

# Norwegian CO<sub>2</sub> emission factor 2021-2025 – an updated analysis

## Characteristics of the Norwegian power market

The CO<sub>2</sub> emission factor represents the effect of the carbon price on power prices and should preferably be called CO<sub>2</sub> price transfer factor since it reflects a power price impact rather than an emission outcome. However, for this memo we will use the Commission term CO<sub>2</sub> emission factor.

Prices in power markets are in principle determined by the cost of generating one additional unit of power and prices in interconnected markets influence each other through imports and exports. Power generation in Norway is characterized by renewable electricity, dominated by hydro power with significant reservoir capacity. The Norwegian electricity market is strongly integrated with the rest of the Nordic market and connected to the European electricity market through interconnectors. The carbon price is important for European power prices and – due to the interconnection - also for Norwegian power prices. The significant reservoir capacity in Norwegian hydro power plants strengthens this effect as producers can shift power production between periods, based on expected profitability, which is influenced among other things by European electricity prices.

## Definition of “CO<sub>2</sub> emission factor”

A communication from the Commission dated 21 September 2020 includes Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post 2021. The guidelines define how the terms ‘CO<sub>2</sub> emission factor’ and ‘market-based CO<sub>2</sub> emission factor’ should be understood. A market-based CO<sub>2</sub> emission factor is directed at Member States intending to grant indirect cost compensation arising from the EU greenhouse gas emission allowance trading system, which is the case for Norway. The Commission’s definition of “market-based CO<sub>2</sub> emission factor’ is included in paragraph 15 (11) of the Guidelines.

‘market-based CO<sub>2</sub> emission factor’, in tCO<sub>2</sub>/MWh. Member States intending to grant indirect cost compensation may, as part of the notification of the relevant scheme, request that the applicable CO<sub>2</sub> emission factor be established based on a study of the CO<sub>2</sub> content of the actual margin setting technology in the electricity market. Such a notification of a market-based CO<sub>2</sub> emission factor must demonstrate the appropriateness of the *retained market-based CO<sub>2</sub> emission factor based on a model of the electrical system simulating price formation* and observed data on the margin setting technology over the entire year t-1 (including the hours when imports were margin setting). This report must be submitted to the national regulatory authority for approval and transmitted to the Commission when the State aid measure is notified to the Commission pursuant to Article 108(3) of the Treaty. The Commission assesses the appropriateness of the study and the resulting market-based CO<sub>2</sub> emission factor as parts of its compatibility analysis under Article 107(3)(c) of the Treaty and the present guidelines.

## Method for calculating the Norwegian CO<sub>2</sub> emission factor

Based on the guidelines we suggest that the following appropriate method should be used to determine the applicable CO<sub>2</sub> emission factor for Norway. The entire European power market is modelled by an appropriate power market model, Sweco’s Apollo model, for several years t and results for Norway are analysed in detail. The Apollo model simulates price formation in hourly resolution based on a representation of thermal and RES-E capacity, demand and load profiles, interconnectors, inflow, production profiles and fuel prices as the most important ones. Backtesting has shown that the model reflects the function of the European and Nordic power market very well. Modelling the European power market is basically the only feasible method to derive the CO<sub>2</sub> emission factor, unless one has access to all highly confidential bids in a market.

$$\text{CO}_2 \text{ emission factor} = \frac{\text{Modelled power price year } t \text{ (with CO}_2 \text{ price)} - \text{Modelled Power price year } t \text{ (CO}_2 = 0)}{\text{Actual CO}_2 \text{ price year } t - \text{CO}_2 \text{ price (CO}_2 = 0)}$$

The method states that the power price for year t should first be calculated with a model setup with a CO<sub>2</sub>-price, in that case the price for CO<sub>2</sub> in the year t. Then, the power price for the same year t without a CO<sub>2</sub>-price is calculated. The CO<sub>2</sub> emission factor is then found by comparing the results of the two scenarios. When determining the CO<sub>2</sub> emission factor for t we look at the CO<sub>2</sub> emission factor at an annual level. Therefore, we compare the annual average power prices to annual average CO<sub>2</sub> prices.

The appropriate CO<sub>2</sub> emission factor should represent the simulated outcome from the electricity market in a “normal” year *t*, and not be influenced by factors such as unexpected major plant outages, interconnector outages, crisis years with low demand or years with extreme inflow or wind conditions, all of which could affect the CO<sub>2</sub> emission factor strongly. Especially in the Nordics with its high share of hydro and wind power, a normalisation for inflow and wind condition is required. 90 per cent of Norway’s power production capacity is hydropower. Norwegian power prices are therefore highly sensitive to variations in hydrology (inflow). Inflow varies considerably during the year and from one year to another. In the period 1990 to 2019, annual inflow to Norwegian hydropower plants varied by about 65 TWh.

