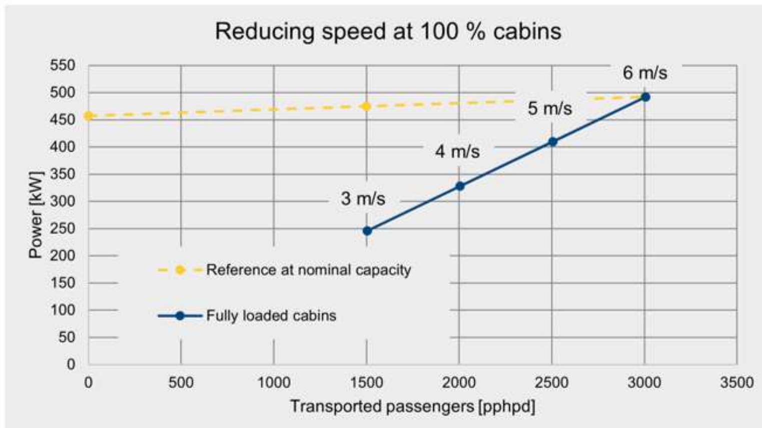


Fig. 11: Power vs. speed

These strategies could be combined obtaining the performance map of the cable car (Fig. 12). All capacity and power combinations within the rhombus can be achieved. The limits of this performance map are given by the minimum permissible speed and number of cabins.

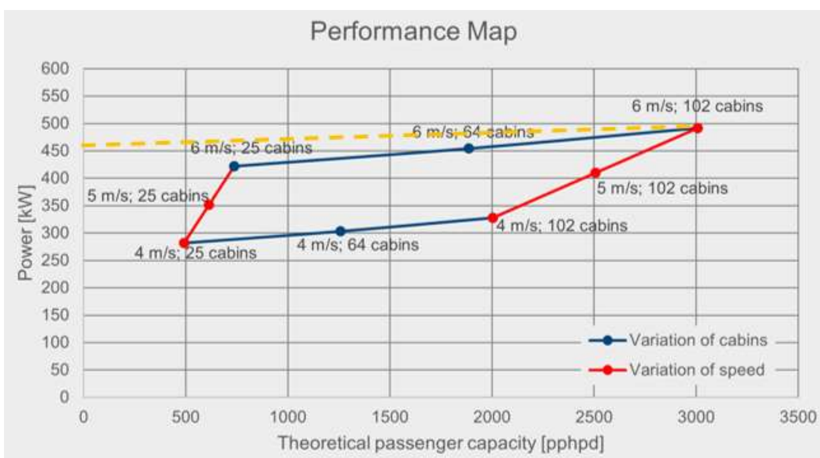


Fig. 12: Performance map Ecatepec LV

Example (Fig. 13):

The actual passenger volume of Ecatepec is 1,500 p/h. In that case, the power consumption of the installation will be around 475 kW instead of the 491 kW at the nominal capacity of 3,000 p/h. By removing 50% of the cabins from the line, the power consumption could be reduced to 445 kW. By reducing the speed to 4 m/s and removing 25% of the cabins, the power consumption drops to 312 kW which is the minimum that can be achieved. Other configurations between 312 kW and 475 kW are also possible, the difference between the extreme values is around 34%.

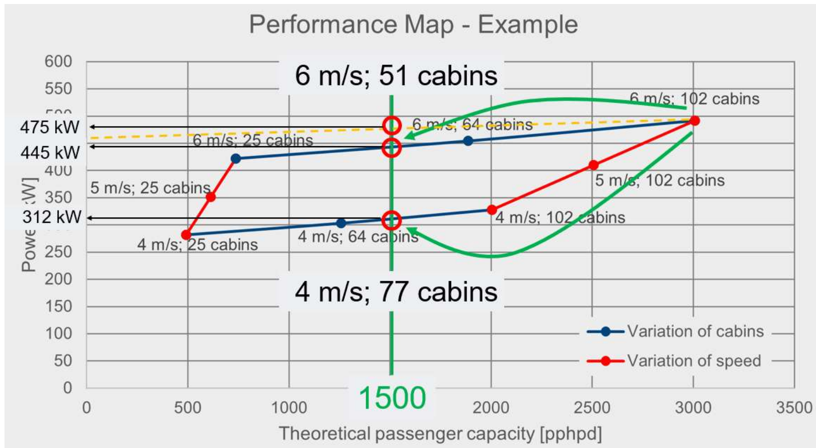


Fig. 13 (animated): Example of utilization performance map

4. Comparison between alternative configurations

The Ecatepec Linea Verde installation was designed for a capacity of 3,000 pphpd at a nominal speed of 6 m/s. This basic configuration was compared with 5 alternative configurations, which are shown in fig. 14.

