Position Paper / Recommendation
of Charging Interface Initiative e.V.

Subgroup “Charging Acoustic Function”

Date of last change (2024-05-08)

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1. Introduction

CharIN is an umbrella, cross-industry organization that represents stakeholders such as manufacturer of EVSE and EV as well as operators of charging infrastructure and mobility service providers. Our main goal is to move towards interoperable charging, where vehicles, chargers, and software systems work together, and to make the EV user experience reliable, easy, and smooth. CharIN´s holistic approach is not limited to passenger cars. Its international community is comprised of leading global companies representing every link of the e-mobility value chain and multiple experts, who have been working together as a team to drive the requirements of charging all kinds of electric vehicles. For instance, CharIN has been working on a Megawatt Charging System to be used to charge other heavy-duty commercial vehicles, like-e-ferries, ships, and planes.

This document analyses the implications of the noise immission requirements that the charging station (CPO) must comply with, taking into account the electrical charging systems and electrical vehicle noise emissions when charging. The terms immision and emission will be expanded in the next section. The analysis assumes that there are stringent immission requirements to be fulfilled, typically in urban areas. In the case of highway or depot charging in industrial sites these may not be relevant.

This document shall provide an overview of the topic, give background information, and offer viable solutions for the future.

2. Regulations on Noise

Regarding sound, there is a difference between the sound emission (sound which is sent out or emitted from a source) and immission (sound which is received at a certain point at a distance from the sound source). In simple words, when someone speaks, sound is emitted and the immission of speaking is heard by someone else. Sound immission is reduced by increased distance between source and receiver (Figure 1).

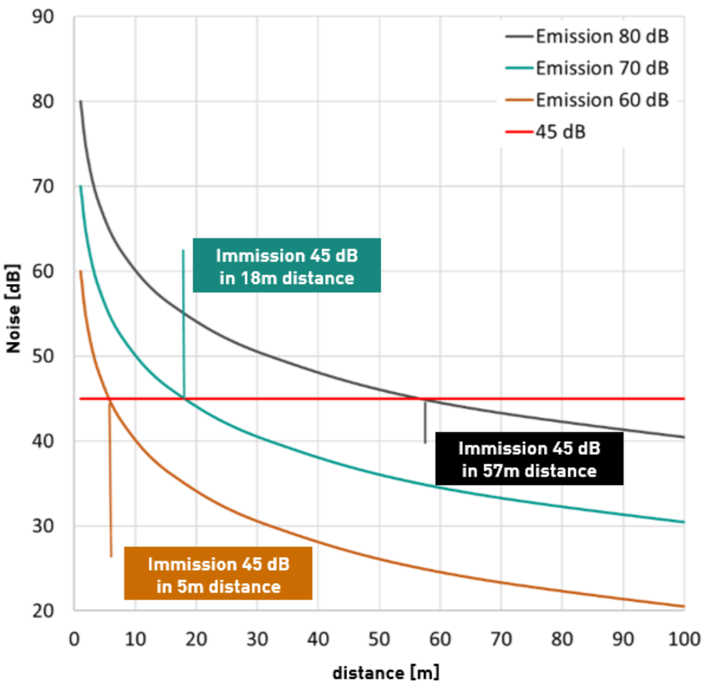


Figure 1: Emission and immission in relation to distance.

Emission:

No special regulation is given for EV charging; therefore, the limits apply to charging sites as well.

Immission:

Sound immission regulations aims to protect citizens from the harmful effects of long-term noise exposure, by limiting the sound level on the facade of buildings at various locations. These regulations differ between countries and no general rule can be extracted. However, often a classification of the area (e.g., residential, industrial) is relevant for the noise limits. Thereby, charging stations or charging sites are not treated differently by the regulation.

Typically, it is the responsibility of the site owner to comply with local applicable regulations. Transferred to the problem at hand, this means a CPO would be obliged to meet the local noise regulations. In practice, this can be achieved by assessing the site concerning noise sources and regulation to offer in the results to local authorities when a planning permit is being sought. However, it is on a case-by-case basis.

An ideal regulation is presented in the following section.

In Germany sound immission is regulated by (German Environment Agency, 1990). There, first the area is categorized. Secondly, the Sound immission values at the closest residence are defined for day and night, e.g.:

- Industrial area: maximum 70 dB(A) both day (equivalent sound pressure level for 8h) and night (equivalent sound pressure level for 1h)
- Mixed area: maximum 60 dB(A) during the day and 45 dB(A) in the night

However, other countries can have a different approach on sound immission regulation. An overview is given by the following table:

Table 1: Countries with their sound immission regulation.

Country	Residential areas	Charging Cars	Charging Infrastructure
Germany	Sound Immissions are regulated, depending on the area classification and the time.	No detailed regulation; indirectly defined by resident protection.	
China	Sound Immissions are regulated, depending on the area classification and the time.	No detailed regulation; indirectly defined by resident protection.	No detailed regulation; indirectly defined by resident protection. Recommendation for the noise emissions defined.
USA	Diverse local regulations on state or even city level make a comprehensive overview difficult.		
France	Additional noise is allowed. The higher the surrounding noise is, the higher is the permitted additional noise level.	Regulated like any other additional noise.	
Sweden	Sound immissions are regulated, depending on the area classification and the time.	No detailed regulation, indirectly defined by resident protection.	

Austria	The noise must not exceed the usual local noise and must not disable the common use of the next property.	No direct noise limits.	
Italy	Sound Immissions are regulated, depending on the area classification and the time. (higher or similar limits than Germany except 65dB(A) for industrial)	No detailed regulation, indirectly defined by resident protection.	No detailed regulation, indirectly defined by resident protection. A recommendation for the noise emissions exists.
Japan Korea United Kingdom	Sound immissions at the residents are regulated, depending on the area classification and the time.	No detailed regulation, indirectly defined by resident protection.	

