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Olympic Games 2026: New Integrated and Sustainable Connections from Milano to Livigno

ELECTRIC SYSTEMS FOR MOBILITY

Group 5

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Abstract: In view of the Milan-Cortina 2026 Winter Olympic Games, the project aims at improving connections and introducing infrastructure facilities in the Lombardy region, by the creation of two sustainable mobility hubs, principally regarding public means of transport, respectively in Bormio and Livigno and a vertiport in Milano Linate. The project includes a new electric railway line from Tirano to Bormio, from where an electric bus shuttle service and an eVTOL aircraft service that will make direct connections from Milano to Bormio and from Bormio to Livigno.

This mobility system is organized to meet the expected increase in transport demand by promoting environmentally friendly and efficient solutions. The decision to extend the railway to Bormio aims to offer a fast, reliable and low-emission alternative to the often-congested road network. From Bormio's mobility hub, spectators can choose either to take electric buses that will ensure fluid connections to Livigno or for the additional eVTOL taxis, an innovative solution particularly thought for flexible and fast mobility. This integrated system not only supports the logistics of the Olympics but also creates a sustainable transport model for the region that can be, without any doubt, exploited even in the future.

Key-words: Olympic Games, Mobility Hub, Modal Shift, Sustainable Development

1. Introduction

The Valtellina is a mountainous area located in the north of the Lombardy region of Italy. It corresponds to the Adda river basin, which rises in this territory and flows into Lake Como, before progressing into the Pianura Padana and flowing into the Po River further down the Lombardy region.
The area is home to approximately 150.000 people and the major city and provincial capital is Sondrio; other notable localities are Tirano, Morbegno, Aprica, Grosio, Teglio, Sondalo, Bormio and Livigno [1].

Bormio and Livigno are important touristic locations very well known for their skiing structures that, according to Visa's *Travel Insights Newsletter* of February 2018 [2], are ranked 10*th* in the list of the top 25 global winter ski destinations. Not surprisingly, they will be two of the places where some competitions of the Milano – Cortina Winter Olympic Games will take place in 2026: Bormio will be hosting the SkiMo - Ski Mountaineering - races and the men's Alpine Skiing on the Stelvio slope, while Livigno will be hosting freestyle and snowboard competitions. This important event stands as a vital chance to improve transport infrastructures as well as enhance sustainable mobility in Northern Italy [2].

The purpose of the project is, indeed, the development of a completely sustainable way to improve the existing connections from Milano to Bormio and Livigno with "green" means of transportation, like electric trains, e-buses and eVTOL aircrafts, in order to exploit the high potential of this areas and create mobility hubs with the related significant benefits in a long-term perspective for the region. Better linking will attract tourists, enhance the local economy and support development in crucial areas like Valtellina [3].

2. State of the art

2.1 The connection nowadays

2.1.1 Railway

Currently the area is served by the following railway lines operated by Trenord [Figure 1], the local railway company in the Lombardy region:

- **RegioExpress RE8** Tirano-Sondrio-Lecco-Milano: this line connects Milan Central Station to Tirano, with 10 intermediate stops, so only in the principal towns. Journey time is approximately 2h and 30 minutes. Frequency is approximately every hour.
- **Regionale R12** Sondrio-Tirano: this line connects Sondrio to Tirano and stops at every station in between. Journey time is approximately 40 minutes. Frequency is lower: there are only 9 trains daily.
- **Regionale R13** Lecco-Colico-Sondrio: this line connects Lecco to Sondrio and stops at every station in between. Journey time is approximately 2 hours. Frequency is almost every hour.

In Colico, passengers can transfer to the Lecco-Colico-Chiavenna line.

Figure 1: Actual Railway Lines

2.1.2 Roads

The upper part of the Valtellina area, so northward from Tirano, is not served by the railway. Regarding private vehicle options, the following road communications are present: SS38 "Stelvio National Road", which provides a direct link with characteristics of a fast-flowing suburban motorway and the provincial road SP27, which follows the ancient route passing through all the towns along the way. Depending on traffic levels, which can be very intense during weekends due to tourist flows, travel time between Tirano and Bormio ranges from 30 minutes to 1 hour or even more during peak traffic times. Following the SS301 from Bormio, the journey to the town of Livigno takes almost 50 minutes.
A bus service, operated by "Perego" company, is active in the Alta Valtellina. Specifically, line A070 connects Tirano to Bormio, with a travel time of approximately 1 hour. Considering the fact this line has multiple stops at every town, no direct connection is available between Tirano's station and Bormio. The same company also connects Bormio to Livigno in 1h 10min with the line A072, operated with diesel buses.

2.2 The connection in the future

Lecco-Tirano railway currently requires a general upgrading in order to improve the performance, particularly in terms of line capacity and travel times. Bormio will be an important destination for the "Milan-Cortina 2026" Olympic Games and, for this reason, works have recently been made to improve accessibility, both by road and by rail. In fact, the line faced closure from June 10th, 2024 to September 8th, 2024. The co-financed interventions between RFI and Regione Lombardia within the framework of the convention on the development and enhancement of singletrack lines in the Valtellina and Valchiavenna envisage a new PRG for the improvement of the crossing section in Bellano, a new PRG for the improvement of the crossing section in Ponte in Valtellina and a new service location (crossing point) in Dubino. Additionally, there are plans for enhancement interventions at 4 more stations, elimination of some level crossings and accessibility improvements at the stations [4][5].

3. The proposal

The project aims to extend the existing railway from Tirano to Bormio. From Bormio, where there will be a Mobility Hub[1], an electric shuttle bus service will connect the new train station to Livigno. Not only there will be a bus service from Bormio to Livigno but even, as an alternative option, an eVTOL aircraft service between the two mountainous locations and between Milano and Bormio. The outcome of these infrastructure projects will serve as a green and fast mode of transportation for athletes and spectators of the 2026 Olympics and will bring long-term benefits to the whole Valtellina area.

3.1 Train

3.1.1 Train Route

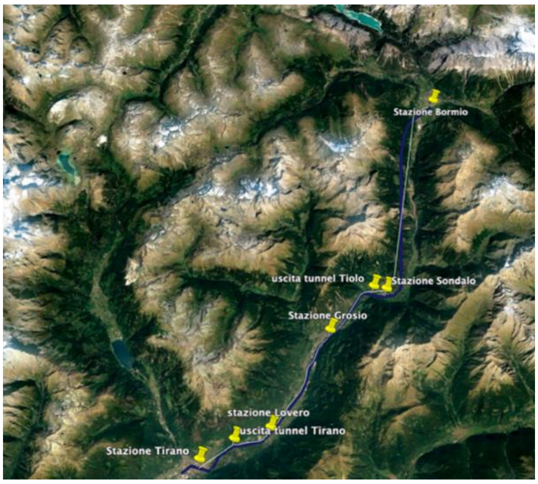

Figure 2: Railway Extension

[1] "A Mobility Hub is a recognisable place with an offer of different and connected transport modes supplemented with enhanced facilities and information features to both attract and benefit the traveller" - *CoMoUK definition*

The Tirano-Bormio train route is 37,3 km long and operates in two ways: the first as an extension of the RE8 RegioExpress, considering a direct line without stops, the second as an extension of the R12 line considering Lovero, Grosio and Sondalo as intermediate stations [Figure 5]. Normally the train frequency is 120 min, but given the Olympic situation and the influx of visitors, we assumed a train frequency to be every 45 min.

