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Overview Paper on Charges for Traction Current

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Introductory Remarks

Traction current is an essential rail-related service for providing rail transportation using electrical trains and locomotives. In a context of great volatility and increasing prices for electricity, IRG-Rail analyses for the first time the charging system of this service, covering several topics, such as its connection to the rail infrastructure and the IM, or the different technical differences that might be accounted for by the charging systems. In this paper, 23 IRG-Rail members provided information by replying to a questionnaire on this matter.

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1. Introduction

The provision of traction current is an essential service for railway undertakings (RUs) in order to operate electric trains and locomotives and, thus, provide transport services. Electricity is a necessary production input which has to be supplied continuously throughout the whole trip. The intrinsic characteristics of this service imply that its provision is closely tied to the rail infrastructure and the services included in the minimum access package (MAP) and, therefore, the infrastructure manager (IM) usually plays a key role in its provision.

In this paper IRG-Rail addresses for the first time the charging scheme for traction current in a moment in which the energy market is experiencing relevant changes due to its transition towards a more sustainable system and due to tensions in the global markets that make electricity production to become more expensive. This, consequently, poses major challenges for energy consumers. Energy consumption has become a major cost component for RUs, who might eventually translate it into price increases for rail transportation, which, in turn, might affect rail competitiveness and demand for transport.

Consequently, it is appropriate for IRG-Rail to analyse the different charging schemes for traction current that are in place in Europe and try to identify common traits and different solutions applied by charging systems that can improve the efficiency in consumption and that are more beneficial for RUs, end users, and the rail market as a whole.

This paper is divided into six chapters. Chapter 2 analyses the European framework of the service and its implementation in the different countries. Chapter 3 deals with the general definition of the services and its relationships with the rail infrastructure. Chapter 4 presents a more in-depth analysis of the charging system, focussing on technical differences and other elements that are taken into account for the calculation of the tariffs. Chapter 5 reports a few regulatory experiences of some RBs. Finally, Chapter 6 addresses the challenges of increasing energy prices and their linkages to the charging systems. For the development of this paper, IRG-Rail distributed a questionnaire covering questions related to the different topics. Therefore, this document includes information covering the following 23 countries: Austria, Belgium, Bulgaria, Croatia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, The Netherlands, Norway, Poland, Portugal, Serbia, Slovenia, Slovakia, Spain, Sweden, Great Britain, and Romania.

2. European framework for traction current, implementation in the different countries

The provision of traction current is one of the services listed by the Directive 2012/34/EU (the Directive) in Annex II No.3 (a), which states that "*Additional services may comprise: (a) traction current, charges for which shall be shown on the invoices separately from charges for using the electrical supply equipment, without prejudice to the application of Directive 2009/72/EC*"

This definition shows that, even though this service is tied to the use of electrical supply equipment for traction current (like access to the catenary or substations), which is listed in Annex II No. 1(e) of the Directive, it is separated from the Minimum Access Package (MAP).

The legal framework set by the Directive was transposed into national law directly using the same text or a text with the same meaning in those countries who answered to the questionnaire. However, given the connections between this service and the energy market, in some cases, legislation regulating this sector also affects the provision of the service in the rail network. Indeed, in Germany, while the text of the Directive has been adopted into national law, the national electricity law EnWG provides more detailed regulation. The provision of the service is effectively regulated by it.

In all countries for which there is available information, national rules classify the provision of traction current as a rail-related service, and thus, not part of the MAP. Following the definition set by the Directive in its Annex II No.3 (a), those members who reported information on the matter answered that the service is qualified in the national law as an additional service. In this regard, charges shall not exceed cost of providing the service plus a reasonable profit if supplied by just one provider.

3. General definition of the service and common traits

The legal framework set by the Directive does not contain a definition of the service itself, although it is easy to understand by just looking at its name. Indeed, this service consist of providing traction current so electric trains can use it to feed their engines and provide transport services.

This straightforward definition is not always that simple as there might be several complementary activities, such as energy measuring, frequency conversion and others, as well as there might be several parties involved in the provision of the service, meaning that different activities are split between them.

Although this document analyses more in-depth the different activities that might be included in the provision of the service when analysing the cost components that are covered by the charge, at this point it is relevant to highlight general traits of the provision of the service, as well as main difference across countries.

In general, this service is tied to the distribution of electricity itself, what implies that the provider distributes the required energy throughout the rail network by either buying it in the energy market or by directly producing it. The electricity obtained in the public energy market is usually bought by the service provider, although, in some cases, the choice of the energy supplier is open to RUs, who can also directly contract with an energy undertaking.

This scheme, however, is not always met. In Finland, the IM is the only provider of the service, although it is conceptualised differently. In this country the prevailing practice is that the IM resells to RUs as an additional service the electricity transfer, which is performed by external grid companies (ca. 23 companies). The service is called “Electricity transmission service” and it includes also 1) measurements, 2) energy losses (dissipation) and 3) balance management. In this case, the service provider does not distribute the electricity, but only provides complementary activities, meaning that the actual distribution of the electricity is not regulated and involves contracting with energy undertakings which take no part in the rail sector. This situation is similar in Bulgaria, where the RUs have to sign a contract with an energy supplier directly.

In this regard, it is possible to differentiate between the service (traction current) provider and the energy supplier, which it is usually a company that sells electricity in the market. Therefore, it is important to analyse how these two parties interact and how those relationships affect the charging scheme for the provision of traction current.

Also connected to the provision of traction current, it is also worth mentioning that the regulation of this service might be affected by the legislation regulating the energy sector, what might constrain or determine how this service is provided. Finally, other technical or practical circumstances might affect the way this service is provided and charged.

3.1 Connection between public electricity network and railway infrastructure

In fact, the distribution of electricity throughout the rail network requires a physical connection between the rail infrastructure (particularly, the electrical supply equipment for traction current) and the public electricity network so the different rail lines can be effectively electrified. This connection generally happens at certain infrastructure points, such as substations, meaning that the rail infrastructure directly connects to the public electricity system.

Therefore, no other infrastructure (electric network or electric supply equipment) between the public grid and the railway infrastructure is necessary and, in general, there is no equipment (other than that used for the provision of the MAP), nor further infrastructure associated to this ancillary service.

Nevertheless, the system is more complex in some cases, such as in Austria, where the railway network operates with 16,7 Hz frequency, respective to the 50 Hz frequency with which the general network operates. Here, the IM (OEBB-Infrastruktur AG) is the operator, around 60% of the traction current provided is produced with 16,7 Hz frequency by waterpower plants of which approximately half is owned by the IM. The other 40% is transformed via converters which connect the railway and the general network. The transport of the traction current takes place via 110kV and 55kV high voltage transmission lines (~2,000 km), transformed to 15kV and fed into the overhead contact lines. The high voltage transmission lines and the frequency converters are part of the service facilities, thus not part of the MAP. The RUs may contract with the IM for only the service of distributing the energy, which in this case would be contracted with third party energy providers by the RU itself. In most cases though, the RUs contract also the provision of energy with the IM. The IM then contracts the quantity it cannot produce with third party providers.