3. Noise Sources at Electrical Vehicle Charging Sites

This section presents an evaluation of the main noise sources at an EV charging site, namely passenger cars, heavy-duty vehicles, and electric vehicle supply equipment (charging stations). The relevant impact factors are identified, and the magnitude of the emissions are investigated.

While charging, all the mentioned devices must be cooled to cope with the heat created by the charging current. Therefore, a cooling fan is typically installed which emits noise. This section focuses on HPC (High Power Charging) charging, since the current is very high compared to other charging types, and therefore the noise.

3.1. Electrical Vehicles

In general, during charging there is a thermal loss in the battery which depends on the charging current, which in turn heats up the EV battery. The heat loss is proportional to the square of the charging current, so the trend to higher charging will lead to much higher heat loss in the battery.

The battery has a thermal mass, so some heat loss can be stored during charging in the battery. So, at the beginning of the charging there is normally no cooling needed. When the temperature reaches a given point, the battery must be cooled. Alternatively, the cooling starts at the initiation of charging to avoid thermal derating. Thereby, constant cooling during charging can reduce the noise, because with increased cooling time a smaller cooling power is sufficient to remove the same thermal energy from the battery.

The heat loss must be absorbed by the surrounding air. Because the temperature level of the air after the condenser is limited, an increasing cooling demand will lead to a rising air flow through the condenser. By raising the air flow, the noise is rising. The main influence on noise emissions thereby is the size of the blower at a given air flow, but also other properties of the blower (e.g. blade shape). The size of the radiator (air speed) and other structural parts in the air flow especially in the vicinity of the fan can influence noise. An additional noise source is the refrigerant compressor which can be louder than the fan with a different, more annoying noise characteristic. The types of noise sources are technology-dependent, and the above statement is valid for current products but may change in the future.

An illustration of the dependencies is given in the following figure:

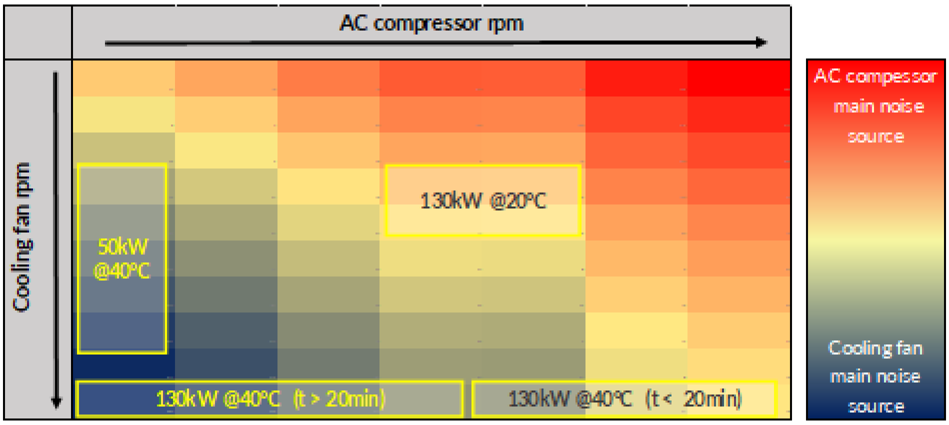
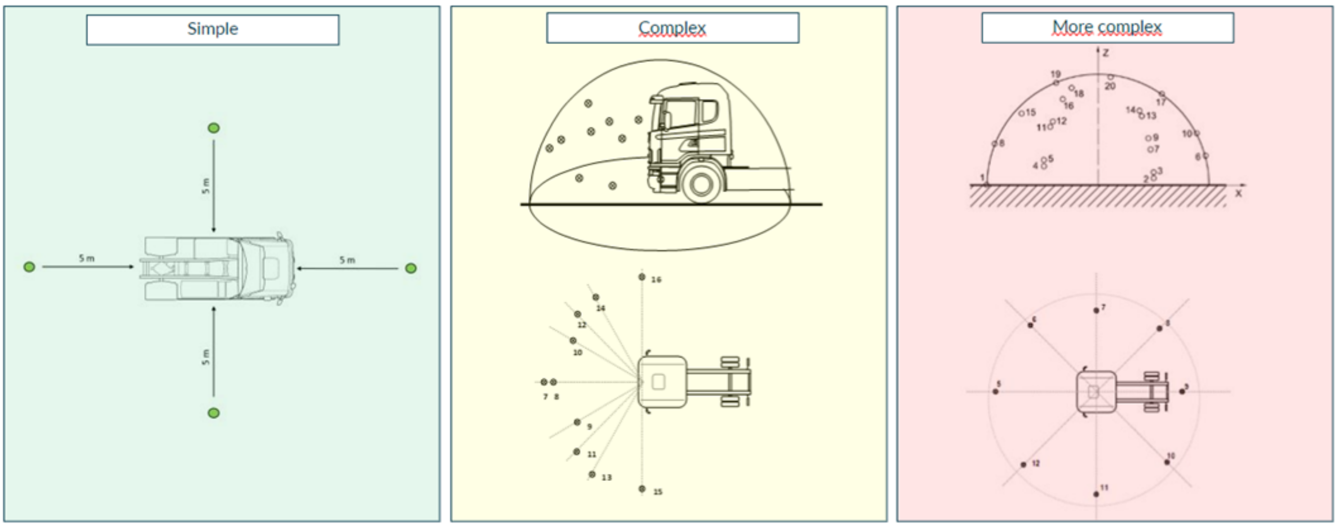


Figure 2: Example of main sources for vehicle exterior noise in several charging conditions. Source: Renault.