The modelled power prices are based on installed production capacity data for year *t*, forecasted demand, and assumed fuel prices actual CO<sub>2</sub> prices for the period 2021-2025. Other significant factors such as hydrology, nuclear plant outages and other major plant outages, wind conditions and availability of interconnectors are normalized in order to avoid under- or overestimating the CO<sub>2</sub> emission factor.

### Difference between absolute and marginal CO<sub>2</sub> emission factor

The CO<sub>2</sub> emission factor derived from the proposed method can be labelled as the *absolute* CO<sub>2</sub> emission factor: the factor is calculated from the modelled price differences between a scenario with and without CO<sub>2</sub>-prices and describes the *total impact* from introducing a carbon price in a certain generation capacity mix on short notice. Thus, it describes the entire power price impact eligible sectors face and should be used as the applicable factor for indirect cost compensation.

As there exists a price on CO<sub>2</sub> today, a question that is often analysed is: “What would the impact of an additional increase in today’s (high) CO<sub>2</sub>-price be on the power price?”. To answer this question, the carbon price’s impact on power prices is assessed by inflicting a smaller change in the CO<sub>2</sub>-price and observing how the change impacts power prices. The derived factor can be labelled as the *marginal* CO<sub>2</sub> emission factor and is described by:

$$CO_2 \text{ emission factor}_{\text{marginal}} = \frac{\text{Modelled power price year } t \text{ (CO}_2 \text{ price)} - \text{Modelled Power price year } t \text{ (CO}_2 \text{ price} - \Delta)}{CO_2 \text{ price} - (CO_2 \text{ price} - \Delta)}$$

The margin setting technology depends on the carbon price and the fuel price combination, where a higher carbon price increases the costs of CO<sub>2</sub> emissions, making low-carbon technologies with high efficiency more competitive. As the carbon price increases, less efficient high-carbon content technologies will therefore be replaced by more efficient low-carbon technologies with otherwise higher marginal costs, causing an additional increase in power prices.

The difference between the absolute and marginal CO<sub>2</sub> emission factor, is that the absolute CO<sub>2</sub> emission factor describes the impact on the power price when introducing a carbon price into the power system, while the marginal CO<sub>2</sub> emission factor describes the incremental change in power prices in a system that already has a significant CO<sub>2</sub>-price impact.

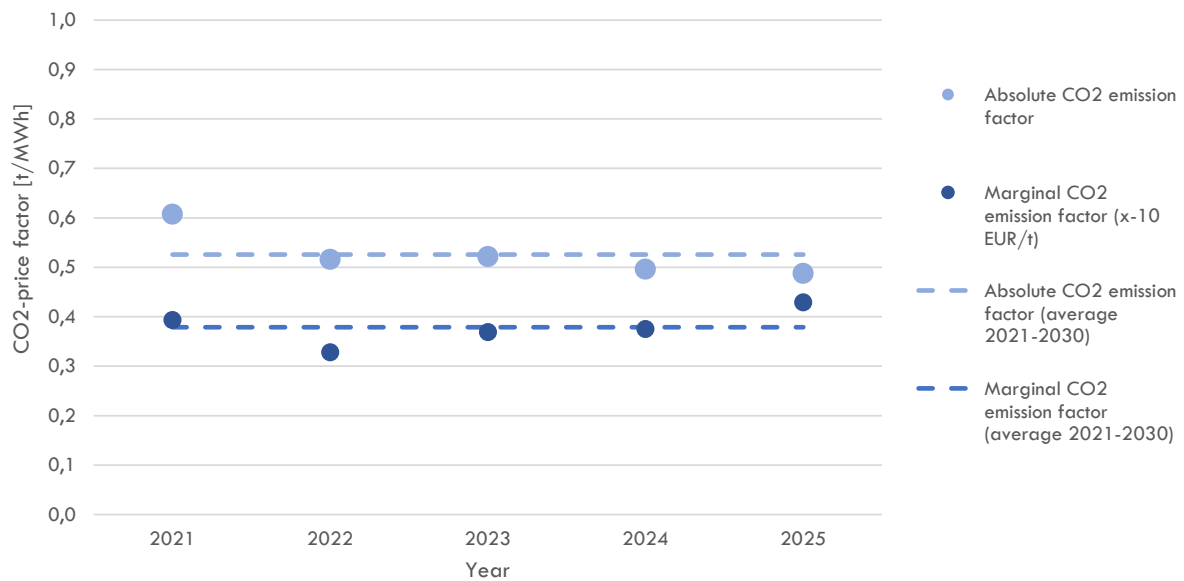
### Results for 2021-2025

Figure 1-1 shows the development of the absolute and marginal CO<sub>2</sub> emission factor for Norway during 2021-2025, where the marginal factor has been calculated based on a CO<sub>2</sub> price difference of 10 EUR/t. The modelled power prices are based on Sweco’s short-term scenarios of installed production capacity data and demand. Fuel and carbon prices are based on current market prices but are adjusted to remain constant during the simulated period<sup>1</sup> 2021-2025. Other significant factors such as hydrology, nuclear plant outages and other major plant outages, wind conditions and availability of interconnectors are normalized in order avoid under- or overestimating the CO<sub>2</sub> emission factor.