3.2 Number of providers and contracting

As traction current is both a necessary resource for running electrical trains and a commodity of another regulated market in itself (the energy sector), the provision of this service to the RUs is either done from a railway perspective or from an energy perspective. The actual approach depends on which perspective was chosen in the particular country. This leads to different ways of provision of traction current in the countries for which information is available. It also leads to a variation of numbers of how many providers of traction current exist in a country. Indeed, as mentioned before, in some cases, it is possible for RUs to directly select and contract with an energy undertaking, which will eventually supply the required electricity.

In 17 out of the 23 countries for which members provided information, there is only one provider (either because no other choice was possible or because no other choice was made). In 15 of those countries this sole provider is either the IM or a company affiliated with the IM. There are two exceptions to this. In Poland the sole provider was a company not affiliated to the IM, while in the Netherlands, all RUs are part of a group purchasing organization that have contracted an energy supplier, so right now, only one energy supplier supplies energy to the RUs in this country.

With regards to the remaining countries, in five of them there is more than one provider of traction current. In Portugal, there are two energy suppliers that are under contract, which were chosen by the IM and the incumbent RU for the whole network in a call for tenders. In the other four countries (Austria, Bulgaria, Germany, and Finland), RUs can choose their traction current supplier on the market, with a variety of 2 to 23 providers. Finally, there is no information available on the number of suppliers in France.

As the supply of traction current is handled differently in IRG-Rail's member countries, the number of providers differs as well as the possibility to contract directly with the energy supplier. Indeed, despite the fact that there is only one supplier, in some countries it is possible to contract with an alternative energy supplier directly, but practical reasons lead to that outcome.

There are 7 countries in which it is possible for RUs to directly contract with an energy supplier. Apart from the abovementioned cases of Austria (2 providers), Bulgaria (6 providers), Finland (23 providers), and Germany (5 providers), it remains an option in Belgium, France, and Great Britain. Portugal is the only country in which, although there are two suppliers for traction current, RUs cannot contract with another supplier, given that the two companies were chosen as a result of a tendering procedure. Currently, the Portuguese authority AMT is leading a working group to study the possible legal ways for RUs to make contracts directly with an energy provider of their choice.

Country	Number of providers	Direct contracting possible for RU
Austria	2	✓
Belgium	1	✓
Bulgaria	6	✓
Croatia	1	
Finland	23	✓
France	N/A	✓
Germany	5	✓
Great Britain	1	✓
Hungary	1[1]	
Italy	1	
Latvia	1	
Lithuania	1	
Luxembourg	1	
The Netherlands	1	
Norway	1	
Poland	1	
Portugal	2	
Serbia	1	
Slovenia	1	
Slovakia	1	

[1] There are 2 providers in total, but each of them is the IM on its own rail infrastructure.

Spain	1	
Sweden	1	
Romania	1	

NUMBER OF PROVIDERS OF TRACTION CURRENT (2021)

3.3 Reasons for a sole provider

Closely related to the previous issue, it is also relevant to analyse the reasons for which, in the majority of countries, there is only one provider, and, in addition, why this party is usually the IM (or a subsidiary company). In this regard, there might be a legal mandate that obliges the IM to be the supplier of traction current or simply practical reasons that justify such an outcome.

In 5 out of 23 countries there is a legal mandate or practical reason that the IM is set as the sole provider of traction current. These countries are Croatia, Hungary, Luxembourg, Spain and Romania. The following additional information, provides further explanation:

- In Croatia, the Railway Act stipulates that the IM is the buyer of electricity through public procurement. The IM then delivers the electricity to the railway undertakings, as end customers, and charges a fee for the traction current.

- In Hungary, the infrastructure managers (MÁV Zrt. and GYSEV Zrt.) are the sole providers (on their own infrastructure). At present, both MÁV Zrt. and GYSEV Zrt. are engaged in the transmission of energy on the so-called "private lines" under the Electric Energy Law. This also has the consequence that the contracting RUs can only buy electricity from the IM, they currently have no other option. In order to enable RUs to purchase directly from operators, the management of network losses on overhead contact wire system should be ensured. To this end, it is necessary to ensure that all delivery and offtake points on the entire overhead contact wire system and on the rolling stock are reliably telemetered. Under the current rules, IMs would be obliged to temporarily or permanently transfer part of their available capacity at their substations. A possible solution to this should be examined in the context of the National Assets Act and the Railway Act.

- In Spain, there is a legal provision set in the Energy Sector Act that establishes that the IM is owner of the electric energy supply points that connects the rail infrastructure to the energy networks and indicates that the IM shall borne the costs related to maintenance and depreciation. Therefore, the IM is the only party that can access the energy market and contract with an energy undertaking.

Out of the other countries where the IM is the only provider of traction current without a legal mandate for this, five members provided economic and/or technical reasons for this situation:

- In Italy, there is no limit or constraint for the RUs to use different external suppliers, but they enjoy an economic advantage to source from RFI.

- In Serbia, the Law on Energy does not provide for the railway undertakings to contract this service directly with the company that provides the energy. The cost of traction current consumption is paid to the IM together with the access charges.

- In Slovenia, the practical reason for the provision of traction current by the IM is that the IM operates the equipment for providing the traction current.

- In Slovakia RUs may sign contract with any electricity supplier in the market, but it is not technically possible yet as locomotives are not equipped with certificated electricity measurement suitable for billing.

- In Sweden, practical reasons lead to the provision of traction current by the IM: There are no legal obstacles known, but it would be much more expensive to buy power from another provider than the IM.

- In the Netherlands, the IM and all RUs have established a joint buying organization. The provision of traction current is accessible to all RUs on a non-discriminatory basis. The (sole) energy supplier is contracted after a public tender. This construction ensures that all RUs, big or small, can profit from bulk purchasing.

3.4 Energy production

Electricity can either be sold directly by its producer or via an energy trader. According to the outcome of the questionnaire, in three countries (Austria, Germany, and Great Britain), the energy supplier produces at least a part of the energy sold, while this is not the case in the other countries.

The following details were given on the national circumstances:

- In Belgium, the supplier of traction current does not have to be a producer. It can also be a trader. The RU has to choose a Balancing Responsible Party and a Supplier. It can be one company having both roles.

- In Croatia, the IM supplies electricity to railway undertakings, but does not produce it.

- In Germany, Deutsche Bahn AG's energy subsidiary, DB Energie GmbH, sells traction current as well as produces it partially.

- In Norway, the provider of the service does not produce the required energy. The IM buys electricity from the open market.

- In Poland, the energy supplier is only the distributor and seller of the energy.

- In Portugal, neither the IM nor the incumbent RU are producers of electric energy for traction.

- In Spain, the IM buys all the needed energy from the market.

- In Sweden, the IM purchases power on the power market, transforms it and supplies the RUs.

- In Romania, the provider of the service SC „Electrificare CFR" SA, is buying the energy from the specialized energy stock exchange.