3.1.2 Technical Characteristics of the Railway Line

The line, considering the three portions Lecco-Sondrio, Sondrio-Tirano and Tirano-Bormio is in total 156 km long and presents the standard gauge of 1435 mm, electrified at 3 kV DC. The infrastructure is currently managed by Rete Ferroviaria Italiana (RFI). Speed limits range from 135 km/h to 65 km/h in the tightest sections. The line ascends from 211 m at Lecco to 299 m at Sondrio, to 437 m at Tirano, with an average gradient of 5 and a maximum gradient of 25; the minimum radius of curves is 250 meters. Despite being a significant achievement at its conception, today the line shows the signs of aging, both in terms of the track itself and its commercial speed.

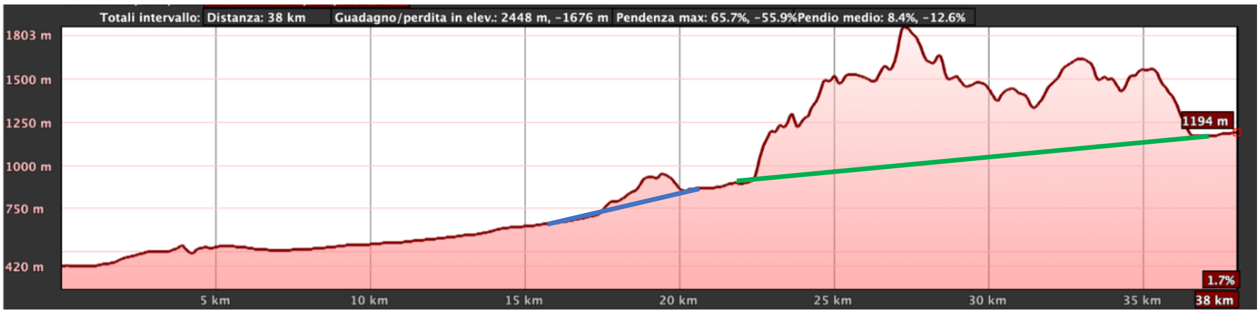

Figure 3: Tirano – Bormio Altimetric Plan

The route begins just before Tirano station, traverses the town of Tirano via a tunnel approximately 4,4 km in length and reaches the first station along the route, Lovero. From there, it continues through a relatively flat area with a constant slope until reaching Grosio station, a town of approximately 4300 inhabitants. Subsequently, the territory becomes more rugged as the valley narrows, requiring the construction of the *Tiolo tunnel* to achieve a suitable slope (blue line in [Figure 3]). Emerging from this area, the railway enters the Sondalo plain, where another station serves the town, which has around 4000 inhabitants and is home to the most important hospital in the Valtellina region. Moving beyond this area, a tunnel becomes necessary to traverse the narrow valley carved by the Adda river. The *Bormio tunnel* is the longest and most expensive segment of the route, spanning approximately 14 km (green line in [Figure 3]). Finally, the route arrives at Bormio, with the station located near the ski facilities. It is necessary to fix a constant slope in the sections that include the *Tiolo* and *Bormio tunnels*, as Google Earth Pro does not recognize these sections as tunnels.

3.2 e-bus

3.2.1 e-bus Route

Figure 4: e-bus Path

Concerning the shuttle bus situation, there will be an intensification of the existing line with an e-bus that will take visitors to their destinations making a single stop at Isolaccia (Valdidentro municipality) to have a more direct journey to the desired place [Figure 4]. The estimation is to have a bus every 30 min, in accordance with charging times and availability of the fleet.

[Datasheet *Timetable* on e-bus Excel file]

3.2.2 Technical Characteristics of the Bus Line

Starting from Bormio and reaching Livigno, the path is 36 km long in total and follows the SS301 road. The strong presence of many tight curves and hairpin bends brings the speed limits range from 50 km/h to 15 km/h in the narrowest and steepest sections. The line ascends from 1194 m at Bormio to 1819 m at Livigno, with a height difference of 620 m. The route is constantly uphill, except for a few sections and the slope varies from 23% to -15%, with an average value of 6.3% [Figure 5].

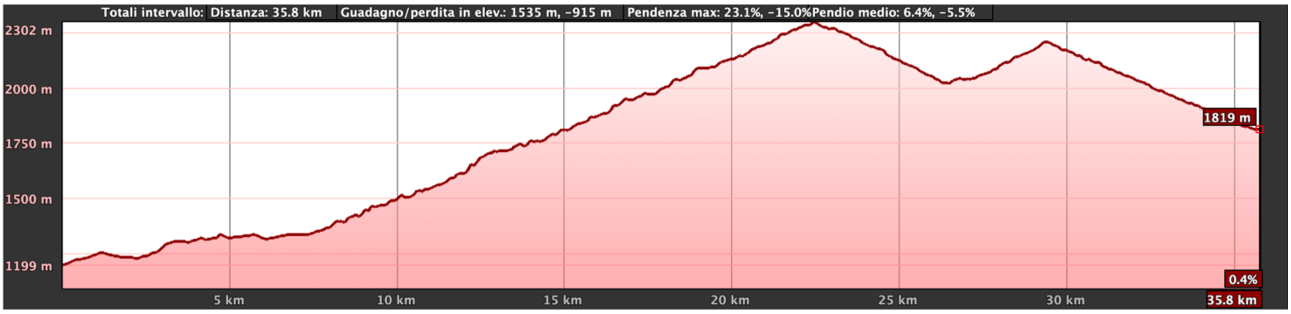

Figure 5: Bormio – Livigno Altimetric Plan

4. Technical Characteristics

4.1 Means of Transport

4.1.1 Train

The line is the natural extension of the Milan - Tirano route and for this reason it will maintain the same power supply characteristics. The factors determining the size of the electrical infrastructure must include the following points, which all impact power absorption:

- Altitude and layout characteristics of the line.
- Speed of trains traversing the section.
- Location of stations and stops.
- Number of trains passing through the route.
- Type of rolling stock operating on the line.

On the line Sondrio-Tirano, the last TPSS is located in Villa di Tirano [6]. Considering that in DC traction, TPSSs need to be installed every 15-20km, it is necessary to construct new Traction Power Substation (TPSS) at Lovero and Sondalo with a configuration of 2x5.4 MW. Fixed structures dedicated to supplying power to the railway line are identified, as much as possible, in areas of minimal environmental impact, close to urbanized areas and in accordance with the power supply needs of the contact line and service structures. These structures will be connected to the Medium Voltage line. The locations proposed for the TPSS meet these requirements [6]. For the contact line, considering the average traffic level, a nominal voltage of 3 kV DC is planned, with a total section of 440 mm^2 (including 2 shaped contact wires of 100 mm^2 each and 2 support ropes of 120 mm^2 each in copper) [7].

Currently, the service is carried out by Trenord's *Donizetti* train. It's an electric multiple unit (EMU) train built in Savigliano by Alstom Ferroviaria, belonging to the Coradia Stream family, intended for regional railway services. It's a single-deck electric train, with 3 (ETR 103) or 4 carriages (ETR 104/204), powered by 4 traction motors, operating on a 3kV DC power supply. In its longest configuration, the train can accommodate up to 509 people and multiple trains can be coupled together in multiple-unit operation. The spacious carriages offer ample seating areas for the typical medium distance journeys of regional and interregional services [8]. [Datasheet *ETR 104* on train Excel file]

4.1.2 e-bus

Nowadays, the Bormio-Livigno line is carried out by diesel buses. The idea, in order to have a completely green solution, is the introduction of BYD C9 e-buses to substitute the higher polluting old buses. They fit perfectly all the needs, in terms of comfort and capacity of passengers, for a suburban line with only 1 stop offering up to 49 seats [9]. [Datasheet *BYD_C9_TechSpecs* on e-bus Excel file]

