B&H Electrical Engineering, Volume 19, Issue 2, 2025
ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2025-0021

Original scientific paper

Submitted: April 25, 2025

Accepted: October 11, 2025

TECHNO-ECONOMIC AND REGULATORY ANALYSIS OF THE APOLLO-LINK HVDC INTERCONNECTOR

Wolfgang Hribernik[1,4], Sabine Silke Landwehr-Zloch[2], Gilbert Guntschnig[3]

Abstract: APOLLO-LINK - The Mediterranean Solar Bridge is a privately financed electricity transmission project establishing a new interconnector between Italy and Spain. It will constitute the first direct bidding zone border between Itay North and Spain with a capacity of 2,000 MW. This interconnector will promote European electricity market integration, boost the exchange of renewable energy and re-enforce the East-West connections of the EU's power sector by connecting Spain's substantial renewable generation with Italy North's high-load zone. The APOLLO-LINK interconnector will make use of a rigid bipole configuration that operates two converter poles per station at a voltage level of ± 525 kV without the need for a neutral return path. The envisioned interconnection offers numerous advantages for the national energy systems in Italy and Spain, including an estimated net annual social welfare gain of up to € 860 million and a long-term reduction in end-consumer electricity prices. This project enhances PV generation efficiency, improves energy security by linking high-demand areas in Italy with renewable sources in Spain and supports symbiotic development with Spain's and Italy´s planned network improvements. The proposed APOLLO-MODEL is a harmonized regulatory model that enables interconnector investments to be financed based on expected congestion revenues, potentially combined with a cap-and-floor structure that protects both investors and consumers. This provides predictability for investors and socializes excess gains, balancing private initiative with public interest.

Keywords: Interconnectors, Regulation, Cost-Benefit Analysis, HVDC

MOTIVATION

The EU plans to fully decarbonize its energy supply by no later than 2050 [1]. This requires significant efforts in the areas of energy efficiency, the expansion of renewable energy sources, and especially European energy transmission grids. An essential component of implementing the necessary transformation is the expansion of European electricity interconnectors as connections between bidding zones. The strengthening and expansion of the interconnectors are necessary to integrate large quantities of renewable (volatile) energy into the power grid, to ensure a reliable and secure energy supply, and cover projected rising electrical consumption due to envisaged electrification of final energy consumption. Additionally, the transmission grid expansion enhances the European electricity internal market enabling free trade of electricity throughout Europe and reducing costs for all electricity consumers.

Overall, the EU Commission estimates that investments of 584 billion EUR will be required for European electricity networks across all voltage levels in the current decade [2]. For interconnectors alone, ENTSO-E identifies an investment requirement of six billion euros per year until 2040, with simultaneous annual welfare gains of nine billion euros [3]. Simultaneously, the International Energy Agency anticipates a global investment need in electricity networks of 600 billion USD annually from 2030, which is a doubling of current investments.

Part of this identified investment need is currently being realised through concrete development projects regularly published by ENTSO-E in a ten-year network development plan (TYNDP). Most of the projects included are initiated by national TSOs and primarily funded from congestion incomes on existing interconnectors, regulated network tariffs and/or public funds.

It is becoming more and more evident that the currently developed projects cannot cover the identified need for interconnectors expansion, creating a gap between required and planned investments. Reasons for this gap include limited planning capacities at TSOs, high market entry barriers for new actors (such as innovative project promoters) and, most importantly, limited public funds for network expansion. In November 2023, the

This paper was submitted to the Conference of the South-East European Regional Council of CIGRE (SEERC 2025), held in Sarajevo, Bosnia and Herzegovina, on June 4–5, 2025.

[1] *Europa-Link Development GmbH, Austria, Germany*
[2] *Hochschule Mainz, Austria, Germany*
[3] *Omnia GmbH,Austria, Germany*
[4] *Correspondence email: wolfgang.hribernik@europa-link.eu*

EU Commission presented an action plan to address these central challenges and measures to rectify them [4]. One measure currently under further examination is the exploration of alternative sources of financing through private investments (Action 9), with a particular focus on the development phase of infrastructure projects.

In order to solve the challenges mentioned above, innovative approaches to regulation and financing are being developed on the basis of which concrete projects will then be developed.