- In Austria, the IM which is also the SF provider produces a partial quantity of the required energy itself, while contracting the delta from b2b partners as well as from the energy stock exchange. As SF provider, the IM supplies the traction current to the RUs in all cases, RUs can and do choose other energy providers though.

As energy is a fundamental component of a RU's cost base, it is of interest how the price of energy is determined. Two possible options are pricing at market level and pricing based on "cost of providing it plus a reasonable profit" as stated in Article 31 (7).

Five countries answered that the provided energy could be sold at market price (Austria, Finland, France, Germany, the Netherlands).

In eleven countries, the energy is sold at cost only (from the providers point of view, containing the possibility of a profit for the producer). These countries are Belgium, Croatia, Hungary, Italy, Latvia, Luxembourg, Norway, Spain, Sweden, Great Britain and Lithuania.

Two countries (Portugal and Romania) allow the sale of traction current at cost plus a reasonable profit.

3.5 Fallback option

If there is more than one supplier of traction current, mechanisms for securing the supply of energy in case of a shortfall of one supplier are a measure that can be taken. Such measures are usually called fallback option.

In six countries a fallback option would exist:

- In Austria, the IM as main provider offers a default or emergency option for RUs, so that they can continue their operations even when their SFO does not deliver energy.

- In Belgium, in this case the electricity law must be applied. If the energy supplier of the IM is in default, the IM must choose another energy supplier or become its own Balance Responsible Party and buy the electricity directly on the power exchange. If the IM has chosen its own supplier and this supplier goes in default, the IM becomes the supplier.

- In Germany, RU and supplier can agree on a fallback supplier in case the supplier cannot fulfil its contractual obligations. Usually, this is done by choosing the default option of DB Energie GmbH, the incumbent's energy subsidiary. The prices of this option are released on their homepage (https://www.dbenergie.de/dbenergie-de/Preisblaetter-Rueckfallversorgung-Bahnstrom-4570484).

- In the Netherlands, this will be solved within the energy regulation framework: When an energy provider goes bankrupt, customers will be taken over by another energy provider.

- In Portugal, the IM will remain as a traction current provider for any RU.

- In Slovakia, in every case there is main energy supplier as subject of "last fallback" for the period of 3 months.

4. Charging system and technical differences

Although, in general, the provision of traction current is quite homogenous, charging systems differ between countries. Differences can be found not only in prices and costs covered by the charge (both cost of providing the service and the possibility of charging a reasonable profit), but also in terms of technical differences for which the system does or does not account for. For instance, in some countries it is possible to charge according to the actual consumption provided by energy measurement systems installed on-board or it is possible for trains to return power to the grid and, thus, lower the charge.

The fact that charging systems allow for technical differences to play a role in the calculation of charges may have a direct or indirect effect on the investments carried out by RUs. Indeed, these companies, which use electricity as a production input, might consider the choice of investing in more energy efficient trains or locomotives. Therefore, this chapter also analyses how charging systems address technical differences of trains which could incentivise certain investments.

Finally, this chapter analyses how charging systems deal with power losses that occur throughout the grid and that introduce a distortion between what the RUs actually consume and the energy that is flowed into the rail grid, which is either produced by the supplier or bought from the energy market. In addition, imbalances in the system might occur as well due to changes in prices (for instance, variation in energy prices) or due to differences of metrics between actual and forecasted consumption. In this regard, it is also relevant to analyse how charging systems deal with deficits and surpluses in energy consumption and whether there are adjustments mechanisms to correct for a possible shortage or excess in the amount charged by the service provider.

4.1 Costs that are covered by the charge

The costs that are borne by the traction current supplier, and that are later included in the charge as part of the tariffs, include the cost for different inputs and activities. The main cost item is the price of electricity itself, which is the energy produced or bought from the market that is ultimately used by the trains. This cost is included in the charges for every country except for Finland where, as explained earlier, the service of traction current does not include this component, which is later directly contracted by the RUs by signing individual agreements with energy undertakings.

The cost of energy itself is the main cost component and includes the consumption in megawatt-hours or kilowatt-hours registered in the rail grid. In some countries, such as Croatia, Italy, Luxemburg, Norway and Serbia, this is the only cost that is covered by the charge. Nonetheless, there might be other related costs which are, indeed, covered by the charge, but not explicitly mentioned.

The cost of other related inputs or activities include the cost of access or connection to the network, transmission and measurement, which are included in the charge in Finland, Germany, Hungary, Latvia, Spain, Great Britain and Lithuania. In Latvia and Sweden, the charge also includes the cost of converting the electricity to the correct frequency or to meet technical requirements. Also, in Sweden and in Spain charges include the administrative costs of the IM that are allocated to the provision of the service.

In Austria, where there is associated infrastructure to the provision of the service, charges include depreciation of assets and cost of capital as well as other operational and labour costs incurred in the provision of traction current.

Finally, in some countries, namely Germany, Hungary, Latvia, Sweden, Lithuania and Great Britain there are other cost components that cover different items, such as taxes, electricity certificates and other surcharges (e.g., remuneration for electricity exchanges). Electricity certificates or the obligatory purchase component, which are explicitly mentioned in Sweden and Latvia, cover the cost of funding renewable energy sources or that foster the usage of clean energy.

4.2 Reasonable profit and the provision of traction current

A service that is offered in a regulated market opens the question on profit for this service: Is the provider of this service allowed to make a profit, and, if so, how high is this profit allowed to be, leading to the need of defining a reasonable profit for the supply with traction current.

Apart from the electrical supply equipment for traction current (which is part of the rail infrastructure used to provide the MAP), it might be the case that other infrastructure dedicated to the provision of the service actually exists. In those cases, it might be possible to charge a reasonable profit together with the cost of providing traction current. In this regard, the Regulation on charges for additional services established by Art. 31(8) stipulates that, when provided by a single operator, charges shall not exceed the cost of the provision plus a reasonable profit.

According to the outcome of the questionnaire, the provision of traction current follows a profit neutrality rule in most of the countries under study. Specifically, fifteen countries stated that their charging schemes do not currently include a reasonable profit. Moreover, in a third of respondent countries "profit neutrality" is explicitly mentioned in the description of the charging scheme. In these cases, the provider acts as a mere intermediary between the energy market and the RUs, which are the final energy consumers. As shown before, in most cases, it is the IM or a subsidiary company that provides the service, so this profit neutrality principle makes sense given that electricity is a necessary production input for RUs to provide their transport service on the rail network.

On the other hand, in those countries where reasonable profit is charged, its calculation varies. In particular, Austria and Slovakia[2] calculate reasonable profit by applying the WACC methodology, whereas Romania applies a predetermined fixed amount per MWh. In the case of Germany, electricity itself is delivered on a free market contractual basis, so there are no guidelines concerning profit, given that rules of market competition apply. However, the network fees have to be approved by the regulatory authority and contain a reasonable profit

[2] In Slovakia reasonable profit is defined by the Regulatory Office for Network Industries (RONI): https://www.urso.gov.sk/hodnoty-parametrov-pre-rok-2022-na-vypocet-maximalnej-miery-vynosnosti-regulacnej-bazy-aktiv-wacc/

according to energy law. In that case, the principle of conditions and fees for network access according to § 21 Abs. 1 EnWG apply "[C]*onditions and fees for network access have to be appropriate, free of discrimination, transparent and not adverse to the conditions granted to other companies in comparable cases or to companies associated to the provider*". As a result, traction current providers underly the same regulation as providers of electricity for the general electricity provision.