Today there is no established industry standard on measuring noise emitted by EV cooling fan during charging. This makes comparison of different test results very difficult. The first step to get a reliable and comparable sound level from cooling fans should therefore be to start developing a measurement standard. Some measurement set-ups that have been used by different manufacturers, and which could form the base of a measurement standard is given in the figure below:



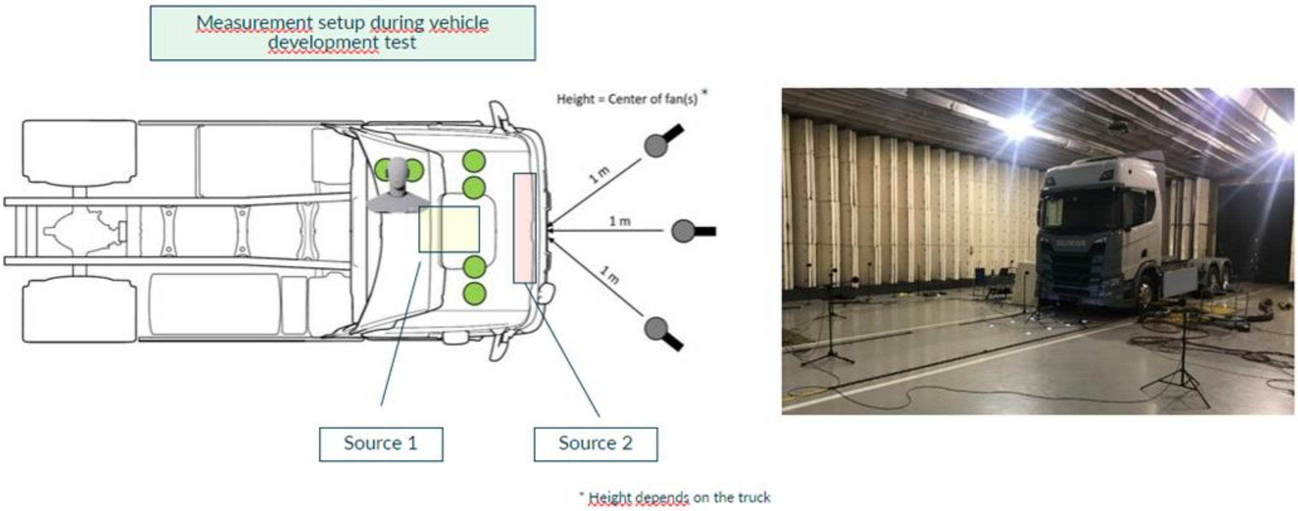


Figure 3: Measurement set-ups used by different manufacturers.

3.2. Passenger Cars

In the previous section, it was explained that battery size, battery temperature, outside temperature and charging power influence charging noise. Due to the high variation of these parameters between car models, it is difficult to predict the charging noise of a car.

This was also shown in a study by EnBW (Scheubner & Leonetti, 2023). There, different vehicles were plugged in at an HPC charger and the noise emissions were measured. An example is illustrated in *Figure 44*. It can be seen that emissions change during charging sessions and between cars. Some vehicles have a very high blower rpm in a short period of time, some vehicles stay constant at lower rpm whereas others seem to have a demand-oriented approach instead of hysteresis control algorithms. The total sound levels differed significantly: one EV emitted between 46 dB(A) and 64 dB(A) in one charging session. At a given outside temperature (26°C) the maximum sound level of the four different cars ranges between 69 dB(A) and 77 dB(A). Over a temperature span between 12°C and 30°C, the maximum sound level differs between 57 dB(A) and 78 dB(A).

