Impact Assessment of REDII Delegated Act on Electrolytic Hydrogen CO_2 Intensity

Technical Annex: Countries Data Deep Dive

This annex reports the country-by-country data analysed in the process of writing our latest briefing on hydrogen production, where we assessed the circulating proposal for the delegated act of the Renewable Energy Directive on Renewable Fuels of Non-Biological Origin (RFNBOs).

This annex provides an assessment of the sustainability of the hydrogen produced within the System-Level Matching regime, as well as some country specific conclusion for the development of a sustainable hydrogen industry**.**

The original wording of the REDII ensures a temporal and geographical correlation between hydrogen production and the contracted renewable energy used to power it. This delegated act seeks to substitute this with a system-level comparison. Instead of using production evidence in real-time, a proxy is built by comparing today's hourly renewable energy penetration against the average renewable energy penetration from two years before. **System-Level Matching in essence defines green (or renewable) hydrogen as hydrogen produced when the share of renewable electricity generation running on the grid is higher than the average two years prior, in each specific bidding zone.**

The conclusions in the upcoming pages are derived from applying this regime on real-world high-resolution hourly electricity generation and consumption data from 2020. The data used to perform the analysis was collected by Tomorrow[1], a European electricity data firm. To assess the System-Level Matching, we compared the renewable penetration for every hour in every bidding zone in 2020, to the yearly average renewable penetration in 2018.

The six countries were selected as they have varying penetration of renewable electricity, but as of 2020, none have average grid electricity low carbon enough to produce green hydrogen year-round.

[1] https://www.tmrow.com/

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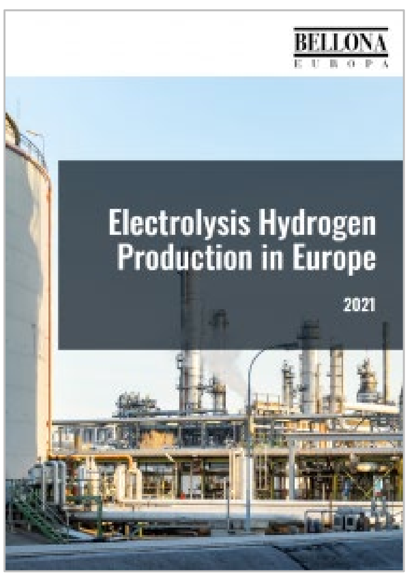
Country	Electricity Grid Bidding Zone	Page
Austria	AT	3
Denmark	DK1: West Denmark	5
	DK2: East Denmark	
Germany	DE	7
Ireland	IR	9
Spain	ES	11
Italy	IT CNO: Central North	13
	IT CSO: Central South	
	IT NO: North	
	IT SO: South	
	IT SAR: Sardinia	
	IT SIC: Sicily	

The proposed System-Level Matching allows hydrogen to be produced when renewables are generating at or above average when compared to two years before. In reality, this allows for a large increase in the operational hours for hydrogen production to be labelled green.

The carbon intensity of electrolytic hydrogen can be calculated using the carbon intensity of the electricity and the efficiency of the electrolyser used. For the calculation in this Annex, we assumed an efficiency of 70%. More information on how to calculate the carbon footprint of electrolytic hydrogen can be found in our previous report.



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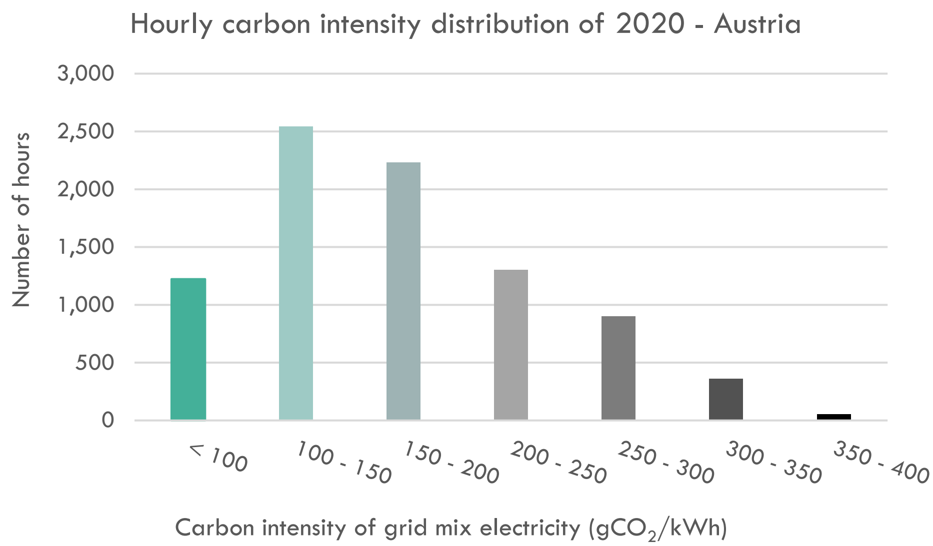
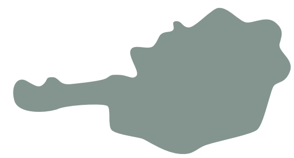
Austria





In Austria, renewable energy makes up almost 80% of the electricity mix. Historically, hydroelectric production constitutes the main source of electricity in the country, representing over 60% of the total electricity generation. Recently, wind and solar PV have been steadily increasing, reaching respectively 10 and 2% of the mix, while coal has been decreasing[2].