The marginal CO<sub>2</sub> emission factor is lower than the absolute, which can be expected. During the period, the absolute CO<sub>2</sub> emission factor is on average 0.53 tCO<sub>2</sub>/MWh while the marginal factor is on average 0.38 tCO<sub>2</sub>/MWh. While the absolute CO<sub>2</sub> emission factor continuously decreases, the marginal CO<sub>2</sub> emission factor remains around 0.4 tCO<sub>2</sub>/MWh during the period. This indicates that the share of gas in continental power generation is already high under the applied fuel and CO<sub>2</sub> price assumption, reducing the impacts from coal phase out in continental Europe that we see in the absolute CO<sub>2</sub> emission factor.

<sup>1</sup> Fuel price assumptions as follows, CO<sub>2</sub>: 50 EUR/t, Coal: 9 EUR/MWh, Gas: 19 EUR/MWh

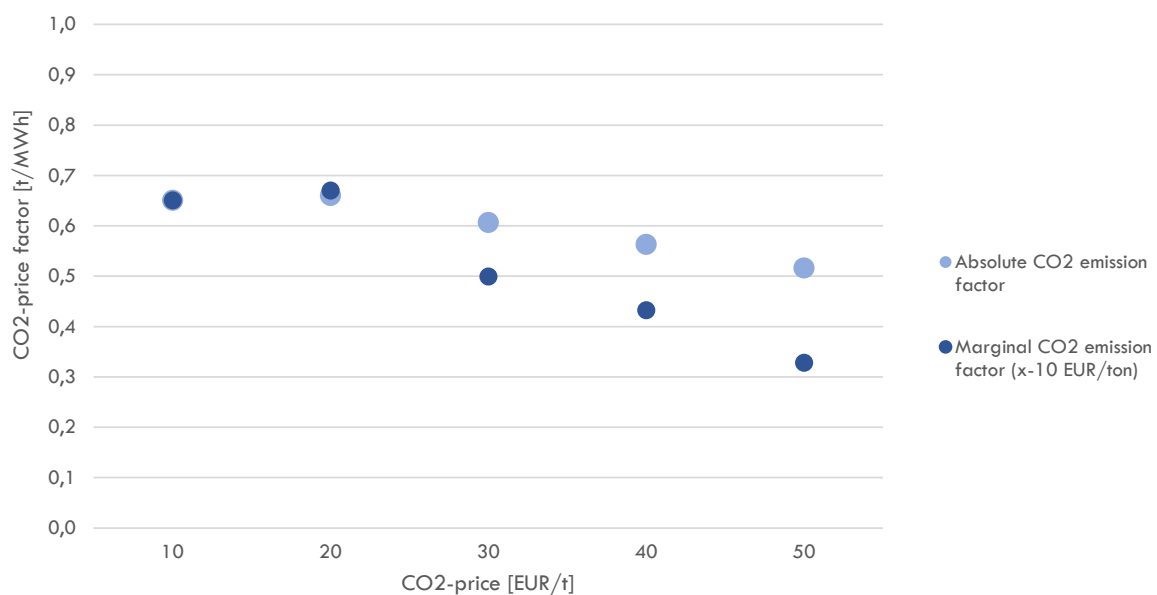
**Figure 1-1 Absolute and marginal CO<sub>2</sub> emission factor for Norway 2021-2025 for an assumed carbon price of 50 EUR/t. The marginal factor is calculated by modelling the scenario for an assumed carbon price of 40 and 50 EUR/t.**



Source: Sweco

As stated above, the margin setting technology and consequently the CO<sub>2</sub> emission factor depends on the CO<sub>2</sub> price. Figure 1-2 shows the absolute and marginal CO<sub>2</sub> emission factor in 2022 for different CO<sub>2</sub> price assumptions. For low CO<sub>2</sub> prices, the CO<sub>2</sub> emission factor is relatively high, which means that power prices are strongly impacted. The difference between the absolute and marginal factor however is small since the carbon price does not significantly impact the merit order of power generation, and fuel switching between coal and gas does not occur. With fuel price assumptions for 2021-2030, the carbon price starts having an impact on merit order between 20 and 30 EUR/t, after which the difference between the absolute and marginal factor grows larger as the carbon price increases. For the modelled year, the absolute CO<sub>2</sub> emission factor ranges between 0.52-0.66 tCO<sub>2</sub>/MWh, and the marginal factor ranges between 0.33-0.65 tCO<sub>2</sub>/MWh.

**Figure 1-2 Absolute and marginal CO<sub>2</sub> emission factor for Norway 2022 for different CO<sub>2</sub> price assumptions. The marginal factor is calculated by reducing the CO<sub>2</sub> price by a Δ 10 EUR/t.**



Source: Sweco