	Basic Configuration (Ecatepec LV-A)	Config. 1	Config. 2	Config. 3	Config. 4	Config. 5
	6 m/s	7 m/s	6 m/s	7 m/s	7 m/s	7 m/s
	3.000 pphpd	3.000 pphpd	4.000 pphpd	4.000 pphpd	5.000 pphpd	6.500 pphpd

Fig. 14: Alternative configurations

The range of application of these theoretical configurations is shown in fig. 15. The higher the nominal capacity, the bigger the working area becomes. The power consumption increases obviously, but at higher nominal capacity there is a margin of optimization in periods of lower capacity demand by reducing speed and number of cabins of the installation. Therefore, an installation with a higher nominal capacity could have a lower power consumption than an installation with lower nominal capacity (example shown in Fig. 15a).

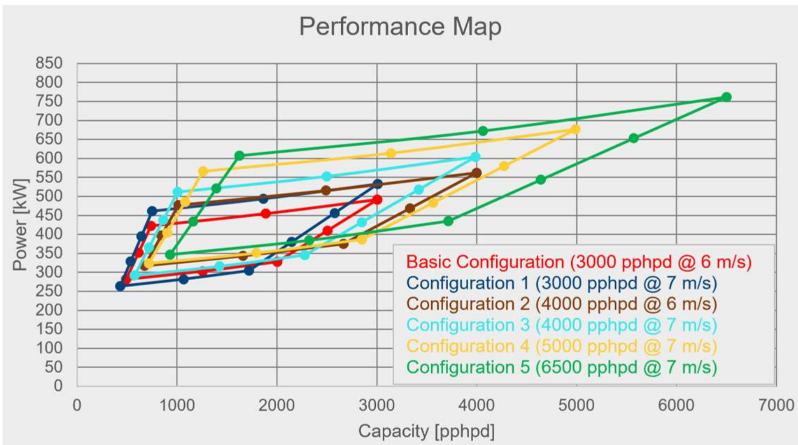


Fig. 15: Performance map alternative configurations

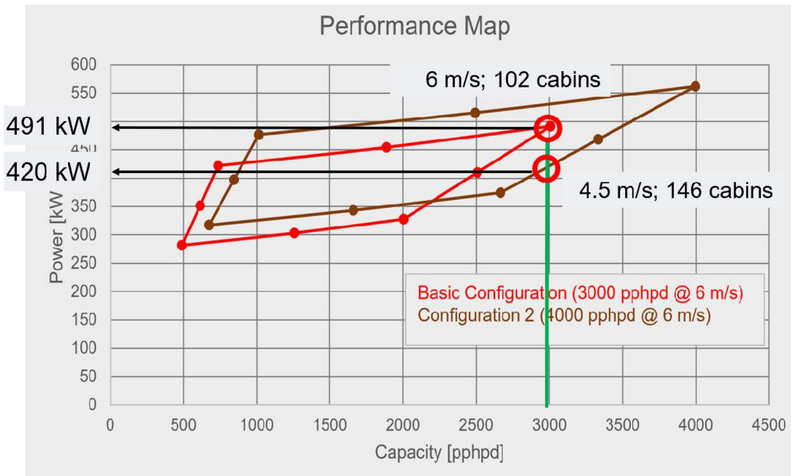


Fig. 15a (animated): Example of performance map interpretation

A higher nominal capacity naturally also requires larger stations. Increasing the capacity by increasing the speed requires longer acceleration and deceleration lengths. An increase in the number of cabins means that the distances between the vehicles become smaller and therefore boarding must be restricted to the straight part of the station. This is because the vehicle speed in the station has to be increased and the rear part of the station can no longer be used for boarding (boarding speed too high).