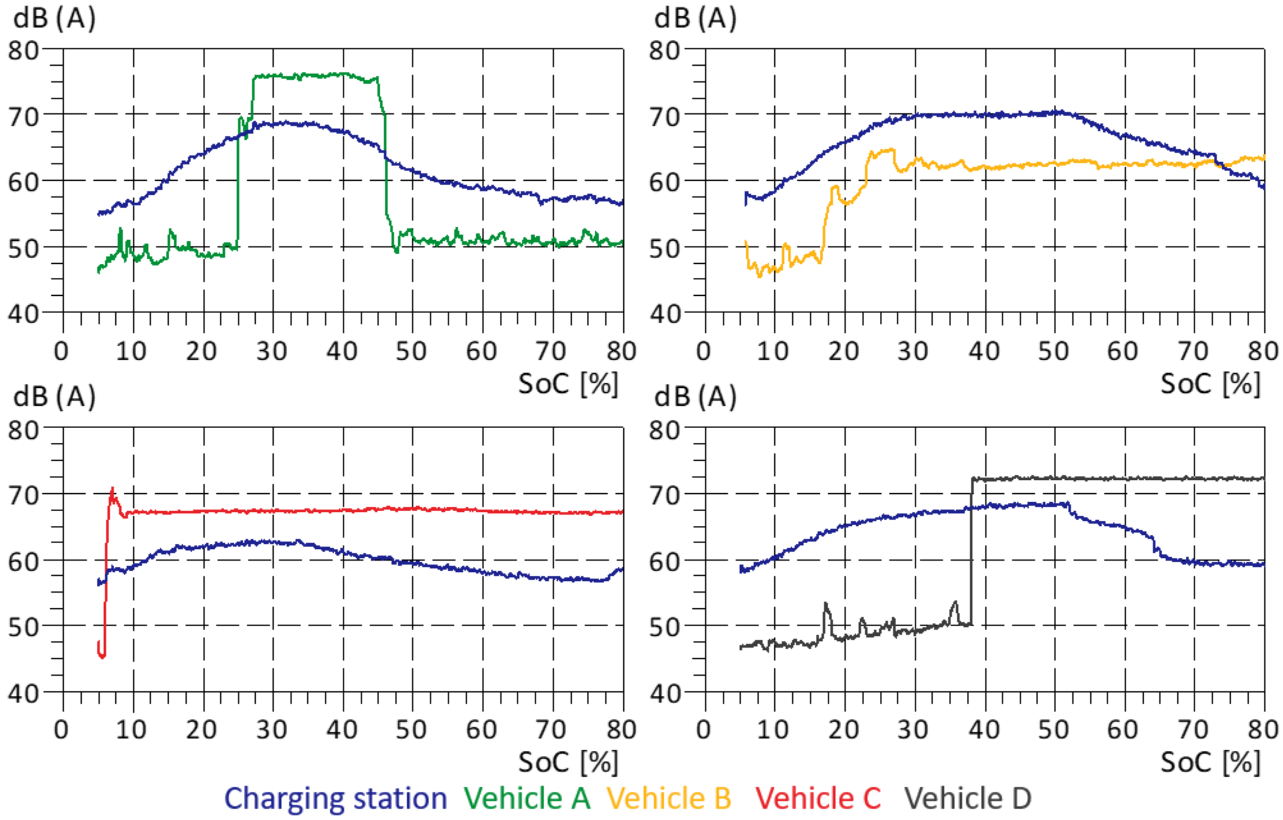


Figure 4: Charging noise of several passenger vehicles. Source: (Scheubner & Leonetti, 2023)

3.3. Heavy-Duty Vehicles

A heavy-duty vehicle (HDV) is considered a working tool to fulfill a function in society, such as time critical transportation of chilled groceries, building material to a building site, parts to a production site etc. The professional driver's working and resting time is regulated by law. Therefore, a high predictability regarding charging rate/time is imperative. HDVs are tailor made solutions to fit the customers' demands (long haulage, construction, city distribution and others). This will result in different placing of fan, cooler, AC compressor etc. in the vehicle.

Heavy trucks will in comparison to passenger cars need a higher battery capacity, charging rate and in general require a higher cooling capacity. Battery temperature depends on how the vehicle is used and ambient conditions It is not always possible to control the temperature of the battery before charging; it depends on where the charging station is situated and the truck and trailer payload.

Electrified trucks are newer on the market compared to passenger cars and no studies on variations between trucks and brands regarding noise level are available. One can, however, expect that the variations in noise emission will be at equal or higher compared to passenger cars, since one truck can have many different battery configurations depending on its application.

3.4. Electric Vehicle Supply Equipment (EVSE)

In DC charging, there is an input AC supply from the grid which must be rectified (AC to DC) locally before being supplied to the electric vehicle (EV). This rectification is done using power electronics, which are non-ideal devices and produce heat, that must be dissipated. Due to the high power of state-of-the-art DC chargers, there is also significant current (up to 500A), which must be handled by the connections and cables within the system. The induced heat loss is proportional to the square of the current being carried.

The EVSE, just as the EV battery, has a thermal mass/heat capacity which can absorb some of the heat during the initial stages of charging (see graph below), but at sufficient power levels this will be overcome and at some point, active thermal management will engage to control the peak temperatures reached for the key components. The heat is typically dissipated directly to the atmosphere by forced convective cooling with fans.

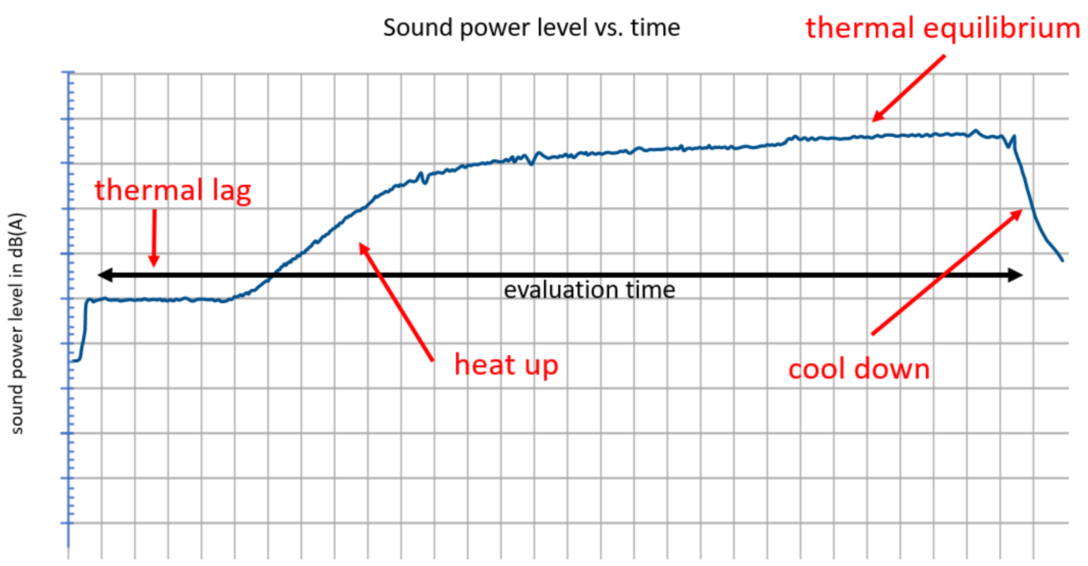


Figure 5: Sound power level over time for a typical EVSE.

There is the option to have liquid-cooled components, which then relies on a cooling radiator that will be forced-convection-cooled via fans. Liquid cooling does not reduce the total cooling requirement of the system but can increase the thermal mass and therefore delay starting the fans and delay any noise generation. In addition, liquid cooling allows different configurations of fan and heat exchanger sizing thus affecting the noise profile of the EVSE and ultimately offering the opportunity to have quieter EVSEs.

The dominant heat generation, and therefore noise generation elements of the system are the power electronics. Other elements are systems for active cooling of the charging cable, cooling of the control logic boards and or cooling of any displays in the system.

The noise levels emitted by the EVSE will be proportional to the ambient temperature as well as the charging power demands. The fan speed – and therefore the noise level – is controlled according to demand.