As a conclusion, in the majority of the charging systems there is no reasonable profit charged by the provider. This is in line with the fact that, in most countries, the provider (particularly when this party is the IM) only acts as an intermediary, who buys the electricity from the public market and distribute it throughout the rail network. Furthermore, since this service is usually separated from the MAP and there are no assets or infrastructure associated to its provision (apart from the abovementioned exceptions), there is no risk associated to the service, and therefore, suppliers shouldn't charge a reasonable profit in the tariff.

4.3 Charging unit

Electricity consumption is usually measured in terms of megawatt-hours (MWh) or kilowatt-hours (KWh), which equals the usage of electricity output of one megawatt or kilowatt continuously for one hour. Therefore, these units are the most common metrics for traction current charges. In 18 out of the 23 countries for which there is available information, tariffs are charged on the basis of euros (or other national currency) per MWh or KWh consumed.

The usage of a charging unit that expresses energy consumption does not necessarily imply that real consumption is used for invoicing purposes, something that only occurs if the charging system foresees the possibility of charging according to measurements provided by power meters installed on the trains. When that is not possible, even though the charging unit is expressed in euros (or other national currency) per MWh or KWh, the estimation of energy consumption might be based on other metrics, such as units of transport production output.

Although the majority of countries use a charging unit based on energy consumption, there are different charging units applied by a few national charging systems. In Croatia, Serbia and Slovenia charges are calculated per gross tonnes-km. This is also the case of Norway for trains without power meters.

This charging unit is also used in Austria and in Spain as an alternative to, or in combination with, charges per MWh or KWh. In Austria, this charging unit is used when the actual consumption is not available (trains without on-board power meters). In Spain, the unit of production (gross tonnes-km) used to be the charging unit for conventional lines, which are electrified at direct current. However, since the last amendment of the network statement, the IM implemented the same scheme used for high-speed lines (electrified at alternating current), for which the charging unit is euros per MWh for all cases. Nevertheless, gross tonnes-km produced by trains are still used to estimate energy consumption when it is not possible to provide an actual measurement of the energy consumed by the train. Therefore, in these cases, even though the charging unit is still euros per MWh, the estimation of energy consumption used for invoicing is based on the number of gross tons-km produced. As mentioned before, this might be the case for other countries in which the charging unit uses a price per MWh or KWh.

The usage of gross tonnes-km as the charging unit is used as a proxy for actual energy consumption. Therefore, service providers that use this charging unit calculate, under several assumptions, which is the equivalence between energy consumption (MWh) and train output production (gross tonnes-km). However, this equivalence is not likely to match real consumption as differences in the types of trains, services, terrain or even driving performance might result in significant differences in the number of MWh actually consumed. In Spain, for instance, there are different conversion ratios for freight and different passenger services that account for technical differences of the trains, so the estimated energy consumption differs across services for an equal amount of gross tonnes-km produced. Nevertheless, this distinction does not account for other factors that could affect real consumption.

In France, apart from the metric of energy consumption (MWh/KWh), those RUs which are not fitted with power meter devices and which are supplied by the IM are charged according to the number of train-km. This charging unit is similar to gross tonnes-km, although it does not take into account the weight of trains, what implies that all trains pay an equal amount for each train-km.

Apart from these three charging units, there are just a few different metrics used to calculate charges for traction current. In Finland, although there is a fee charged per MWh, there is also a basic fee per traction unit which is set in euros per month. In Luxemburg, tariffs are charged in euros per train-path, although the legislation on this matter is currently on the process of being reviewed and it will likely be amended in order to allow for calculating charges according to actual energy consumption provided by energy measure systems.

4.4 On-board power meters (embarked energy measurement systems or EMS)

As explained before, sometimes, charging systems use gross tonnes-km or any other unit of production as a charging unit or as a way to estimate energy consumption by a given train during a journey. However, this way of measuring the amount of electricity consumed fails to provide an accurate estimation, given that several factors might alter the demand for traction current of a particular train (technical differences, characteristics of the terrain or driving performance). This problem, however, can be circumvented by installing the so-called energy measurement systems (EMS) or on-board power meters. According to Regulation (EU) No 1302/2014, "*The on-board energy measurement system (EMS) is the system for measurement of all active and reactive electric energy taken from or returned (during regenerative braking) to the overhead contact line (OCL) by the electric unit*".

These devices allow for directly calculating energy consumption of a given train, so systems can charge according to an accurate estimation of the amount of electricity that has been supplied or consumed. Therefore, RUs using trains with EMS devices are able to provide live consumption in terms of MWh or KWh in a given journey and, if the charging system allows for it, pay a charge for traction current that equals exactly the amount of energy required.

According to the data gathered, in 11 out of 22 countries for which there is available information on this matter, charging system contemplates the usage of EMS for invoicing purpose, what implies that RUs can opt for the modality of charging according to the real consumption of the train. Surprisingly, this option is available only in a few countries, even though the majority of charging systems use a price per MWh or KWh as the charging unit. This fact implies that, in the rest of the countries, charging system use other metrics to convert train output into an energy consumption metric.

Furthermore, the implementation of this way of charging is rather new for some countries which recently introduced this option of charging. In Spain, charging according to EMS measurements is only available for high-speed lines, although the IM expects to implement this modality by 2023/2024 in the whole network. In Italy, the IM just introduced the possibility of using metered invoicing in 2022 and the RB is currently analysing the new, differentiated, reporting methodology.

Charging according to actual consumption has a clear advantage for the system. Charging according to metered consumption not only matches real demand for electricity, but also reduces inefficiencies for both the service provider and the RUs. On the one hand, by making available more accurate measurements of energy consumed in the rail network, supply imbalances are likely to be reduced, what implies that less charging adjustments will be necessary to equal what the supplier charged for energy consumed by trains and what it paid for energy flowed into the rail network.

On the other hand, the usage of EMS by RUs provides a clear signal on the actual cost that they bear in the provision of transport, so they can adjust their services and investments to become more energy and cost efficient. On the contrary, when RUs pay according to production output instead of real consumption, there are no incentives to save energy through a more efficient driving (better performance by the train driver) or to invest in more energy-efficient rolling stock, as they will pay the same charge anyway. Indeed, given that energy consumption is one of the main cost components in transport services, charging according to EMS measurements might become an important characteristic when it comes to selecting new investments in trains and locomotives, since energy savings might translate into cost savings.

Finally, it is common that charging systems which allow for the usage of EMS devices establish some sort of registration process through which the service provider validates these devises, ensures compatibility, and registers train units which installed the on-board EMS. If this process is successfully passed, then RUs can apply for this invoicing method. In this regard, the Commission Implementing Regulation (EU) 2018/868 (amending the abovementioned Regulation (EU) 1302/2014) sets some technical requirements, characteristics and functions to be fulfilled by these rolling stock subsystem given that on-board devices shall be compatible with the on-ground data collection system of the service provider.