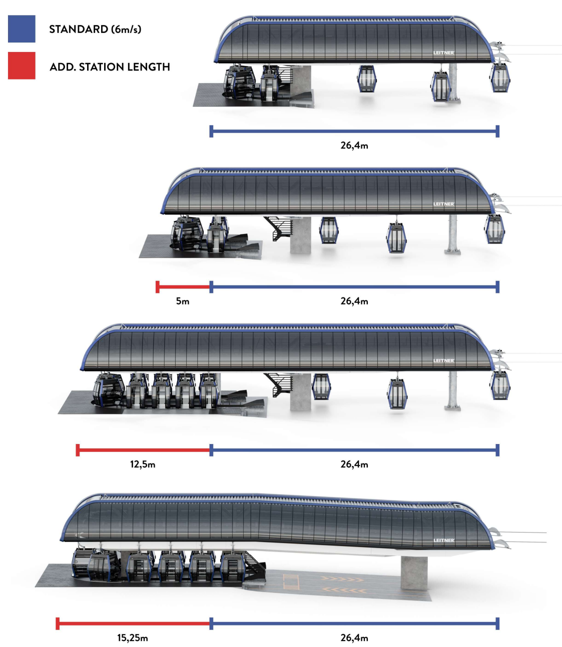


Fig 16 (animated): Station length of alternative configurations

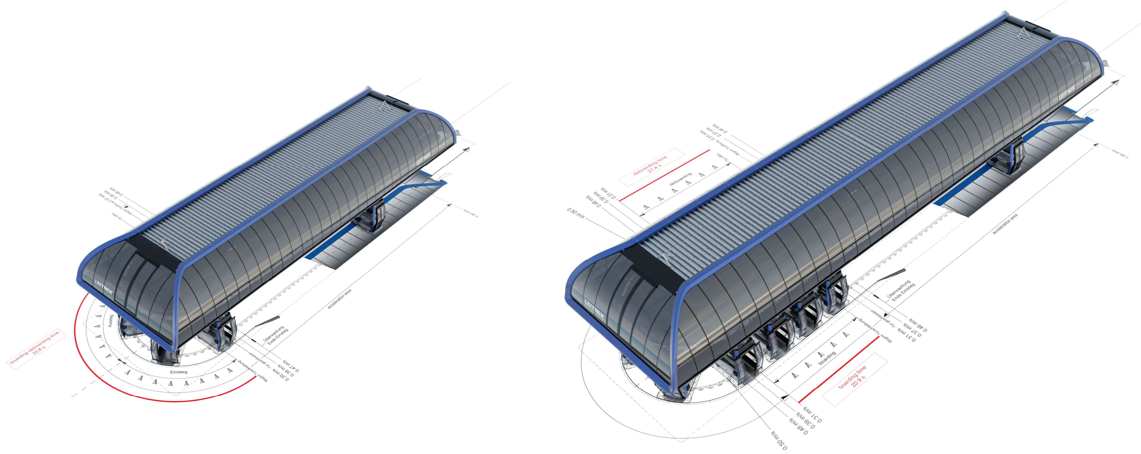


Fig. 16a: Boarding area with low capacity (left) and with high capacity (right)

The investment costs increase more slowly than the capacity. However, from a certain capacity - here for configuration 5 - there is a sharp increase due to a change in technology (16-32 passenger cabins, bicable systems). Fig. 17 gives a comparison of the total investment cost based on the Ecatepec LV installation.

	Basic Configuration (Ecatepec LV-A)	Config. 1	Config. 2	Config. 3	Config. 4	Config. 5
	6 m/s	7 m/s	6 m/s	7 m/s	7 m/s	7 m/s
	3.000 pphpd	3.000 pphpd	4.000 pphpd	4.000 pphpd	5.000 pphpd	6.500 pphpd
$	100%	102%	124%	118%	132%	185%

Fig. 17: Investment cost alternative configurations

As the transport capacity increases, not only the investment costs rise, but also the life cycle costs. Fig. 18 shows the number of towers and line rollers, the number of vehicles and the total station length of an installation with one middle station. All these numbers influence the time and cost for maintenance and inspection. For example, the number of line rollers varies from 384 in the basic configuration to 596 in configuration 5. Considering the long operating time of urban installations, the maintenance of line components has a major influence on the ease of maintenance of the entire system.

Fig. 19 shows the impact of the transport capacity on the ecological footprint of the installation Ecatepec LV. These data are closely related to the annual passenger volume of 12 million in the application under investigation. For example, the carbon footprint per passenger kilometer varies from an excellent 24.5 g to a still good 35.5 g.