The specific need for extra capacity on the border between Spain and Italy was confirmed by the most recent System Needs Study by ENTSO-E (Figure 1)

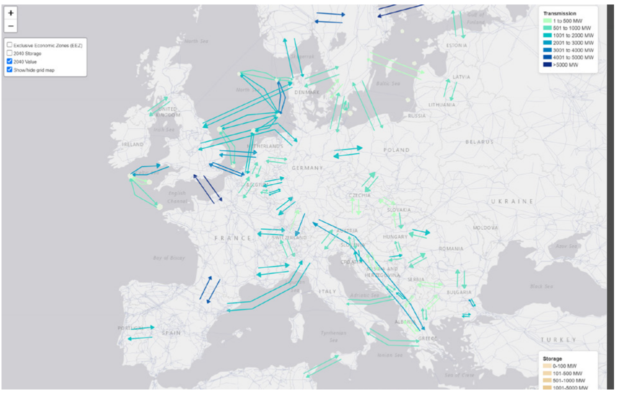

Figure 1: Interconnection System Needs identified by ENTSO-e within the 2025 system need study

1. THE APOLLO-LINK INTERCONNECTOR PROJECT

The Apollo Link project aims at establishing a critical electricity connection between Vandellos, Spain, and la Spezia, Italy, through the implementation of a 525 kV DC undersea cable thereby connecting the bidding zones Spain and Italy North. This cable is set to traverse approximately 850 km beneath the Mediterranean Sea with a capacity of around 2 GW. In addition to its undersea segment, the project encompasses roughly 20 km of underground onshore cable infrastructure, accompanied by the integration of two High Voltage Direct Current (HVDC) converter stations (Figure 2).

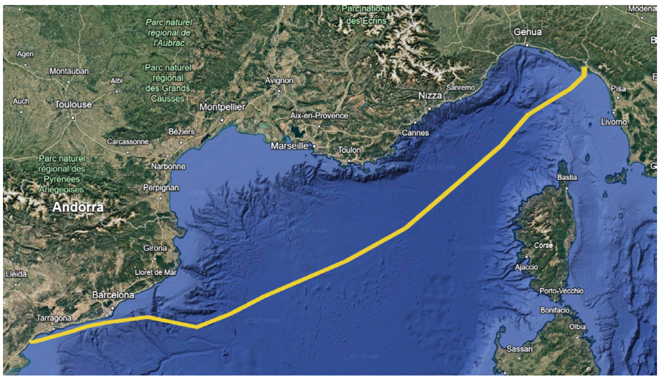

Figure 2: Draft routing of the Apollo-Link Interconnector between Vandellos (ES) and La Spezia (IT)

The envisaged HVDC interconnector project, which is scheduled for commissioning in 2032, will leverage a 2 GW quasi-standard to establish a technologically advanced and robust system. This system will be based on a Rigid Bipole (2DCe-BO according to [6]) configuration where there is no dedicated metallic return path (Fig. 3). In case of contingencies, i.e. one of the two pole converters out of operation of in case of an insulation fault on one cable, one pole can be operated in so-called metallic return using the other HV pole conductor. Under these conditions, the HV pole conductor must be disconnected from the rest of the HVDC grid at both ends and be connected to the neutral point of the related HVDC stations.

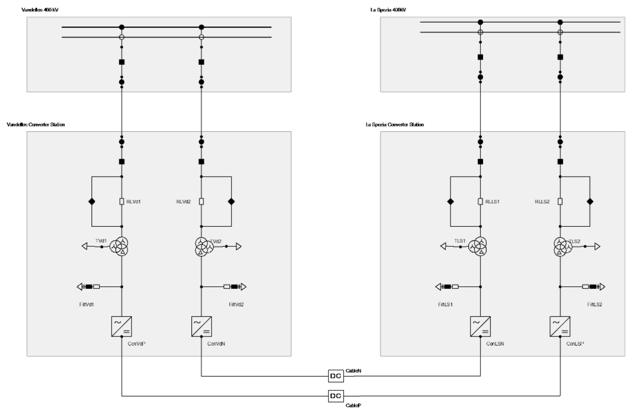

Figure 3: Single-line diagram of the Apollo-Link Interconnector in Rigid Bipole Configuration 2DCe-BO

The system will employ a pair of 525 kV Mass Impregnated Non-Drained (MIND) submarine transmission cables allowing for long cable lengths and high depth applications. Nevertheless, during the planning phase of the projects, the application of next generation extruded submarine cables, that allow for higher operational temperatures and lower environmental footprint, shall be evaluated.