It's a reasonable expectation to have 12 e-buses running on the line: the main depot will be the one in Bormio at the new sheltered bus station, just outside the new train station. It will be equipped with 4 *ABB Terra 184 HC* charging stations, able to recharge up to 2 buses each at the same time (during their inactive periods) in DC mode. The maximum power supplied from one single unit is 180kW in DC mode (90kW in case of 2 buses charging together) and 22kW in AC mode. Here it is shown how to obtain the approximate time necessary for a typical charge of the e-bus trip from 50% (162 kWh) to 75% (243 kWh) with a fast DC charging mode using *1 ABB Terra 184 HC* unit [10]:

$$Approximate\ Time\ required\ to\ charge\ 1\ bus = \frac{75\%\ battery\ capacity - 50\%\ battery\ capacity}{Power\ supplied\ to\ 1\ bus\ (DC)} = \frac{81\ kWh}{180\ kW} = 27\ min$$

$$Approximate\ Time\ required\ to\ charge\ 2\ bus = \frac{75\%\ battery\ capacity - 50\%\ battery\ capacity}{Power\ supplied\ to\ each\ of\ the\ 2\ buses\ (DC)} = \frac{81\ kWh}{90\ kW} = 54\ min$$

In Livigno, the plan is to offer 2 charging stations with the same characteristics. Anyway, for this kind of solution, it's very important to have covered bus station in Livigno too in order to mitigate the challenges posed by harsh winter conditions. Another very important thing to be considered is, indeed, the implementation of de-icing systems on the e-buses to ensure operational reliability to contain the risk of battery failure. The high estimated auxiliary power necessary of 40 kW is, indeed, the consequence of de-icing and air conditioning systems, constantly working on board the bus [11][12]. [Datasheet *BYD_C9* on e-bus Excel file]

5. Alternative Connection

In the 2024 Paris Olympics, the use of electric vertical take-off and landing (eVTOL) air taxis was planned as a sustainable transportation solution. These innovative vehicles possess several advantageous characteristics. Firstly, eVTOL air taxis have the capacity to reduce travel time significantly by facilitating direct movement to their destinations rather than being constrained by ground infrastructure. Additionally, eVTOL aircraft produce far less noise pollution compared to helicopters, making them more suitable for urban environments. Furthermore, their all-electric design eliminates direct carbon emissions from the vehicles, thereby contributing to environmental sustainability.
Finally, the on-demand nature of eVTOL air taxis provides passengers with greater flexibility compared to conventional modes of transportation.

Figure 6: eVTOL Air Taxis

The reason why the integration of eVTOL technology into the Paris Olympics did not take place was due to regulatory and infrastructure challenges that had not been fully addressed in time for the games. The potential of using this new mode of transportation remains promising at future events, such as the upcoming 2026 Milan Winter Olympics [13].

Although air mobility is a revolutionary mode of transportation, there are many aspects to be considered. As first step, by analyzing operative full electric airplanes and considering their characteristics inclusive of range, number of passengers, battery capacity, cruise altitude and infrastructure needed including charging facility, Joby S4 from Joby aviation has been chosen.

5.1 Safety

Safety is the most important concern that should be resolved. Electric vertical takeoff and landing air taxis are designed to have a high degree of automation, including autonomous flight. Joby air taxi can take off, navigate and land autonomously without human intervention. Also, the aircraft's performance is being constantly monitored, and adjustments are made as needed. Furthermore, aircraft can detect and avoid obstacles. While the aircraft can fly autonomously, Joby's air taxis will have a human pilot on board who can take control of the aircraft if necessary. The pilot serves as a backup and can intervene in case of emergencies or unexpected situations. As a result, this system helps to reduce human error's risk and guarantee reliable and more efficient performance [14].

5.2 Mission Design and Geographical Analysis

To define mission specifications a geographical analysis is necessary to determine the appropriate cruise altitude, as well as to ensure that the cruise and descent rates are suitable considering the regional characteristics. Height map below of operational region for Milan-Bormio route and Bormio-Livigno route reveals that cruise altitude from takeoff point in Milan-Bormio route should be higher than 1200 meters and cruise altitude from takeoff point in Bormio-Livigno route should be higher than 600 meters [15].

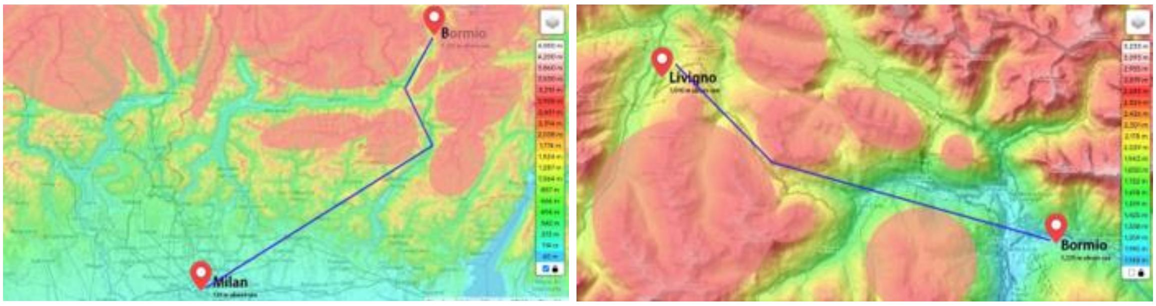

Figure 7: Planimetry Maps for eVTOL

Since the descent phase consumes little power, which can be neglected, routes with higher energy consumption are chosen. Calculation of energy consumption is discussed in [Datasheet *eVTOL Energy Consumption* in eVTOL excel file]. As a result, mission profiles for each route are presented below.

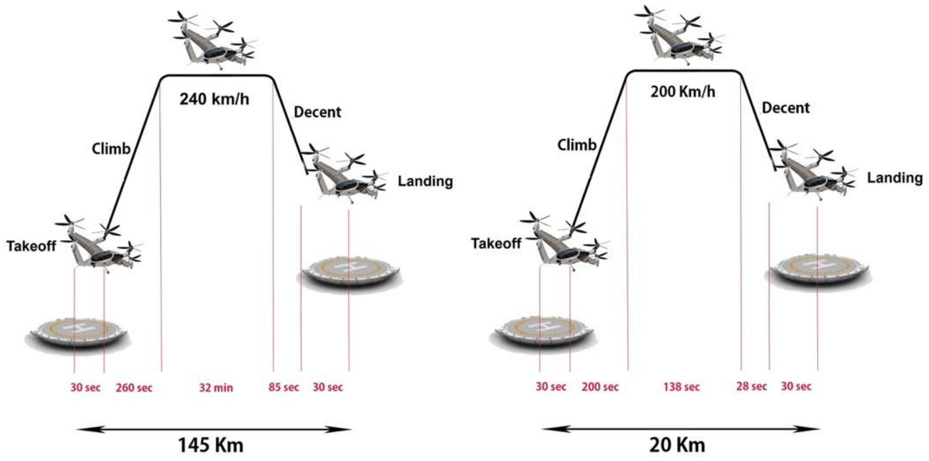

Figure 8: eVTOL Mission Profiles

For Milan-Bormio route 104 kWh and for Bormio-Livigno 36 kWh energy is needed. The optimal range for lithium-ion battery usage is approximately between 20% to 80% charge, as this minimizes stress and extends battery lifespan. The energy consumption charts for each mission are shown in the figures below. It is also assumed that the initial battery charge for both missions is at 85%.