The parameters available for tuning the noise emission of the EVSE include:

- Layout – some EVSEs have the power electronics housed in separate cabinets remotely located from the customer connection point; these could be strategically placed to reduce noise emission / immission through the use of palliatives (e.g. sound screens).
- Charging current – the higher the current, the larger the I2R losses in the system.
- Power electronics design – Silicon Carbide MOSFETs in lieu of IGBTs to reduce thermal switching losses.
- Cooling system design – reduced number but larger sized fans can produce less noise for a given mass-flow but need to be balanced with packaging; optimized fan blade design to reduce noise signature.
- Housing design – optimized air flow paths and optimized air filter elements to reduce fan load through reduced static pressure requirement can allow lower fan rpm; can also remove features inside the housing that creates turbulent flow that might create specific noise issues.
- Charging cable design – liquid-cooled cables offer better customer experience (lighter cables, higher flexibility) but require active cooling elements that produce noise.

The measurement of EVSE noise can be done with existing norms. Thereby, either sound pressure or sound power level can be measured. The latter is better for measuring equipment that will be located at various locations and in various orientations.

Applicable standards for this include the ISO 3740 series, for example *ISO 3744:2010 Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for an essentially free field over a reflecting plane.* This standard allows for environmental & background noise correction.

The sound power level can then be converted to an emission Sound Pressure Level for a given installation location, using other norms, for example ISO 11203:1995.

Figure 6: Acoustic measurement of an EVSE (Graphic courtesy of alpitronic GmbH).

4. Sound Emission and Immission Impact of Charging Site Periphery

At a typical HPC-charging site, the EVSEs and EVs are surrounded by peripheral elements installed by the CPO such as roof, power station etc. In this section, the various impact areas at a charging site are presented and evaluated towards the acoustic impact. If available, typical values in dB(A) are given. The following image firstly offers an intuition about different noise emission values in dB(A):

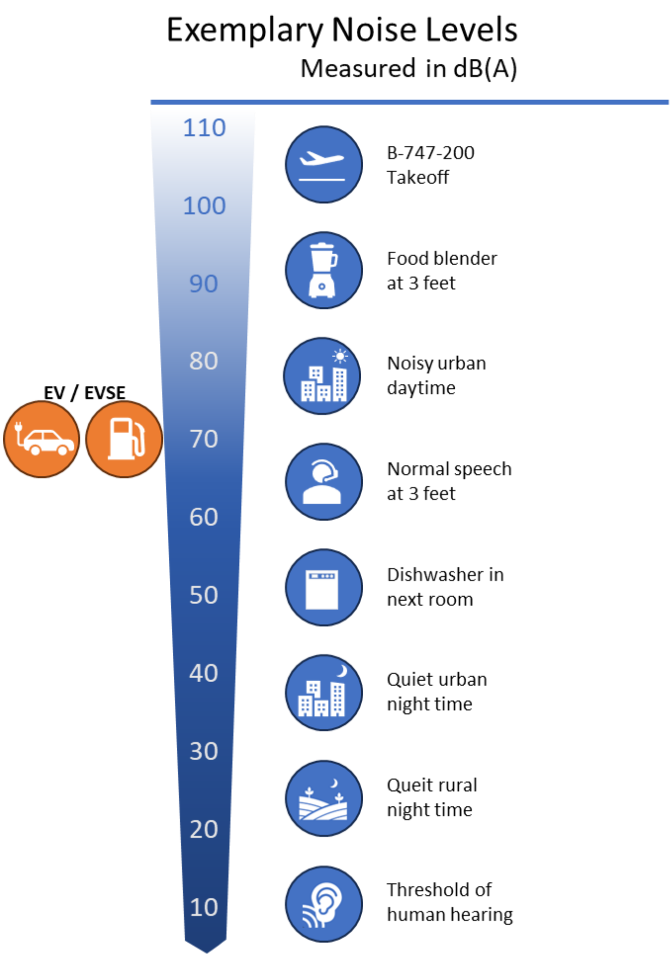


Figure 7: Image based on (Minnesota Department of Transportation).

4.1. Sound Emission Sources: EVSE and EV

As shown in Section 3, both EVSE and EV can emit high noise levels. An example can be seen here (measurements by (Scheubner & Leonetti, 2023)):