2. COST-BENEFIT ANALYSIS

The cost-benefit calculations are carried out over a 25-year operational period, starting in 2032 and running to 2057. All figures for the CBA presented below are in EUR using 2023 real terms. Additionally, values are annual and thus do not require seasonal adjustments.

The benefit numbers presented below represent the Socio-economic welfare (SEW) benefit of the project and are based on 2024 TYNDP market simulations in which the impact of the interconnector on the markets has been evaluated under different scenarios. Simulation data is considered for the scenarios National Trends for the years 2030 and 2040, and Distributed Energy for the year 2040. For the National Trends scenario the SEW benefit has been linearised between 2030 and 2040 based on the values attained through the simulations and the yearly values for the years after 2040 are kept at the level of

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2025-0021

2040. For the Distributed Energy scenario only values for 2040 are available, which are used as yearly values over the entire operational period.

Apollo Link's cost is expected to be around 3.5 billion EUR. Of these, OPEX is estimated to be around 20 million EUR per year over a period of 25 years, amounting to around 500 million EUR. The predominant portion of the project expenditure is anticipated to manifest in the form of capital expenditure (CAPEX), estimated at approximately 3.1 billion EUR.

The quantifiable benefit stemming from the Apollo Link project pertains to the arbitrage value generated by the electricity transmitted multiplied by the price differential it captures between Italy North and Spain. In addition, consumer and producer surplus changes are included in the SEW benefit of the interconnector.

The SEW figures for the two considered scenarios naturally diverge significantly as their underlying assumptions of how the energy system will evolve in the coming years is also assumed to be drastically different under them. The calculated project SEW benefit for National Trends is 547 million EUR per year in 2030 and 860 million EUR per year in 2040. For Distributed Energy on the other hand the SEW value for 2040 is calculated to 382 million EUR per year.

The calculation of the net benefit of the project based on these numbers yields 250 million EUR per year under the Distributed Energy scenario, and 720 million EUR per year under the National Trends scenario equalling 6.3 billion and 18.1 billion EUR respectively.

Apart from Socio-economic welfare benefits Apollo Link has numerous additional benefits, which have been evaluated under the 2024 TYNDP market simulations. The RES integration benefit, which reflects both the avoided RES curtailment as well as additional RES integration facilitated by the interconnector, amounts to 2.7 TWh in 2030 and 7.3 TWh annually under the National Trends scenario, while this value is 2.6 TWh under the Distributed Energy scenario. Furthermore, the security of supply adequacy benefit, which reflects the ability of an interconnector to enhance adequacy by pooling the risk of loss-of-load while simultaneously pooling the generation capacity, amounts to 171 MWh in 2030 and 302 MWh annually under the National Trends scenario, while this value is 536 MWh under the Distributed Energy scenario (2040).

While the initial investment with 3.5 billion EUR is substantial, the long-term benefits are high with the net benefit ranging from roughly 250 million EUR per year under the Distributed Energy scenario to 720 million EUR per year under the National Trends scenario. Based on these numbers APOLLO-LINK is one of the top ranked projects out of a total of 376 evaluated in the current TYNDP 2024. Compared to the investment required to reap the SEW benefits (SEW increase per Euro invested) the project is the best performing project amongst a peer group of comparable other offshore HVDC projects (Figure 4).