4.5 Regenerative brakes

As mentioned above, apart from EMS, charging systems might account for other technological devices like regenerative braking. Regenerative braking is a mechanism that reduces the speed of a vehicle by transforming part of its kinetic energy into electrical energy. This electrical energy can be returned to the system, which results in an improvement of energy usage efficiency. The main advantages of regenerative braking are, on the one hand, energy savings, and on the other hand, the reduced wear and tear of brake shoes and wheel tires, which leads to lowering maintenance costs. However, this system requires that RUs carry out higher investments in comparison to conventional train braking systems.

Given the benefits of regenerative braking on trains, it is worth exploring how the different charging systems across countries account for this type of technology and consequently, whether its deployment is fostered or not.

For instance, the Norwegian charging system accounts for regenerative brakes by deducting the amount of energy produced by RUs using regenerative brakes from their electricity bill. As a result, RUs have an incentive to use this type of technology. In this regard, Belgium only invoices RUs for their net consumption (i.e. consumption minus regeneration) if energy metering data from EMS pass the required validation. Similarly, one of the approaches to calculate the Traction Electricity Charge (EC4T) in Great Britain is to deduct the regenerated electricity from either the metered electricity consumed (based on readings taken from the electricity meters on trains) or modelled (estimated) electricity consumed.

In Spain, the IM is implementing a new invoicing system to better capture the energy that is actually consumed by each service provided by RUs. This new mechanism recognizes the energy returned to the system by trains with regenerative brakes for the entire network, not only for those using alternating current (mainly high-speed lines) as it used to be in the past. In order to discount the returned energy in their invoicing, RUs using trains with regenerative brakes must notify the IM the units or series equipped with regenerative braking in advance. In the absence of on-board power meters, there are ratios to calculate the estimated consumption and regeneration according to the estimated gross tonnes-km produced measured by pantographs. These ratios consider whether or not the train is equipped with regenerative braking. The foreseen values for these ratios are published in the IM's Network Statement covering a one-year period but they are adjusted on a monthly basis based on total gross tonnes-km production and actual consumption at substations. According to the latest available data, in Spain, energy returned to the network on high-speed lines account for 7,5% of total energy consumption.

In the case of Germany, regenerative brakes are accounted for in the way that RU can choose an energy supplier that offers them to pay for their net consumption.

4.6 Other technical differences and modulation of charges

Apart from EMS and regenerative brakes, charging systems might contemplate other technical differences to justify different tariffs or different consumption estimations. According to the questionnaire, there are some examples of technical differences or alternative ways of estimating consumption that are applied by charging systems:

- As mentioned before, in Spain there are different conversion ratios for the different services running in direct current lines (conventional lines), which provide a different estimation of energy consumption per gross tonnes-km produced by freight and passenger (differentiated by long distance, medium distance and urban) trains. These ratios do not explicitly provide information on technical differences of the trains, but they implicitly account for them according to the average characteristics of the trains running on those segments.

- In Croatia, the system contemplates more variables and determines the basic price of electricity according to the train category, the railway sections category (hilly and lowland), the direction of mountain railway sections (rise and fall) and the time period of electricity consumption (higher and lower tariff).

- In Belgium, the system estimates energy consumption based on train-km, tonnes-km and degree days (for compensating consumptions for heating and cooling).

- In the Netherlands, the energy consumption of locomotives with EMS can be automatically billed. For the remainder, a settlement model is used that estimates the electricity consumption per RU. This model takes into account the material type (mass, train resistance, etc.), timetable (speed, number of stops, etc.), heating energy and energy savings. For freight services, the weight is also taken into account.

- In Italy, the measurement system currently applied by RFI uses the so-called virtual meter, which is an algorithm that takes into account the technical characteristics of the rolling stock and the characteristics of the line section to estimate the consumption along it.

- In Great Britain, apart from the metered consumption modality, the charging system foresees two other approaches to estimate consumption. The first one, named modelled consumption, is based on estimated consumption, subject to an end of year volume reconciliation exercise (this exercise is further explained later in the paper). Modelled charges are calculated using the following formula: EC4T charge (pence) = electrified train miles x traction electricity modelled consumption rate (kWh/train mile) x tariff (pence/kWh). The second approach, which is called partial fleet metering, or PFM, extrapolates metered consumption from metered trains to estimate consumption for un-metered trains. PFM is not currently used by any operator.

- In Germany, where EMS are standard, older locomotives without on-board EMS devices can be settled via average consumption values. Regenerative brakes are accounted for indirectly, as it is usually contractually agreed that the RU pays for the net consumption (gross energy consumption minus refeeded energy). Nonetheless, the system does foresee a difference in case of delays of trains (not being in the pre-ordered consumption grid at the expected time). For these cases, the network operator can bill additional costs for the delay (as the operator has to make sure the energy is there when it is needed).

According to the available information, there is a wide variety of charges and changing modalities across countries that account for technical differences of trains and other characteristics that affect energy consumption. The following table summarizes this information.

Country	Power meters (EMS)	Regenerative brakes	Other technical difference
Austria	✓	✓	✗
Belgium	✓	✓	✓
Bulgaria	✗	✗	✗
Croatia	✗	✗	✓
Finland	✗	✗	✗
France	✓	✗	✗
Germany	✓	✓	✗
Great Britain	✓	✓	✓
Hungary	✗	✗	✗
Italy	✓	✗	✓
Latvia	✗	✗	✗

Lithuania	✗	✗	✗
Luxembourg	✗	✗	✗
The Netherlands	✓	✓	✓
Norway	✓	✓	✗
Poland	N/A	N/A	N/A
Portugal	✗	✗	✗
Serbia	✗	✗	✗
Slovenia	✓	✓	✗
Slovakia	✗	✗	✗
Spain	✓	✓	✓
Sweden	✓	✓	✗
Romania	✗	✗	✗

As shown before, EMS and regenerative brakes are contemplated in some countries. In as much as charging systems deal with trains with and without these devices, different charging modalities coexist. This implies that there might be differences in the final amount paid by different trains for the provision of traction current. Therefore, it is important to analyse how charging systems address such technical differences, particularly whether the systems set direct on implicit incentives for some modalities and how power losses are distributed between them.

4.7 Incentives

The traction current provider can implement direct or implicit incentives that benefit certain technologies through lower charges or discounts on the final tariffs. The way the abovementioned technical differences are dealt with by the charging system might have a direct effect on favouring some modalities.

Some incentives are rather generic and result from the fact that usage of regenerative brakes allows for returning power to the network and reduce net consumption. The implementation of EMS also allows for cost savings due to more efficient driving and encourages more energy-efficient trains which might become more attractive for future investments purposes. These incentives are recognized by most of the RBs in which the charging system account for these devices.