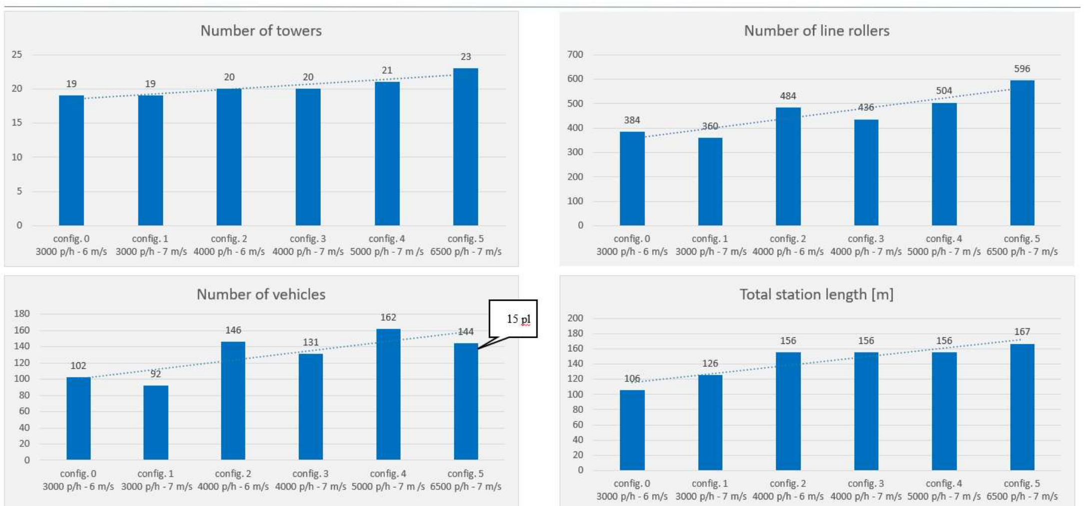


Fig. 18: Factors influencing the life cycle costs

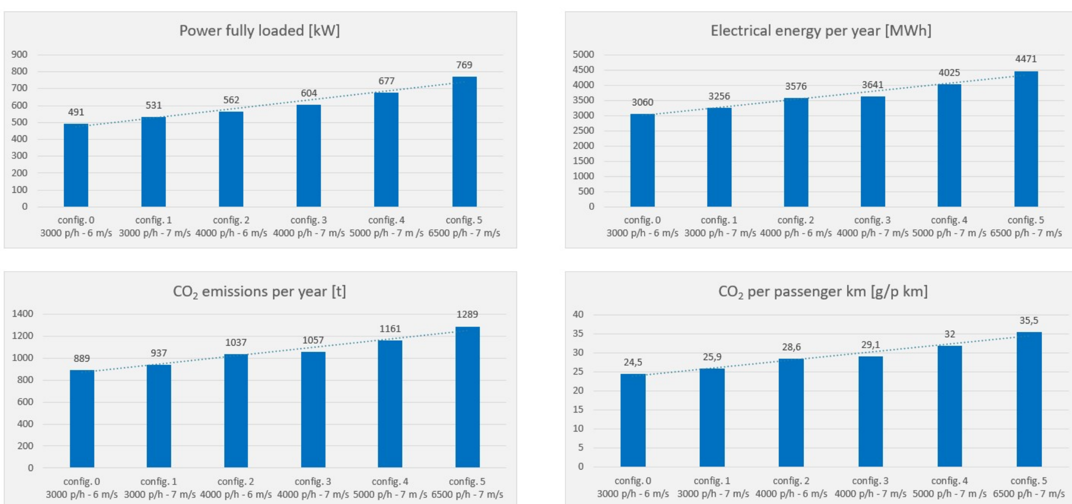


Fig. 19: Factors influencing the ecological footprint

5. Summary

The Ecatepec Linea Verde installation is a best-practice example of an urban cable car. Some important findings are:

- A daily passenger flow up to 36,000 – 40,000 could be realized with an installation designed for a capacity of 3,000 pphpd
- A yearly passenger flow up to 12 – 15 million could be realized with an installation designed for a capacity of 3,000 pphpd
- There are two peak periods where 100% of the capacity is needed. A limited waiting time could be accepted during rush hours (7 min is observed at the Ecatepec installation)
- The reduction of the speed in periods with lower passenger flow is advisable with a reduction of energy consumption and CO_2 emissions of 15-20% by reducing from 6 m/s to 5 m/s. A reduction in the number of cabins is only advisable if the number of passengers is highly variable over the entire year.
- The carbon footprint of travel per passenger kilometer of 24.5 g is almost unrivalled.

And finally, some general recommendations for the planning of urban cable cars are:

- Cable cars are infrastructure-driven means of transport. The real utilization rate has a minor influence on investment cost and lifecycle costs
- A precise analysis of the expected traffic flows is highly recommended
- Undersizing leads to long waiting times and is almost impossible to rectify
- Oversizing leads to high investment and operating costs and to a higher carbon footprint
- Slight oversizing ensures a margin for future higher traffic volumes
- It is advisable to create this margin by designing the installation for a higher number of vehicles and not for a higher nominal speed.