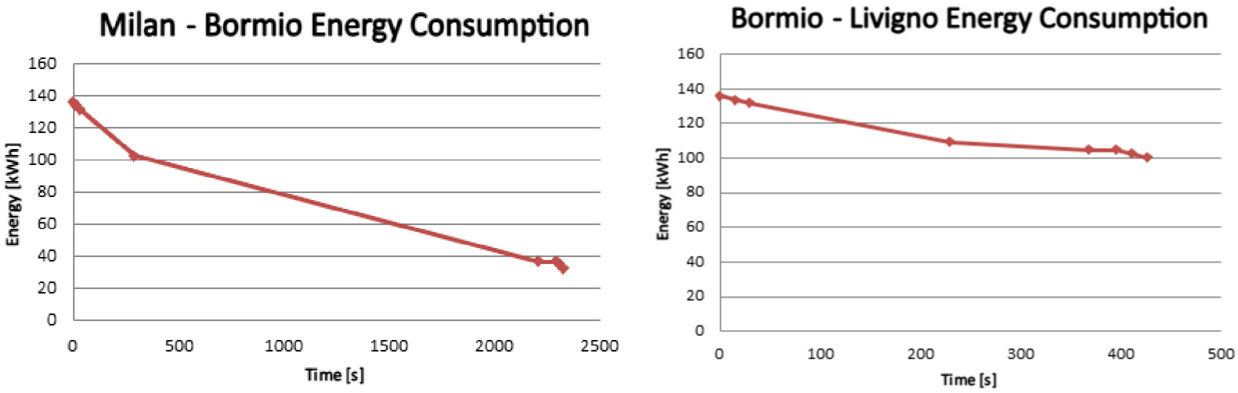

Figure 9: eVTOL Energy Consumption One Way Trip

It is planned to charge either in Milan or Bormio mobility hub. For each trip from Milan to Bormio or reverse the batteries need to recharge, considering that the consumption will be equal to 65% of the capacity of the battery. For Bormio to Livigno roundtrip instead batteries need to recharge only once when the aircraft is back in Bormio mobility hub, having a lower consumption equal, for the roundtrip to 40%. To reduce infrastructure' financial expenses, we can use the same kind of e-bus charging station facilities in Bormio, having 4 extra units of *ABB Terra 184 HC* in Bormio:

$$Time\ required\ to\ charge\ (Milano \rightarrow Bormio)\ = \frac{85\%\ battery\ capacity - 20\%\ battery\ capacity}{Power\ supplied\ (DC)} = \frac{104\ kWh}{180\ kW} = 35\ min$$

$$Time\ required\ to\ charge\ (Bormio \leftrightarrow Livigno) = \frac{85\%\ battery\ capacity - 40\%\ battery\ capacity}{Power\ supplied\ (DC)} = \frac{72\ kWh}{180\ kW} = 24\ \text{min}$$

Considering 5 minutes for passengers boarding or off boarding and operating hours between 6 AM and 7 PM, there will be 15 trips for each eVTOL. Considering 15 airplanes as the operational fleet, a total of 900 passengers will be transported throughout the day. [Datasheet *Timetable* on e-VTOL Excel file]

5.3 Technical Characteristics

Selected air taxi uses lithium-ion batteries that are optimized for high energy density, rapid charging and long cycle life includes built-in thermal management, redundancy and advanced monitoring systems. The air taxis require charging stations capable of quickly charging the aircraft's batteries. This company has developed its own special charging infrastructure to support the Joby S4 eVTOL aircraft. These charging stations can deliver extremely fast charging rates, with the ability to recharge the batteries in 15-30 minutes. Typically, these charging stations are rated at 150-350 kW DC to provide the necessary charge rates. The charging stations feature advanced battery management and safety systems for secure charging. The charging stations are designed to be easily deployed at vertiports, heliports or other urban mobility hubs. In addition to the fixed charging stations, also mobile charging units are developed that can be transported to remote locations or used as temporary charging solutions. These mobile charging stations are designed to be rapidly deployed and can be powered by local grid connections. With fleet rotation, each temporary charging station with 4 charging places could support more than 15 airplanes.

6. Infrastructures: Bormio and Livigno Mobility Hubs

After exiting *Bormio tunnel,* the railway arrives at Bormio station, which serves as the terminus of the railway. Here, the railway reaches its highest altitude on the route, at 1195 meters. This area is relatively flat, making it suitable for the construction of the station. Due to its size, it offers the necessary space to accommodate a modern and sustainable infrastructure, ensuring areas dedicated to parking electric vehicles, waiting and interchange between public transport vehicles, especially during major events such as the Milan-Cortina 2026 Winter Olympics. The project provides the creation, in the area in [Figure 10], of an integrated hub in Bormio including the electric train as the main mode of connection between Tirano and Bormio with its new station, an electric bus shuttle system with a covered station and charging stations to continue the journey to Livigno and a vertiport for electric vertical take-off and landing aircraft (eVTOL). The energy to the hub is supplied with the already existent current lines and also collected from the nearby hydroelectric power plant of Grosio.

For Livigno, there is, in [Figure 11], the selected area for the construction of the electric bus terminus equipped with DC charging stations with, next to it, a dedicated space for the landing and departure of electric planes (eVTOL). Regarding energy supply, the hub will count on a solution with a direct connection to Bormio station, from which again, part of the energy produced in Grosio and the rest of the required electric power will be transmitted via a reinforced distribution line. This combined system will ensure a stable and sustainable energy supply, reducing environmental impact and promoting operational efficiency.

A new contract has been signed between SEA Milan Airports and Skyports to build vertiports at Milan for the 2026 Milan Cortina Olympics. Linate Airport vertiport will be used for eVTOLs to charge. The vertiport will have four charging pads, ensuring efficient energy supply for electric aircraft during the event. It will not serve as a mobility hub but will play a crucial role in supporting the use of eVTOLs for logistics and transport during the Olympics [16].

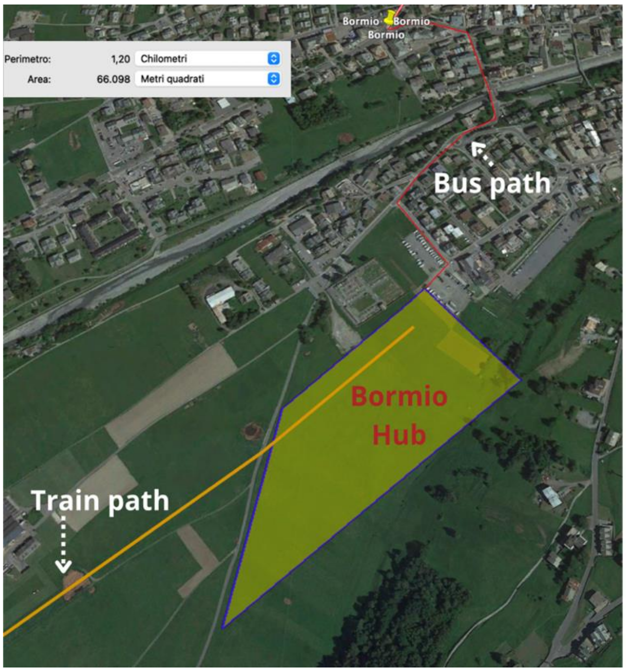

Figure 10: Bormio Hub

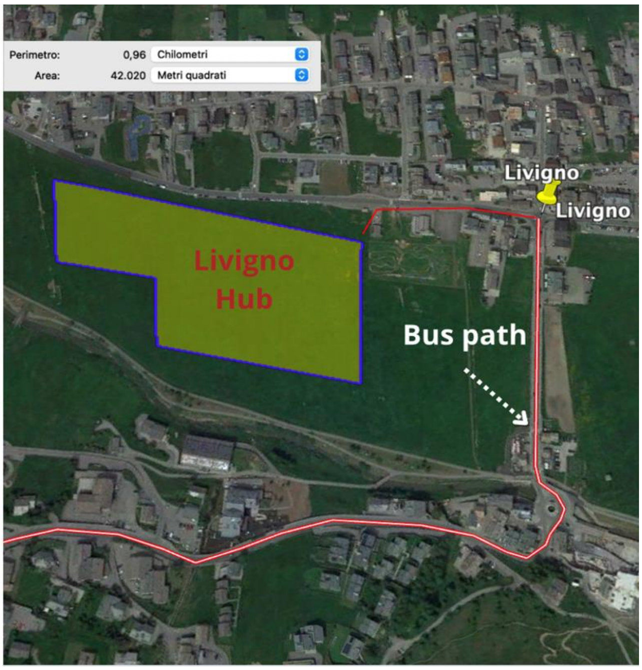

Figure 11: Livigno Hub

7. Performance Analysis

To evaluate the performance of the new bus and train lines it is important to deal with different aspects from geographical to kinetics, dynamic and electrical. Microsoft Excel is very useful to process data and to design, model and evaluate the project: after the creation of specific sheets to show all relevant aspects, it was possible to represent key features (KPI) through graphs.