Another generic incentive related to the usage of EMS stems from the fact that more accurate measurements of energy consumption might be more beneficial for charging purposes than estimation of consumption based on output of production. This is acknowledged by the Swedish RB which considers that, even though the system does not include explicit incentives for the implementation of EMS, in most cases, trains with power meters are charged less per kWh than trains charged based on template values for consumption as shown in a study from 2014. Therefore, this would be an incentive to use power meters.

In addition, deployment of EMS might create other benefits for RUs in comparison to other operators which do not use them. For instance, in Belgium, all the electricity remaining after accounting for the consumption measured by the EMS devices is distributed among the remaining trains, meaning that they bear the cost for energy losses. The same system is used in Austria.

There is also one example of explicit incentive to foster implementation of EMS. In Spain, the IM has introduced a reduction in tariffs for energy consumption and access to the electric network. This discount only applies to high-speed lines electrified at alternating current, since EMS devices are not yet used in the charging system for direct current on conventional lines. This discount was initially set at 5%, although the applicable percentage might change each year.

4.8 Power losses and distribution

The energy that is finally consumed by the train does not fully match the energy that is flowed into the system, as there are losses throughout the network. This section describes whether or not the electricity that is lost in the distribution through the grid is taken into account by the different charging systems and, if so, what are the economic and technical elements used.

Based on the information provided by IRG-Rail members, most of the countries take into account the losses of the system. The process followed by countries considering energy losses is described below:

- In Austria losses are recovered within the charging system based on the consumed MWh for trains with power meters or gross tons-km for trains without meters.

- The Belgian Network Statement considers that losses represent 4% of the energy that is flowed into the system. The cost for these losses is invoiced via grid fee. However, real losses are expected to be around 7%. The non-allocated energy is distributed to trains without EMS (reallocation). This was accepted by the regulator as a way to support installation of EMS.

- In France, losses by the electrical systems from substations up to train capture points are covered by the *redevance* RCTE (*redevance pour le transport et la distribution de l'énergie de traction*)-component A.

- In Croatia, at the connection of the public network and the catenary network, the electricity consumed by the catenary network is measured in electric substation. It includes the energy for train running and losses that occur in the catenary.

- In Finland, energy losses are taken into account through the charging system, and they are charged based on MWh consumption. According to the IM's "Electricity transmission service" description, the net consumption of the individual consumption targets subtracted from the net consumption of supply stations equals the contact-line dissipation.

- In the German case, system losses are not charged separately, but are covered by the network fees. The network operator is responsible for balancing network losses and for the procurement of the energy needed for this. The costs for this include the so called "loss energy" as part of the network fees according to § 10 StromNEV. Reductions of network fees are only possible under the rules of § 19 StromNEV, especially depending on peak load, usage hours and consumption quantity.

- In Hungary, the network loss of transmitted traction current is part of ensuring electric energy for traction service. This loss is defined in the following way: Network loss of transmitted traction current = (Costs of the network loss related to the total volume of traction current to be prospectively transmitted in the given business year) / (Volume of traction current to be prospectively transmitted in the year of charge).

- In Luxembourg, power losses are indirectly considered by billing the net energy cost entering the system.

- In Norway, the RUs pay for the conversion and transfer losses at Bane NOR facilities through the MAP.

- The Polish system takes into account the energy losses of the system as well, but its regulation is beyond the Railway Transport Act.

- In Portugal, energy losses are considered through the charging system. The railway undertakings pay for the energy measured in the substations, which includes the energy consumed by the rolling stock and the losses in the wires of the catenary and other equipment.

- In Slovakia, losses are partially covered in traction current charge regulated by RONI.

- The losses under the Spanish system are considered in the formula used to calculate the charge by including the coefficient "p", which is estimated as the 7% loss of efficiency in the energy transmission. This coefficient increases the energy consumed that is initially estimated, therefore augmenting the charge. The effect is the same if the train has or does not have an on-board power meter (EMS), but it is different if the train has regenerative power brakes. In this case, the coefficient "p" does not multiply the amount of energy that is returned to the system, implying that the charge is reduced by the full amount of energy returned without accounting for potential loses.

- In Sweden there is a loss surcharge added to the charge. This loss surcharge has two components: a general loss surcharge (of 1.14) added to all vehicle types, and a vehicle specific surcharge depending on the type of vehicle (1.0-1.13). There is no difference for trains with or without power meters or regenerative breaks.

- In Great Britain, a transmission losses uplift is included in the charge calculation that uses electricity consumption measured by an on-board meter (metered consumption). In the case where consumption is modelled (estimated), a distribution system loss factor is applied. Regenerated electricity is also accounted for in the calculation of charges.

- In Romania when determining the electricity consumed by the end customer, the losses of electricity for the supply of the railway contact network are taken into account. The distribution of losses is made in proportion to the electricity consumed, without any other criteria that considers the technical equipment (regenerative brakes or power meters).

4.9 Deficit and surplus of the charging system

At the end of the billing period, the provider of traction current might deal with some charging deficits or surpluses of the system. For instance, it might be the case that the provider had charged too much for the energy that it is actually consumed by RUs (therefore, running a surplus) or on the contrary, too low (which led to a deficit). According to the information gathered, in the event that these imbalances occur, charging systems deal with them through different approaches:

- In the case of Belgium, if the framework changes, tariffs can be adjusted. In fact, deficits or surpluses are taking into account while defining the tariff for the next year.

- In Croatia, the amount charged to RUs and the amount paid to the electricity supplier is adjusted twice a year in order to deal with the system imbalances.

- In the case of Finland, in September 2020, the IM prepared an estimate of the prices of transport services based on the Network Statement for the 2022 timetable period, based on the actual and measured energy consumption of the transfer fees for the previous 12 months. The IM charges monthly for the use of the service based on these prices. The estimated invoicing will be checked in spring 2023 with a compensatory invoice to correspond to the invoicing of the external grid companies, the costs of dissipated energy and Energy Exchange and Settlement System costs (EREX).

- In Germany, as the charging system is based on the energy consumed measured by power meters, deficits and surpluses are included in the network fees.

- In the Hungarian case, the IM issues a preliminary and then a final invoice. If the RU has an overpayment, either the IM consults the RU or the RU contacts the IM. The RU may decide to request repayment of the surpluses or request the amount to be credited to another account. In that case, the IM pays back the surpluses within 15 days and, if necessary, issues a corrective invoice. The IMs annually review if there are any surpluses or deficits between the purchased and transmitted traction current. The differences are invoiced (positively or negatively) to the RUs according to the energy already transmitted to each RU.

- In Lithuania the operator has to prove to RU that the charge indicated in the invoice presented to RU was calculated according to operator's established methodology.

- In Luxembourg, the difference is billed or reimbursed proportionally to the RUs that used traction current at the end of a billing period.

- In the Norwegian case, the IM invoices the RUs "*a konto*". This means that the IM first invoices the RUs each month based on expected energy consumption. When the IM have the information regarding the real energy consumption, they calculate the RUs exact energy consumption per month and they invoice the RUs with charging deficits and repay the RUs with charging surpluses, accordingly.