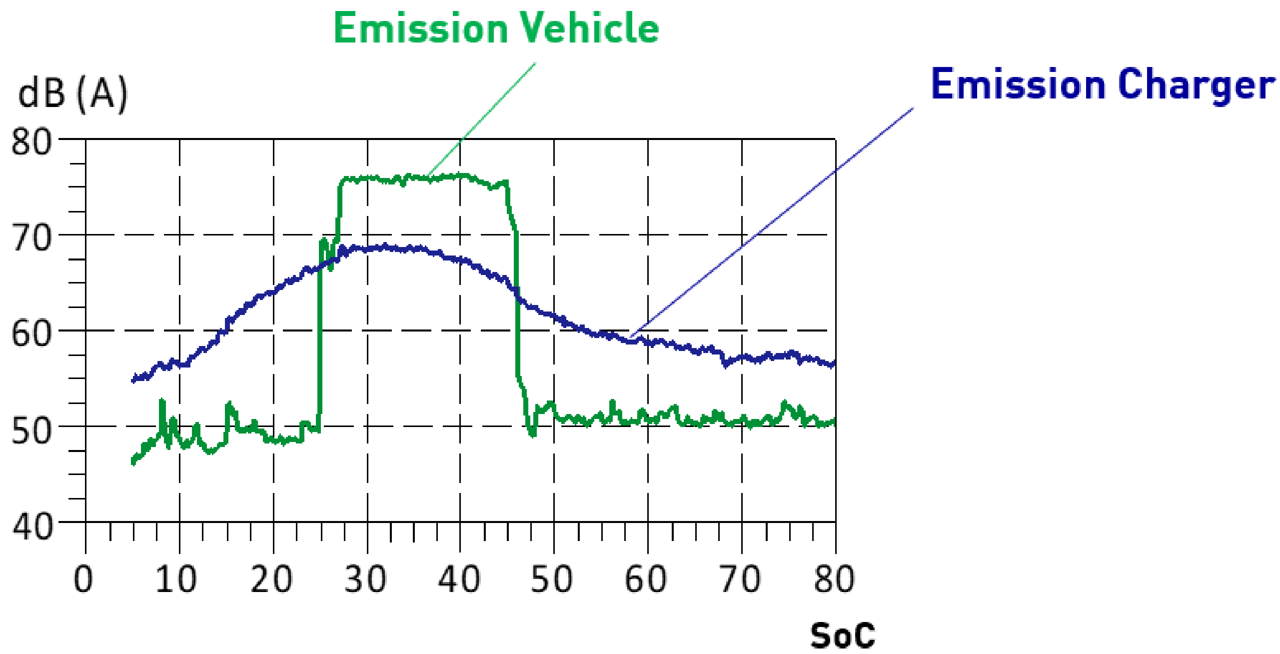


Figure 8: Exemplary measurement of EV and EVSE noise by (Scheubner & Leonetti, 2023).

To ensure compliance with local noise regulations (see Section 2), a CPO can increase the distance to immission points in the planning phase of the charging site. However, the potential sound emission of vehicles is unknown to the CPO therefore the conformity with the regulations can never be ensured 100%.

4.2. Site Usage

Typically, local regulations take the occurrence frequency into account (e.g. Bundesimmissionsschutzgesetz). That means higher usage at charging sites means higher equivalent sound level in the surrounding area. A central goal of a CPO is to maximize usage for economic reasons. One charger for example had over 20.000 charging sessions in one year which translates to over 2 charging sessions in one hour.

Usage of charging sites is normally low in the night. This can match local noise regulations which sometimes are stricter during the night than during the day. How occurrence/frequency is taken into account is determined by local noise legislation.

4.3. Secondary Emissions Sources

Next to the primary emission sources (EV and EVSE), secondary sound sources such as voices or closing vehicle doors can also emit high noise levels. County specific regulations will dictate if this is relevant for planning and running the charging side.

4.4. Number of Sources

A general rule of thumb in acoustics is the dominance of the loudest sound source. Other emission sources emitting significant less noise can then be neglected. If two sources emit the same sound level, the sound will be 3 dB(A) higher than the individual ones.

In a small charging site, typically the EVSE or the EV are dominant. In a larger charging site, this must be evaluated more closely. When many individual sources come together, this would also change the effect of the distance to immission points, as shown in the following illustration. It shows that for an individual source, doubling the distance decreases immissions by 6 dB(A) under free field conditions (no surrounding walls nearby). However, the same emissions from a line of sources (street, parking spaces…) reduces the effect to 3 dB(A).

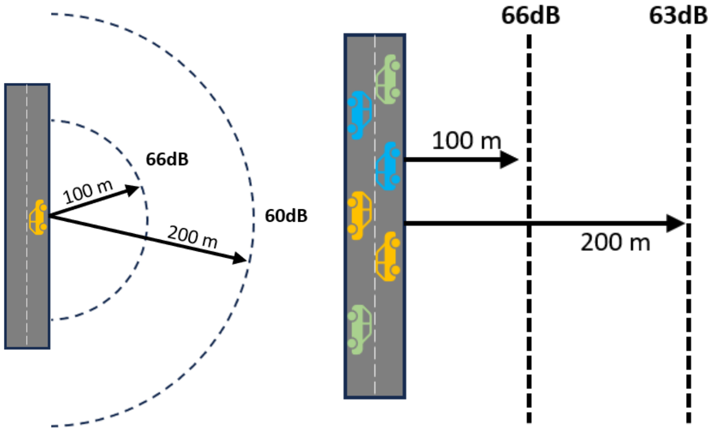


Figure 9: Effect of increasing distance to sound source

4.5. Emission Source Positioning

In the case of charging stations, the primary sound sources are the EVSE and the EV. The layout of the charging station has great impact of the resulting sound immission at the measuring point. For example, in EVs the cooling fans are most likely situated in the front of the cars, therefore the sound level in front of the car when charging is much higher than behind the car. Another impact on the resulting noise at the immission point could be hard surfaces (in an acoustic manner) near the main sound sources. The reflection on these surfaces can result in an even higher noise at the immission point.

4.6. Noise Barriers

Noise barriers can be used to reduce noise levels at the immission points. Depending on the style of the noise barrier they work by diffracting sound as shown by (Minnesota Department of Transportation), or as a sound absorber.

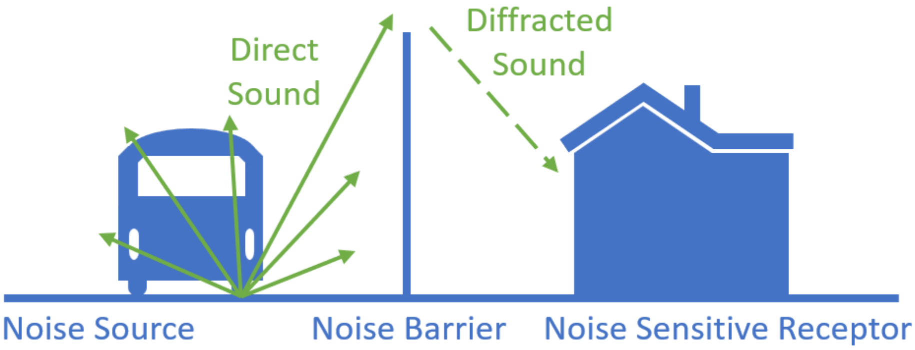


Figure 10: Noise barriers.

Sound barriers with absorbing materials must be maintained on a regular basis, since they lose their properties due to pollution and nesting insects.