The initial part of the simulation is dedicated to collect some geographical information of the path. There are therefore considered, in the file, some important features:

- Stops: starting from the station of Tirano, the plan is to add three stations (Lovero, Grosio and Sondalo), before reaching Bormio. The e-bus instead departs from Bormio station and arrives in Livigno, assuming to have one stop in the municipality of Valdidentro at Isolaccia.
- Slopes: to determine the slope of each segment along the rail and bus line, the tools offered by Google Earth Pro were exploited. This involved visualizing the paths on the map and examining its elevation profile. The total length of the rail line is equal to 37,3 km and the e-bus line is equal to 36 km. Slope variations were captured every 0,5 km interval with the average value computed.
- Curvatures: another crucial consideration involves identifying and measuring all the curves along the line. This task was facilitated again by Google Earth, making possible to point out the curves in the path and measure their radius and distance from the nearest station. This information was compiled into a comprehensive table, adding a formula for calculating the maximum speed for the train and slowing down the bus manually by imposing a negative acceleration when approaching each curve.

7.1 Diagrams

In this section, all the technical information sourced from the datasheet of the vehicles are incorporated, adding coefficients and constant physical quantities. Subsequently, after inserting the path calculus table with different columns, these results were obtained.

7.1.1 Train Results [Datasheet *Regional Stops* on train Excel file]

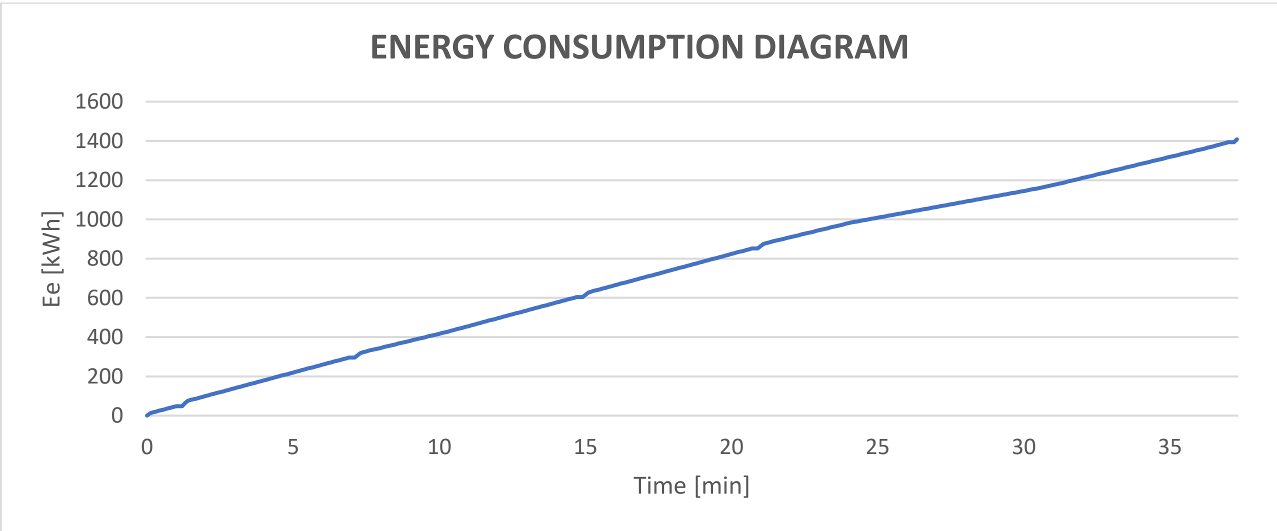

Figure 12: Train Energy Consumption Graph

From the electrical energy consumption graph, it’s clearly visible the monotonic increasing trend with some constant part corresponding to the time in which our train is still in the station to load or unload the passengers. There are also some parts where the trend is slightly descendent; that can be related to the cruising phase or to some descendant slope. The total energy consumption for one ride along the track is slightly over than 1400 kWh [Figure 12].

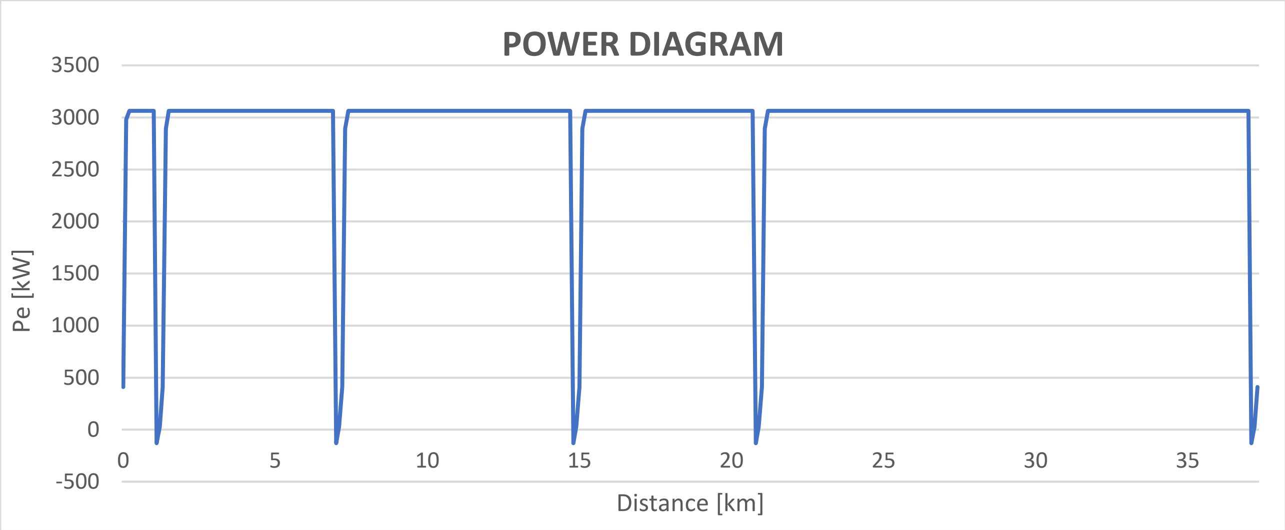

Figure 13: Train Power Request Graph

Analyzing the power graph, a characteristic peak trend can be observed. The descending segment corresponds to the braking phase, then quickly rises again on the tractive phase, followed by a constant portion associated with the cruising phase. After that, a sudden decrease in power can be seen, reflecting the fact that only the auxiliary systems are powered during the braking phase [Figure 13].