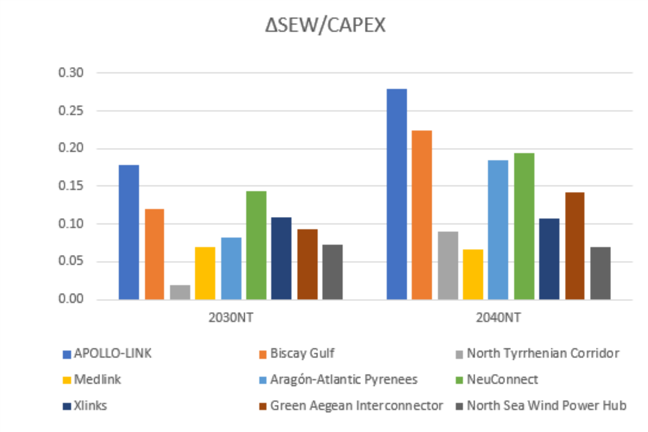

Figure 4: Comparison of a peer group of interconnector projects of the TYNDP 2024: SEW increase per Euro invested

3. THE APOLLO REGULATION MODEL

Under the current regulatory framework, the financing of investments in interconnectors as regulated assets is compensated ex post from the tariff set by the national regulatory authorities (or based on the methodology adopted by them). To shorten the time delay between incurring investment costs and their recovery, and to mitigate the impact of that system on consumers, the recent amendments to the internal market legislation introduced the concept of anticipatory investments in tariff regulation. Further guidance by the European Commission on the circumstances and conditions under which that instrument should be used is to be expected. However, this important modification of the regulatory model was neither designed nor will it suffice to attract private capital in infrastructure development, in particular interconnectors.

The current legal framework also allows for exemptions from the regulated model, which has been used by a relatively small number of (merchant) interconnectors so far. Under exemption, the developers may attract financing based on the future revenues from a tailored tariff model. The fact that exemptions are granted case-by-case by the national regulatory authorities (NRAs) involved in accordance with Article 63 of the Electricity Regulation comes with significant risks, including whether an exemption will be granted, for how long, under which conditions etc. Moreover, practice shows that the decisions are often subject to non-transparent negotiations between the NRAs focused on national welfare gains or losses only. The possibility of the Commission to overrule an exemption decision only provides limited safeguards in that respect. Moreover, merchant interconnectors constitute an exemption from the competitive market model established under the Clean Energy Package and its predecessors, with adverse impact on liberalization. They are also essentially excluded from the TEN-E framework, which establishes two parallel and non-connected regimes.

To overcome the national focus and the limitations inherent in a project-based and not fully harmonized approach, the Apollo model proposes a third way within the regulated system, based on unified European legislation. As in the merchant (exempted) model, the point of departure is the usage of congestion income to attract investments (Figure 5). During the productive operation of the interconnector, congestion revenues are generated due to price differentials between the connected bidding zones. These revenues are collected by the TSO, acting as the entity overseeing the interconnector's operations. The income derived from congestion serves two main purposes: it covers the capital expenditure (CAPEX) and the operational expenditure (OPEX) associated with the operation of the interconnector to be compensated via a lease fee (LF). The latter is a payment from the TSO to the asset owner for the use of the interconnector

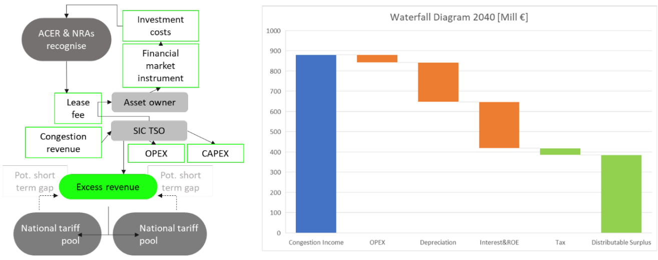

Figure 5: Distribution of surplus congestion income – single-interconnector TSO regulation model

Regulation (EU) 2019/943, Article 19 paragraph 4 provides the basis for the Use of Congestion Income Methodology on the use of congestion revenues for the purposes referred to in Article 19(2) and the conditions under which those revenues may be used for e.g. interconnector development and operation. This has been concretely specified by the ECJ in its ruling on the Baltic Cable case [7].

The APOLLO-LINK is expected to generate congestion income to directly cover its regulated cost including interest and reasonable profit. According to EU regulation, surplus profits can be used to build further interconnection or, if that is not possible, to reduce network tariffs on the participating countries (Figure 5).

According to our estimations, APOLLO-LINK will generate significant surplus revenues that can be distributed to the adjacent grid operators. A Cross Border Benefit Allocation Mechanism, to be agreed upon between the two countries, will reflect the distribution of surplus revenues and any other benefits between the two countries.