The amount of reduction potential depends on the sources, surroundings, distances, and the barriers themselves. A study of (Jiang & Kang, 2016) showed the following values:

Scenario			Sound pressure level (dBA)				
			Without barrier	Tree belt	3 m timber barrier	5 m timber barrier	5 m transparent barrier
High traffic level	100 m distance	Natural landscape	73.9	73.9	64.4	62.1	62.1
		Residential landscape	73.9	73.9	64.4	62.1	62.1
	300 m distance	Natural landscape	66.9	66.9	62.1	61.3	61.3
		Residential landscape	66.9	66.9	62.1	61.3	61.3
Low traffic level	100 m distance	Natural landscape	65.4	65.4	56.0	53.7	53.7
		Residential landscape	65.4	65.4	56.0	53.7	53.7
	300 m distance	Natural landscape	58.4	58.4	53.6	52.8	52.8
		Residential landscape	58.4	58.4	53.6	52.8	52.8

Figure 11: Influence of noise barriers from (Jiang & Kang, 2016).

The costs of a noise barrier can vary widely depending on size and its absorbing properties. One of the main goals during the project planning should be, to adapt the absorbing properties of the sound barrier (if necessary) to the spectrum of the noise emitted by the charging stations and the EVs.

4.7. Roofing

The influence of typical roofing for charging infrastructure on the sound characteristic can often be neglected. However, a roof with a certain angle and nearby walls can function as an acoustic funnel. To avoid such an effect the surfaces should be covered with absorbent material. This would also be beneficial for the overall acoustic emissions of the charging point.

4.8. Greenery

Citing (Minnesota Department of Transportation): "Trees and vegetation can provide visual screening, but they provide very little benefit in reducing noise. For trees to provide a significant reduction in noise there must be at least 100 feet of dense trees that are at least 15 feet high." However, during the different season's greenery doesn't provide a reliable noise reduction.

4.9. Background Noise

If the background noise around the charge point is 10 dB higher than the sound emitted by the charge point itself (due to traffic noise during the rush hour or weather incidents), the noise emitted by the charge point can be neglected. But the presence of special cues like tonalities, humming or beating effects should be considered to reduce annoyance. In this case, even with a 10 dB higher background noise, the noise of the charge point becomes noticeable.

5. Discussed Ideas and Recommended Actions

5.1. Discussed ideas and their Evaluation

Measurement protocol

To have a common understanding of noise emissions, there should be developed a measurement protocol for charging noise at a standardization body. The common understanding of charging noise is the baseline for any further work on the topic of charging noise. To prepare activities at a standardization body, activities at CharIN in advance make sense and should be started soon.

General noise limit for EVs during charging

Since EVs have no noise regulations during charging, a possible idea is to introduce a general noise limit, e.g. in the type approval regulation. However, considering the different noise immission regulations presented in Section 2, it is questionable that a general limit can mitigate the issue. The local noise limits depend on the country, the area type, the distance to the next residence and several more. Introducing a general noise limit for all EVs will result in too strict values for some places (e.g., industrial areas) and too loose values for others (e.g., spa regions). A medium or low noise limit would hinder high- power charging for every use case including charging along highways and in industrial areas. Even this limitation would have no benefits for residents. This will bring a big problem to the long-range ability of BEVs.

A medium or high noise limit, on the other hand, would hinder charging in urban areas and would bring a large disadvantage to people who can't install their own wallbox.

There is no single noise limit that is suitable for every use case, so it is not recommended.

EVs evaluate local noise limits and control emissions

Since a general noise limit for EVs has the risk of being too strict or too loose depending on the area, an approach which evaluates the exact local sound immission limits would be superior. Since local regulations and thus local noise limits differ widely, the requirements towards the EV can only be met if the currently valid emission limit is known during charging. Theoretically, an EV could take its current position via GPS and match it with a database for area types and legal limits. Once the limit is known, the EV control system can make sure the noise does not exceed it. However, some countries take the distance to the next residence or the relation to surrounding noise into account. Getting this information from within the car with reasonable effort is very unlikely.

CPOs solve the problem on their own

CPOs must know the local noise regulations so that they can evaluate the risk of exceeding them during charging site planning. However, the various implementations and noise characteristics of the EVs are impossible to foresee. The effect of noise barriers, especially in urban areas with building restrictions, is limited. Thus, without a solution for the EVs, this idea poses the risk of fewer charging sites outside industrial areas. Helping to predict the charging noise of the EV might be the generic model.

Model development for charging noise

As explained in Section 3, the noise emissions during charging of EVs depends on several parameters which makes prediction very difficult. Because of this, a model should be developed explaining the dependencies between charging power, outdoor temperature, and noise levels for an average car/truck. This model can help CPOs in the planning stage.

There should be activities at a standardization body to develop a reliable model.