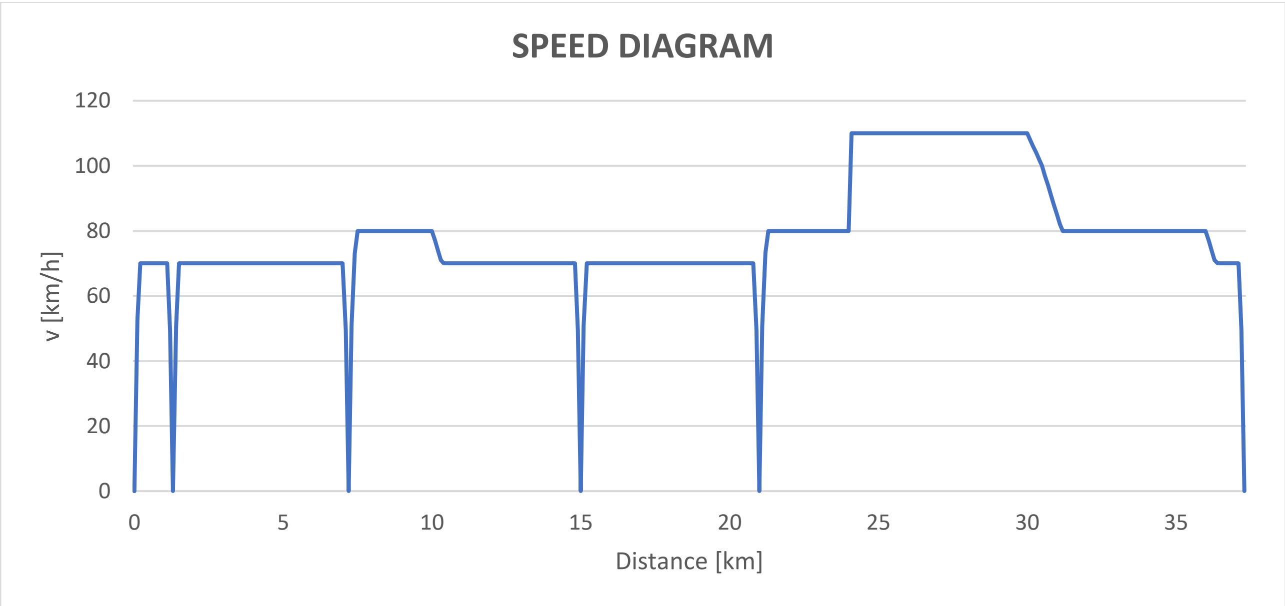

Figure 14: Train Speed and Distance Graph

The speed diagram acts as a complement to the previous ones, accentuating the variations between successive traction phases along the route and indicating the speed limits for each track segment. The graph shows a typical cycle of acceleration, cruise and braking. During acceleration, speed increases rapidly until it stabilizes in the cruise phase. Abrupt reductions represent the braking phases for stops. The cumulative distance increases linearly over time, reflecting the movement of the train on a route with regular stops [Figure 14].

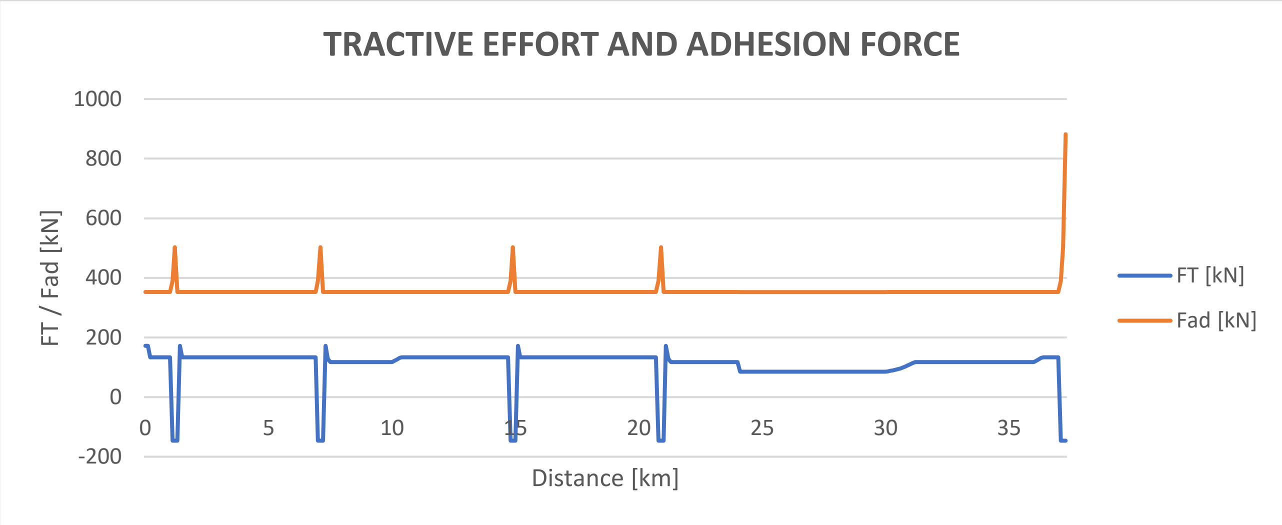

Figure 15: Tractive Effort and Adhesion Force Diagram

The Tractive Effort-Adhesion diagram emphasizes the approach to traction, cruising and braking phases. Notably, distinct constant segments within the graph highlight the transitional phases. These include the phases operated below the base speed, resulting in constant traction at a specific value. Additionally, there are phases of constant speed cruising where traction equals resistances, and braking phases where tractive effort remains constant. It's essential to observe that the tractive effort diagram consistently remains below the adhesion diagram because it proves that there is not the phenomenon of slippage [Figure 15].

7.1.2 e-bus Results [Datasheet *Simulation* on e-bus Excel file]

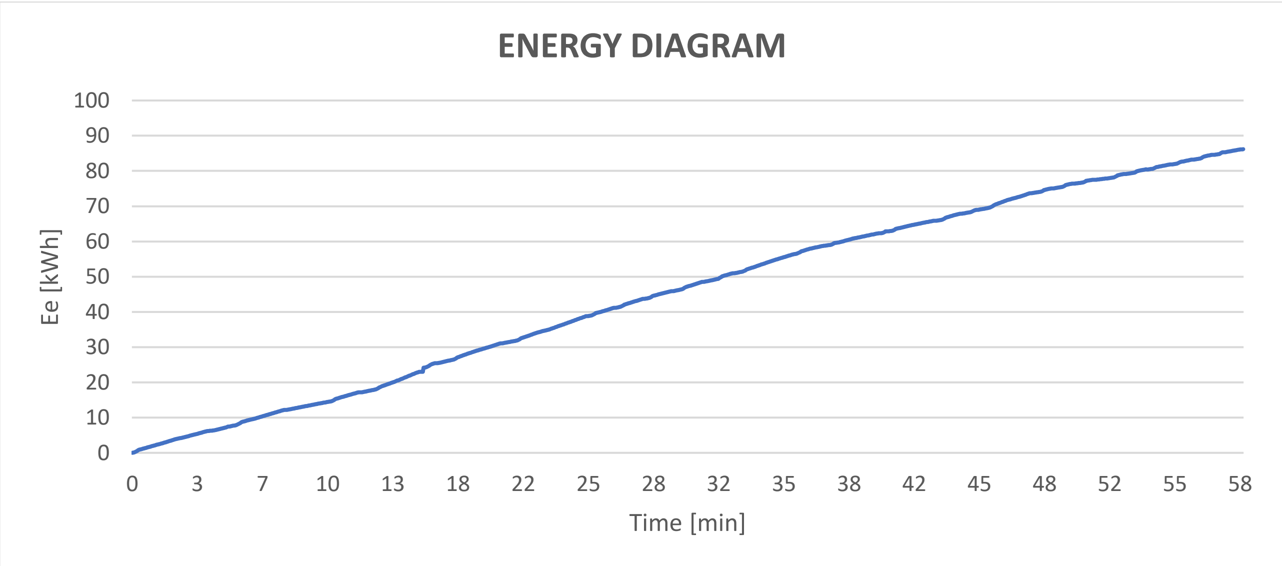

Figure 16: e-BUS Energy Diagram

The graph shows the trend of the energy consumed by the electric bus over the time. The energy increases linearly and continuously over the period of the journey (about 58 minutes), illustrating a constant consumption due to the regular operation of the vehicle. This trend is attributable to efficient energy management by the system, with no sudden peaks or significant drops. The constant gradient shows that energy consumption remains stable despite variations in route or driving. It's not immediate to see from the graph but, in the breaking phase, the bus is recovering some energy due to regenerative breaking effect and the line becomes descent for these short periods [Figure 16].