- The Portuguese methodology for dealing with charging deficits and surpluses is described in the Network Statement, which is basically as follows: "*The infrastructure manager bills the amounts of electric energy* *for traction consumed each month by each EF, according to the apportionment process described the network statement. In the event of delay in the data to be provided by the FEs and for the IP to proceed with the due payment of the invoices for the month under analysis, an amount corresponding to the average monthly consumption value of the last six months, with adjustments being made in the month following receipt of the missing data*."

- In Spain, the IM makes adjustments at the end of the year for tariffs TCG (administrative costs) and TRAT (cost for accessing the network), so the amounts equal the actual costs incurred by the IM in that period. These adjustments are done on a quarterly basis for tariff TE (cost of the energy consumed).

- In Sweden, at the end of the year, the IM compares their actual costs with the amount RUs have been billed. Sixty per cent of all power is billed based on template values which means that the amount of power used by many trains is only an estimate. Hence, the actual costs and the billed amount will not correspond perfectly, there will always be a surplus or deficit at the end of the year. This "volume difference" is regulated at the end of the year by either charging (in the case of a deficit) or crediting (in the case of a surplus) to RUs. The volume difference is allocated based on train rains for trains without power meters. The reason being, according to the IM, that the volume difference is mainly driven by trains that do not have a power meter and whose power consumption is estimated using template values.

- In Great Britain, at the end of each financial year, two 'wash-ups' are carried out, a volume 'wash-up' and a cost 'wash-up'. All parties using the modelled consumption approach (including both RUs and the IM - Network Rail) participate in the volume wash-up, which compares total modelled consumption against total actual consumption across given sub-networks known as electricity supply tariff areas (ESTAs). This results in additional payments by Network Rail to RUs if actual consumption is below total modelled consumption, or by RUs to Network Rail in the opposite case. At the end of each financial year, Network Rail and all RUs using electric traction also participate in a cost wash-up which compares the cost per kWh charged by Network Rail with the cost per kWh paid by Network Rail to electricity suppliers. This also results in additional payments between Network Rail and operators.

- Similarly, in Romania the consumption is recorded on a monthly basis for each end customer (consumer) of the railway contact network. There are no situations in which SC CFR Electrificare SA (the energy supplier) charges more or less for the electricity consumed and thus, no adjustments are required.

- In Latvia, as there is currently only one railway undertaking (passenger PSO) that purchases traction current from the IM, this RU must bear all the costs of the electricity supplied at substation. Thus, there are no deficits nor surpluses.

5. Regulatory experiences

This chapter shows regulation experiences reported by the participating RBs dealing with the provision and charging of traction current.

- In Belgium the IM buys the electricity following a public procurement act. The tendering is open to all possible suppliers and the lowest bid wins the contract.

- In the case of Finland, in November 2021 the Finnish Rail Regulatory Body issued a decision (TRAFICOM/144208/03.06.01/2021) in the case "*Complaint by VR Group Ltd (the incumbent RU) concerning the reactive power costs charged by the Finnish Transport Infrastructure Agency (the main IM)*".

  In its decision, the RB saw the filtering electrical interference in the electrified railway network and the resulting reactive power costs to be included in the minimum access package (MAP) of the Finnish Rail Transport Act. Before the decision, these costs were included by the IM in the traction current service called "Electricity transmission service", which included also the following: the electricity transfer (performed by external grid companies), measurements, energy losses (dissipation) and balance management. Consequently, according to the Finnish RB's decision, the costs due to filters that generate reactive power, included in the transfer fee from high-voltage networks and published by the Finnish Transport Infrastructure Agency in the railway network statements for the timetable periods 2021 and 2022, were not in accordance with the Finnish Rail Transport Act. The RB determined that the costs of reactive power generating filters had to be removed from the context of electricity transfer service and from the contact line network's electricity transfer fees, which were specified in the network statements. It is good to notice that the filters are parts of IM's electricity supply stations, so, in this case, the reactive power was not produced by the rolling stock. The main IM complied with RB's decision.

- In Hungary there is no experience in regulating the charge itself. The expected traction current charges are published in the Network Statement, but these charges are based on information from the last 3 years. The IMs may derogate from this charge, if the RB gives prior authorization. In its procedure, the RB does not examine the charge itself, but only the charging methodology i.e. If it is in accordance with the Railway Act and complies with the principle of equal treatment, the RB then authorizes the derogation.

- The Latvian RB has monitored the publication of information on traction current service in the Network Statement and it has intervened when the publication was missing from the pricing list and relevant internal regulations of the IM. Since then, the IM has published the necessary documentation and price list. The RB has not received any complaints on the charges nor service and it has not investigated the charges on its own initiative.

- In Portugal, up to now, the regulatory activity has been residual, as there is no profit for the infrastructure supply traction current, and there were no complaints about the process and methodologies for charging the electrical energy supplied. Nonetheless, AMT has set up a Working Group with the aim to study if there are the need of new regulations for allow or facilitate the direct arrangements between the railway undertakings and the suppliers of electrical energy.

- In Spain, the CNMC has analysed this service several times when reviewing the content of the IM's Network Statement. The RB's decisions have highlighted the following:

I. It is desirable that the charging system is based on actual consumption by the trains, so it could be an incentive for implementing efficiency measures that improve the train operation and the rolling stock itself. In this regard, the IM implemented a system allowing for charging according to the consumption indicated by the on-board power meter (EMS) of the train.

II. Also related to the previous point, CNMC recommended that the IM should design and implement the correct incentives for RUs to install EMS devices on their trains, so that the high cost of this technology and the possible reluctance of RUs using less efficient trains will not deter the migration to the actual consumption regime. These incentives should not favour more inefficient trains over the others.

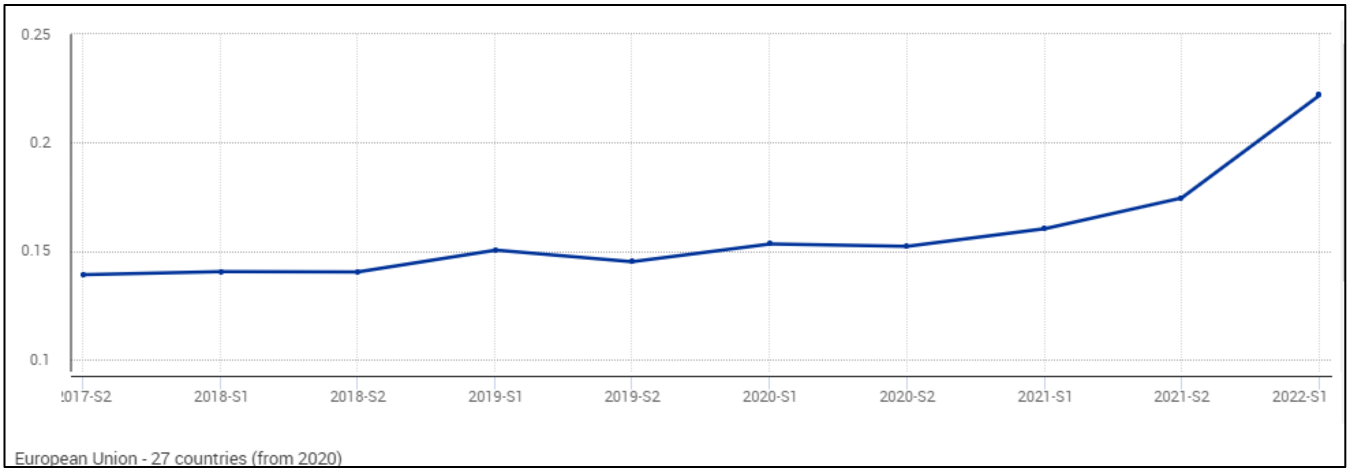
III. Since the IM is the only possible supplier of electricity and given that energy is a relevant cost item for RUs, CNMC suggested that the IM should consult with the RUs before contracting with an energy undertaking, so they can provide their views on the different models of contracts and hedge options against price increases.