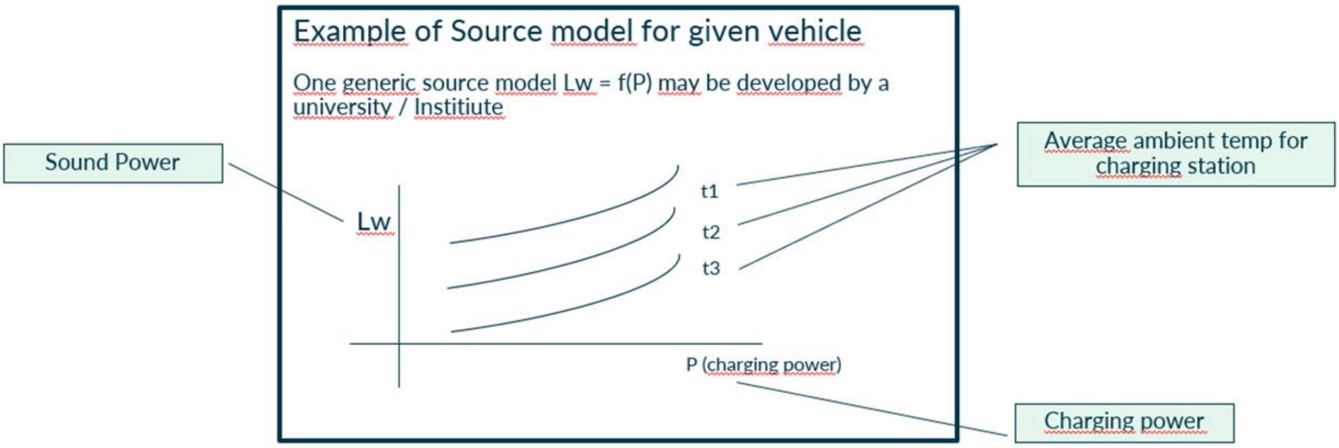


Figure 12: Example of source model for given vehicle.

Legislative database regarding noise regulation

Seeing the same tasks, the CPO to get an understanding of the noise regulations that differ from region to region and city to city, it would make sense to have one database in which these regulations can be found.

Microphone installation at charging sites

A CPO could install extra devices to measure live noise emissions from the EVs and EVSEs at the charging site. If the noise is too high, the CPO can reduce charging power for the respective EVSEs until the limit is met. However, this poses several issues: Firstly, the need to integrate new hardware requires extra resources slowing down setting up charging sites. Secondly, the delay between cooling demand and charging power due to the heat capacity of the battery makes the control loop very slow and possibly ineffective. Thirdly, the noise sources cannot be singled out to EVs or EVSEs, therefore background noise (e.g. a train or plane nearby) has an effect on the charging power.

Noise limit communication in ISO15118

The CPO must know the local noise regulation and thus the local noise limits from planning the site. Therefore, the CPO can define the respective parameters in the EVSEs for them to meet the requirements. Upon plugging in, the EVSE could then communicate the noise limit information to the EV via the protocol ISO15118. By that, a demand-oriented approach is applied. The EV can control its charging power to exactly meet the limit and thus offer optimal charging time with respect to noise regulation.

Currently there is no feedback from the EV to see EVSE implemented in the ISO15118 protocol. In future the information of the actual noise of the EV can be helpful for the CPO.

A static limit, like today in the proposal in the ISO 15118 isn't ideal. A flexible value which can change during charging will allow to adapt the allowed noise to the actual charging conditions.

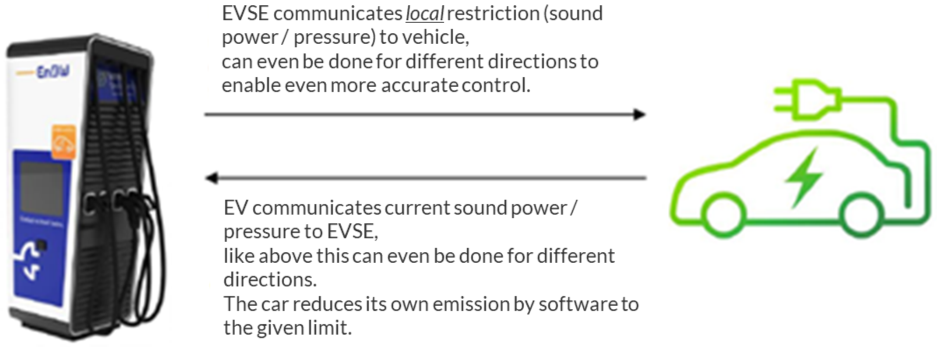


Figure 13: Noise Limit Communication in ISO15118.

Noise limit of the site communication via backend

A local communication of the noise limit via ISO15118 makes the information only available when plugging in. To enable more predictability for EVs, a noise limit can also be communicated by the EVSE to the CPO backend and from there inform partners via applicable databases (e.g., roaming service providers, NAP, OCPI…) This information will be helpful for the route planning of the driver. We recommend a consistency in messaging between ISO 15118 (so Charging Station to Vehicle) and via OCPP or OCPI (from Charging station out to roaming partners) otherwise implementation becomes very difficult.

5.2. Recommended Actions / Next Steps

The advantages and disadvantages of the possible ideas were discussed in the previous section. Seeing all the advantages and disadvantages only 4 ideas are recommended. Of these 4 ideas, 2 ideas are feasible for all type of vehicles:

- Develop a measurement standard for charging noise.
- Develop a calculation model for vehicle charging noise.

For vehicles in category N1/M1, the following options should be progressed and developed.

- Noise Limit Communication via the appropriate protocols.
- Noise Limit Communication via Backend for informing drivers and navigations systems.

To enable a consistent baseline for noise emissions assessment, a standard for measuring for charging noise should be developed by a recognized standardization body, such as ISO. To assist and accelerate this activity, it makes sense for CharIN to prepare in advance and should start as soon as is practicable.

Among the communication methods, the communication between EV and EVSE is considered most important, given that it enables a demand-based, optimized approach. It is recommended this is done via ISO 15118-20.

The Noise Limit Communication via Backend is important for predictability and a suitable communication path must be identified. The possibilities range from roaming services, OCPP, NAP data until exclusive APIs. Once an applicable path is identified, the required datapoints must be introduced, possibly equivalent to the values in ISO15118.

To facilitate and improve charging site planning, the calculation model of charging noise should be developed by a research institute, perhaps in collaboration with industry. With knowledge of the local noise immission regulations, the CPO can evaluate the risk of exceeding them during charging site planning. However, the various implementations and noise characteristics of the EVs are impossible to foresee without the help of the EVSE and EV manufacturers. The layout of the charging points and noise absorbing barriers can be designed to fulfil local immissions requirements.

6. Authors and References

This document was created by the Subgroup **Charging Acoustic Function** within the focus group **Charging Infrastructure** of the CharIN association. Authors include:

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