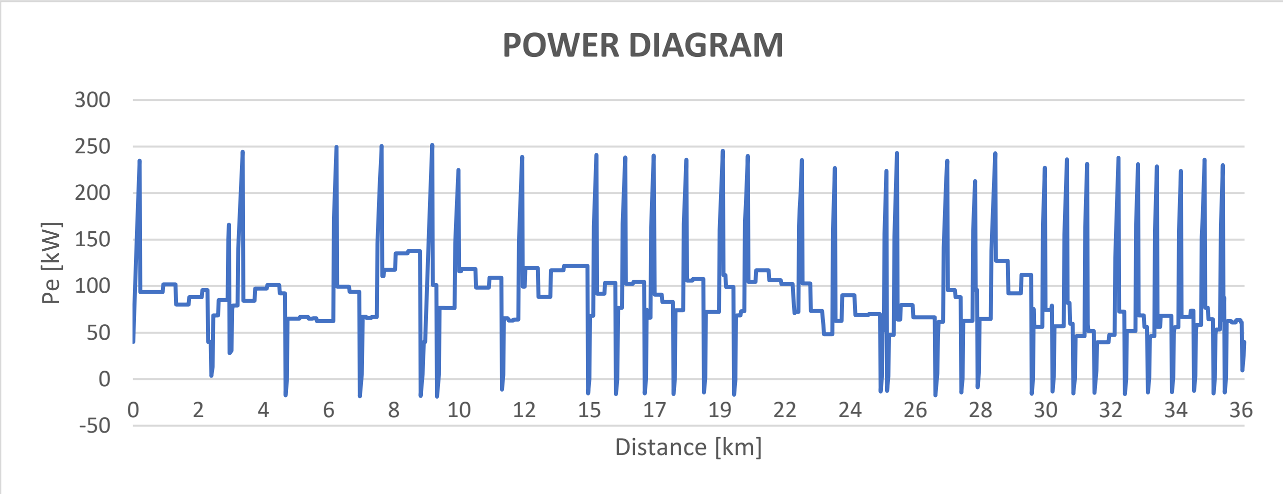

Figure 17: e-bus Power Diagram

The graph represents the trend of instantaneous power used by the electric bus as a function of time. Power consumption is highly variable, with numerous peaks that can be attributed to sudden requests for acceleration or changes in the route [Datasheet *Slopes&CR* on e-bus Excel file]. Power values fluctuate between high peaks (over 200 kW) and phases of low or almost zero consumption, due to regenerative braking, deceleration or stopping periods [Figure 17].

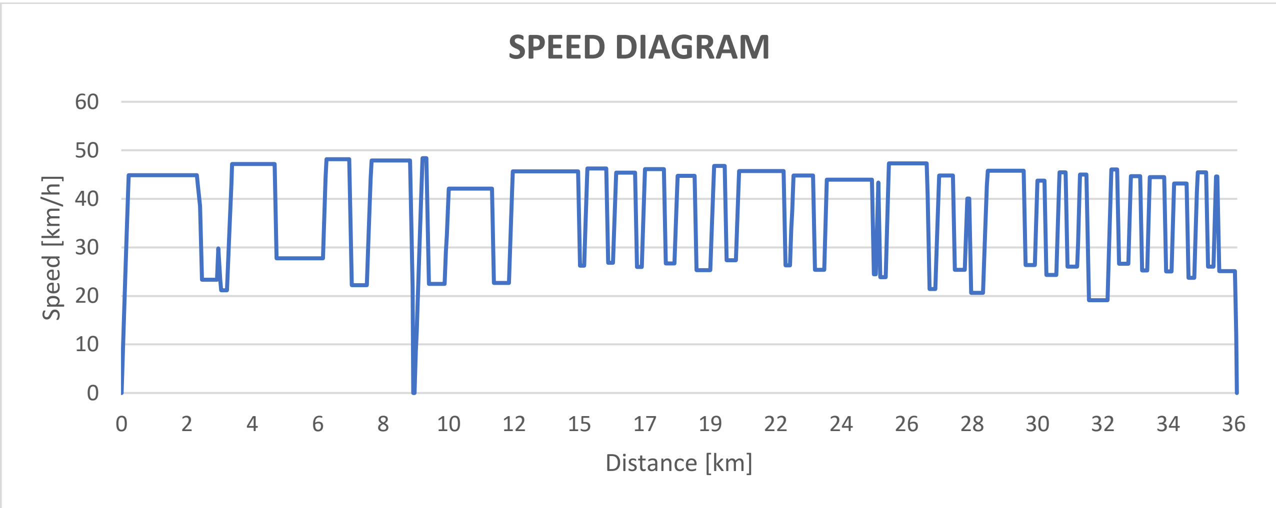

Figure 18: e-bus Speed Diagram

In the graph above [Figure 18], it's possible to see the different speed of the bus along the line: in particular, because of the high number of curves, the e-bus needs to slow down at a speed typically lower than 30 km/h [Datasheet *Slopes&CR* on e-bus Excel file]. The speed goes to zero only at the point of the bus stop in Isolaccia. It was reasonably assumed to input the accelerating phase equal to 0,7 m/s^2 and the braking phase equal to -0,9 m/s^2. Finally, to make the speed diagram for the bus even more realistic, the speed of the bus varies within different values, always < 50 km/h, during the 'cruising' phases.

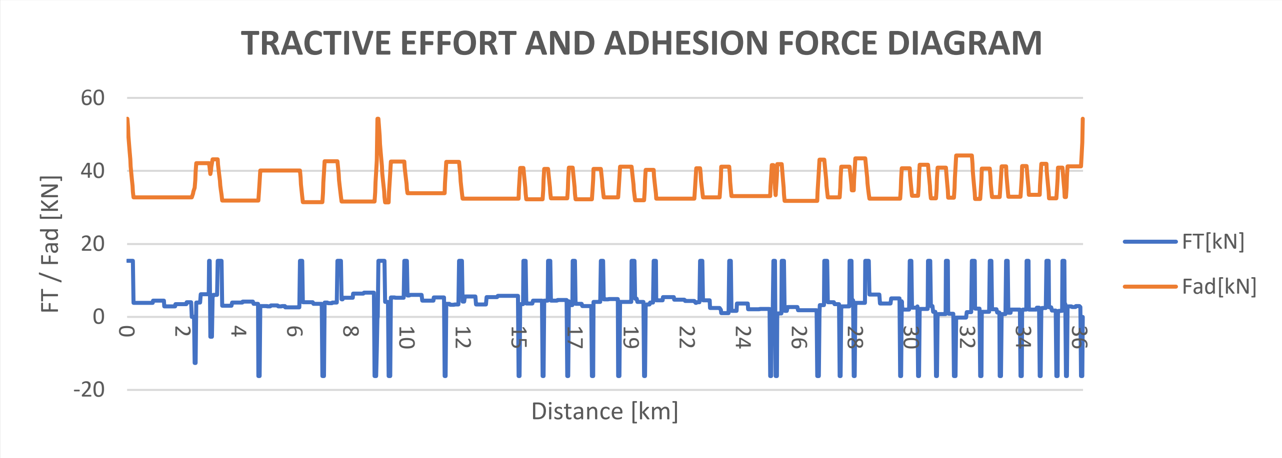

Figure 19: Traction Effort and Adhesion Force Diagram

In [Figure 19], tractive effort is shown compared to adhesion force: this graph was made with the purpose of being sure to avoid slipping effects. Indeed, the blue line (traction effort) is always below the orange line (adhesion force). As the previous graph, for the e-bus there is a more complex situation than with the train, mainly because there is road path instead of rails, where the speed can be more easily constant.