4. CONCLUSION

The proposed European regulation model for electricity interconnectors represents a groundbreaking approach to finance essential electricity infrastructure in a fair, innovative, and efficient manner. What sets this proposal apart is its recommendation to use congestion income for refinancing capital market-financed projects.

The Apollo Model not only attracts new capital and players into the grid development sector but also guarantees a significantly more efficient utilisation of future congestion revenue compared to the current practice limited to national investments.

Applying a cap and floor methodology further incentivises the investors to effectively select the most beneficial bidding zone border for their investment and ensures efficient operation of the interconnector. Regulatory oversight over the split of excess revenue between network users, operator and investor ensures a fair distribution of generated benefits.

Additionally, the proposal has the potential to address some of the shortcomings of the current cross-border cost allocation (CBCA) mechanism by introducing new elements and reshaping the entire pattern from cost to benefit distribution between Member States. This shift towards a win-win structure, away from a cross-subsidy character, is expected to yield more robust outcomes with higher acceptance.

REFERENCES

[1] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

[2] Refer to Grids, the missing link - An EU Action Plan for Grids, EU Commission, Brussels, 28 November 2023. eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0757, accessed on 31.12.2023

[3] Refer to ENTSO-E High Level Forum on Future of Our Grids, Brussels, 7 SEPTEMBER 2023, Future of our Grids: European Policymakers, Grid Operators and Industry leaders met today to put forward concrete steps to deliver the electricity grids needed for the energy transition. (entsoe.eu), accessed on 31.12.2023

[4] Refer to Grids, the missing link - An EU Action Plan for Grids, EU Commission, Brussels, 28 November 2023. eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0757, accessed on 31.12.2023

[5] System Needs Study Opportunities for a more efficient European power system in 2030 and 2040, ENTSO-e, May 2025, https://tyndp.entsoe.eu/explore/what-are-system-needs

[6] High voltage direct current (HVDC) grid systems and connected converter stations - Guideline and parameter lists for functional specifications - Part 1: Guideline, IEC TS 63291-1:2023, ISBN 9782832275719

[7] Curia.europa.eu; Opinion of Advocate General Tanchev, delivered on 14 November 2019(1), Case C-454/18, Baltic Cable AB v Energimarknadsinspektionen; https://curia.europa.eu/juris/document/document.jsf?text=&docid=220659&pageIndex=0&doclang=EN&mode=req&dir=&occ=first&part=1&cid=2246572

BIOGRAPHY

Wolfgang Hribernik is the co-founder and CEO of Europa-Link Development GmbH, specializing in the development of electricity interconnectors across Europe. Previously, he led the largest Energy Research Center in Austria as Head of the Center for Energy at the AIT Austrian Institute of Technology. Wolfgang Hribernik brings over 15 years of experience managing large, expert-driven organizations in the energy and technology sectors. He holds a master's degree in electrical engineering from the University of Technology Vienna and a PhD in technical sciences from the Swiss Federal Institute of Technology Zurich. He has actively participated in national and international boards and is a member of OVE, VDE, a Senior Member of IEEE, and Secretary General of the Austrian National Committee of CIGRE. From 2018 to 2024, he served as the cluster coordinator for the Austrian Innovation Program NEFI (New Energy for Industry).

Sabine Landwehr-Zloch is a professor of business administration specialising in finance and accounting at Mainz University of Applied Sciences. Her research focuses on controlling and financing innovation and sustainability. She is also spokesperson for the interdisciplinary research group VORAN, which is dedicated to promoting sustainability in business and society and, among other things, investigates innovative financing of transformation investments and energy infrastructure. Sabine Landwehr-Zloch brings extensive industry experience from her time as Senior Innovation Manager at BASF and Scientific Advisor to the Chemical Innovators' Club.

Gilbert Guntschnig is Manager at the energy consulting company OMNIA GmbH. He has more than 10 years of professional experience in the electricity TSO business, having held different positions both within an EU TSO as well as senior roles in European market development consortia. He helped implement large-scale European market integration programmes, as well as advance electricity market design in Europe. He is also experienced in stakeholder and programme management, and has led multiple consulting projects helping clients understand and implement EU electricity regulation. Gilbert holds an MSc degree in chemistry and process engineering as well as a post-graduate MSc degree in international relations and environmental technology.