- In 2021, the Swedish RB received a complaint from a RU concerning the IMs charges for providing traction current. The RU argued that the template values used to calculate power consumption and losses, the regulation of the volume difference and the fact that trains equipped with regenerative breaks were reimbursed for 100 per cent of the power they send back to the network were discriminatory against the RU. Among other things, the RU argued that the measurements upon which the template values are based were too old. The RB mostly ruled against the RU. However, it did rule in their favour in that the IM could not properly motivate why all the power produced by regenerative breaks should be reimbursed. The IM must base the amount of power that is reimbursed on studies of how much of the power can be used in the system.

- In Great Britain, the RB regulates the charge and reviews it every 5 years during its periodic review of Network Rail - the mainline IM. RUs can choose their strategy for the procurement of electricity (including the option to lock tariffs) via Network Rail's contract with the relevant electricity supplier. Alternatively, RUs can purchase electricity from a third party (although none currently do so).

6. Prices of the energy market

Apart from all the abovementioned traits of the charging systems for traction current, there are other external circumstances that are of great relevance for RUs. Due to the increasing volatility and persistent high energy prices, the cost of running an electric train has increased considerably. This constitutes a major challenge for RUs' business models and might become a major obstacle for rail transport. According to Eurostat, prices for energy consumption have grown considerably since the beginning of 2021.



SOURCE: EUROSTAT. ELECTRICITY PRICES FOR NON-HOUSEHOLD CONSUMERS - BI-ANNUAL DATA (FROM 2007 ONWARDS)

Indeed, prices for electricity have grown to unprecedented peaks. These price increases, depending on the contractual agreement between the energy supplier and client (either the IM as the service provider or the RU if it can choose the energy provider), might be passed-through, thus increasing the level of the charge and the cost for RUs. This is the case for those charging systems in which tariffs fluctuate with prices for electricity (variable prices), such as in Spain, where the IM publishes a monthly update on the evolution of tariffs according to the price of electricity. Also, in GB the IM buys energy from the energy supplier at market prices, which are variable. The IM, then recovers that cost through a variable charge. In Italy, as well, the price of traction current varies according to the trend in the price of energy

In this regard, this paper has shown how, in the majority of systems, there is only one provider of traction current, which tends to be the IM. There are, however, several legal or practical reasons for such outcome. Nonetheless, under these market circumstances, RUs operating in countries where it is actually possible to choose an energy provider might be in a better position to negotiate fixed prices or hedge against price increases. Therefore, in these countries, RUs are free to choose the provider that better fits with their business model.

This is the case of Finland, where RUs make an agreement on energy itself directly with energy producing companies. However, the Finish RB does not have information on the prices in these agreements (whether prices are variable or fixed). Also in Germany, given that RUs can choose from different traction current providers, they can choose from a variety of different contracts, i.e. short-term spot-market or longer running contracts that provide the chance of fixing electricity prices in advance. In case no individual provider is chosen, the RU can use the IM's fallback-option: Prices for this are publicised; in former years, these have usually been updated once a year. In 2022, there have already been price-updates in January, February and May.

On the contrary, in those countries where the IM acts as a mere intermediary, this party might have less incentives to negotiate a more beneficial agreement (or even a different approach), given that it will not be the party that ultimately consumes the electricity. Nonetheless, there are cases in which the sole provider takes actions to avoid price volatility. In Sweden, 80 per cent of the electricity sold by the IM is bought on the futures market. In any given year, 20 per cent of the annual consumption volume is purchased on the futures markets and the rest on the hourly spot market. Currently, the IM is buying future contracts for power to be delivered in the years 2023 through 2026. This hedging strategy insolates the railway undertaking from much of the price volatility currently seen on the electricity markets as only 20 per cent of the electricity provided at any given time is bought at spot market prices. Also in in Spain, the IM, for the latest energy contract, bought futures in the market to hedge against price increases on energy consumption in the high-speed network, according to what the RUs had requested. In GB RUs are able to 'lock-in' electricity prices/volumes in advance, in which case they are charged on the basis of the electricity they consume at the rate they locked-in.

Finally, in France, the pricing for the period 2021 - 2023 of the RCTE-A and the RFE correspond to the price fixed for the year 2021 (published in December 2020), which may be adjusted, if necessary, in December A-1, of the price contracted for the year A with SNCF Réseau's supplier, depending notably on the market prices of electricity. It may evolve during the year according to the capacity mechanism implemented in France. Since January 1, 2017, pursuant to a ministerial order of November 29, 2016, the price of a megawatt-hour must include the costs related to the capacity mechanism, introduced by Decree No. 2012-1445. This regulatory provision aims to guarantee the security of the French electricity system. The principle of the capacity mechanism is based on the obligation for each electricity supplier to cover, through capacity guarantees, the consumption of its customers during peaks in electricity consumption. In practice, the introduction of this mechanism leads to an increase in production costs for the energy supplier, which are then passed on to the end customer. As the cost of the capacity depends on the actual consumption of the customer and the selection of the peak period by the transmission system operator RTE, it can only be determined ex post, at the end of the delivery year. Thus, the additional cost integrated by the energy supplier at the time of contracting is only an estimate.

As a conclusion, the impact of energy prices on the final bill paid by RUs on their energy consumption depends on whether they are allowed to choose an energy provider or if the sole provider of traction current takes into account what RUs require or takes steps towards mitigating volatility. It is clear, therefore, that the situation is quite different across Europe as there are countries in which this service is open for RUs to select energy providers, while in other countries the supply of energy is subject to decisions taken by the provider of traction current. As the paper have shown, there are legal constrains that might be set by regulations on both energy and rail sectors, as well as practical reasons affecting the number of energy providers.

Also, in connection to this topic, the paper has shown that only in a few countries it is possible to charge according to metered consumption as estimated by on-board power meters (EMS). The fact that some charging systems do not allow for the use of such devices constitute a practical obstacle for choosing energy provider, given that it is more difficult to link energy consumption with output production by RUs.

This situation could also happen if, even if the system allows for charging according to EMS devices, RUs do not install them in their trains. In this regard, incentives for EMS implementation could foster a broader display of power meters.