8. Conclusions

The project proposed could be an important opportunity to develop a completely green solution for connections in Valtellina from many points of view. First of all, the extension of the current train line will enhance regional connectivity, making it easier for residents, spectators of the Olympic Games and tourists to access the interested zones. Moreover, to cover 37,3 km of our route we estimated 29 minutes for the direct train option and 37 minutes for the alternative. Notably, both train options offer travel times that are competitive with the current available options on the path between Tirano and Bormio, whether private or public.

Secondly, once in Bormio the electric shuttle bus offers a very nice solution for many people to go to Livigno. In particular, the e-bus route, with a travel time of 58 minutes and 36 km in length with only one stop in Isolaccia, is designed to benefit visitors travelling to Livigno.

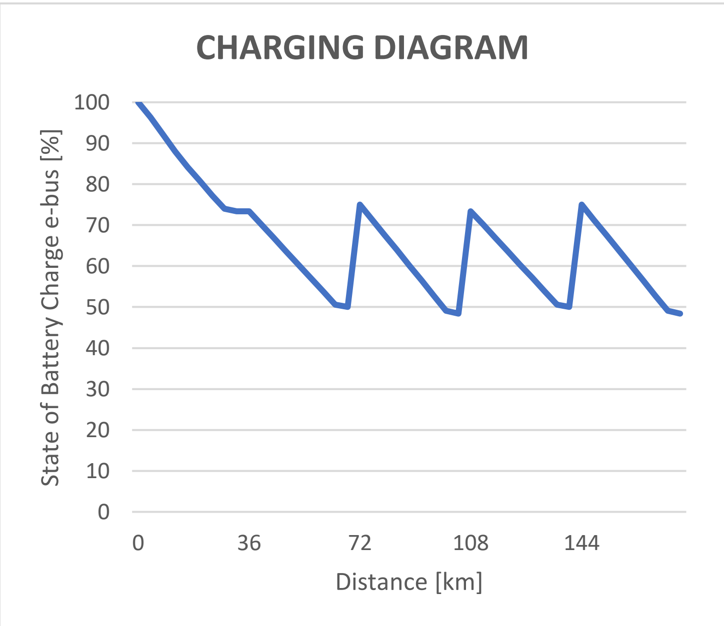

Figure 20: e-bus Charging Diagram

As it is possible to see in the graph on the left [Figure 20], the buses can run the whole day with a typical charge of 27 minutes every trip after the first round-trip [Figure 21]. A one-way trip from Bormio to Livigno has an estimated consumption of 27% [Figure 22], that is quite high for the short path but reasonable, considering the high ascent of the road (+600 metres). We expect the bus consumes less (~23%) on the opposite way (back to Bormio), thanks to regenerative braking in descent. With the charge mentioned above of 27 minutes, the e-bus can recover up to 25% of the capacity of the battery thanks to the 180kW DC charge available both in the terminal of Bormio and Livigno [Datasheet *Charing Diagram* on e-bus Excel file].

BUS 1A												
BORMIO		LIVIGNO					LIVIGNO		BORMIO			
First Roundtrip												
Time	SoC	Time	SoC	Charge	New SoC	→	Time	SoC	Time	SoC	Charge	New SoC
07:00	100%	08:00	73%	/	/		08:00	73%	09:00	50%	27min (180kW DC)	75%
Second Roundtrip												
Time	SoC	Time	SoC	Charge	New SoC	→	Time	SoC	Time	SoC	Charge	New SoC
09:30	75%	10:30	48%	27min (180kW DC)	73%		11:00	73%	12:00	50%	27min (180kW DC)	75%

Figure 21: Extract of a typical timetable (for more, see the Excel sheet of e-bus – "Timetable_BormioLivigno")

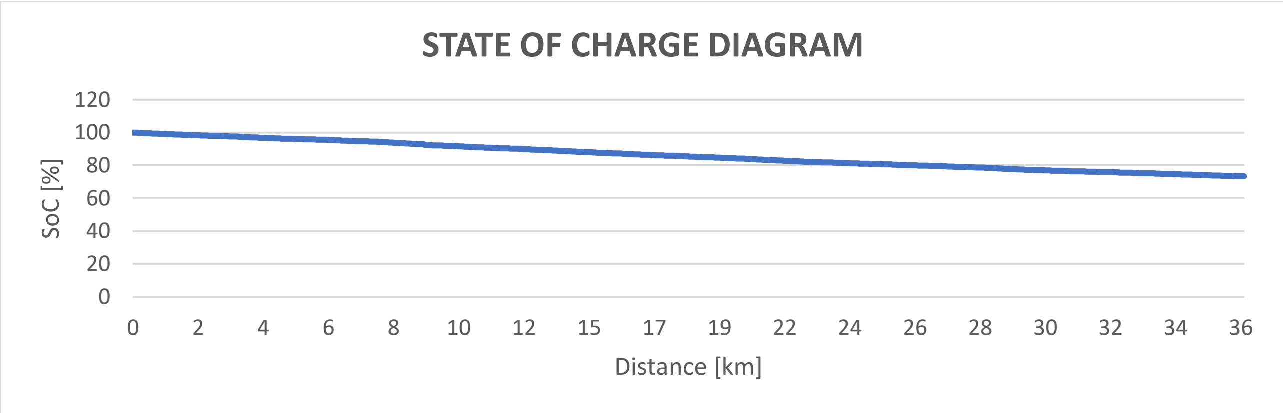

Figure 22: State of Charge Diagram for e-BUS

The aero-taxi service is instead a very nice way for VIPs and athletes both for further reducing travel time and have a unique experience. They offer a futuristic way of transportation, allowing for efficient point-to-point travel. With on-demand mobility, they can provide a more sustainable and flexible transportation solution in urban areas.

However, despite its many advantages, the project has some limitations. The extension of the railway line from Tirano to Bormio involves high costs, in particular for the new underground station in Tirano and the construction of tunnels in the mountainous territory to make the ground suitable for the installation of the tracks and to make it adapt to the technical characteristics of the train.

Critical aspects regarding e-bus solution are mainly related to the behavior of their batteries in winter: cold temperatures could lead to slower charging times, reduced energy efficiency and decreased operational range, impacting overall performance and reliability. Moreover, the realization of new mobility hubs in a wide area such as Bormio and Livigno, including a fleet of electric buses and their charging stations, requires a significant financial investment.

Operating air taxis faces a few challenges, such as difficulty in getting certifications, which can slow down the process of bringing them to market. Public acceptance may also be low at first, as people may have concerns about safety and the unfamiliarity of the technology. Additionally, limited fleet availability due to high financial costs could make it harder to deploy air taxis on a large scale. Also, the high-ticket price for eVTOL services could limit their accessibility, making them a feasible solution mainly for VIPs and athletes, rather than for tourists or visitors.

In conclusion, given the usual touristic spirit of the area and the future situation of Olympic Games, these innovations can promote local tourism bringing economic benefits to the region. It is evident that from the perspective of pollutant emissions and fueling costs, implementing a new electric train line and an e-bus service will bring improvements to the currently available transportation options on the route towards a sustainable development the way of moving.

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