The average intensity of the Austrian grid mix is 170 gCO_2/kWh. Almost a third of the 8,784 hours of the year 2020 has a carbon intensity between 100 and 150 gCO_2/kWh, while the hours falling below 100 gCO_2/kWh were only 14%. In 5% of the hours the carbon intensity exceeded 300 gCO_2/kWh. At an hourly resolution, only 181 hours a year would be clean enough to produce hydrogen compliant with the green hydrogen definition from the sustainable taxonomy (3 tCO_2/tH_2). Producing electrolysis hydrogen that is equivalent or cleaner than grey hydrogen (10.9 tCO_2/tH_2) yields 6,901 running hours. **The possibility of producing actual green hydrogen on the Austrian grid is very limited, however, in 2020 roughly 80% of the time the hydrogen produced on the grid would have been cleaner than grey hydrogen.**

[2] IEA data.

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Applying the System-Level Matching regime, an electrolyser in Austria could have run on the grid for 5,259 hours producing hydrogen labelled as green, at a carbon intensity of 127 gCO_2/kWh, twice as high as the sustainable taxonomy definition of green hydrogen. This average entails both very low carbon hours (28 gCO_2/kWh the lowest) but also much dirtier ones. The most carbon intense hour on which hydrogen could have been produced on the grid and labelled as green would have been at 7 pm on the 18th of March, with a carbon intensity of the grid 222 gCO_2/kWh, hence producing hydrogen with an associated carbon footprint of 10.6 tCO_2/tH_2.

Hydro generation will need to be supplemented with variable renewables for hydrogen production

Although the penetration of renewables in Austria is well above the European average, the high reliance on hydro does not position the country well in terms of drastic increase of production. Although in the last 30 years, additional capacity for hydro has been deployed in Austria, it cannot be expected that all the additional demand coming from hydrogen will be met by this source. The continued deployment of wind and solar PV will be crucial both for the grid decarbonisation and the deployment of electrolysers.

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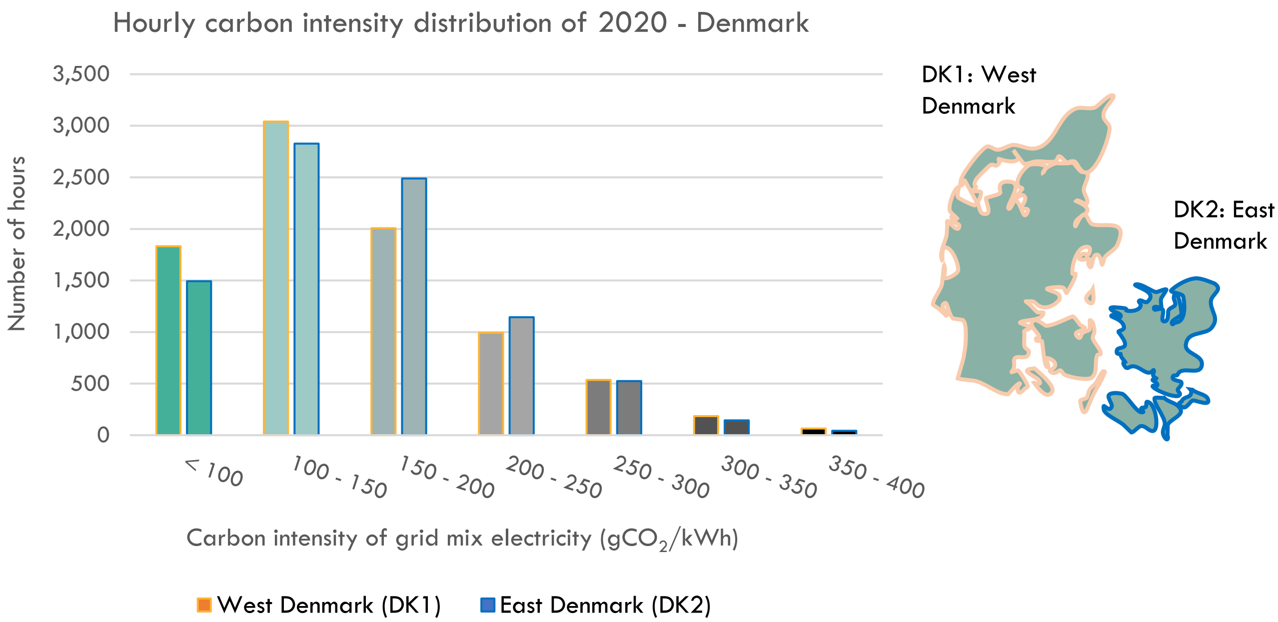
Denmark



Denmark's electricity grid is divided into two bidding zones for geographical constraints which result in reduced electricity exchange between the Eastern and Western areas of the country.

Denmark has seen a remarkable electricity transition from 1990 to today. In 1990, 91% of Danish electricity production came from coal; today, this source represents only 11% of the electricity mix. The main source of electricity is wind, which in 2019 represented 55% of total production, followed by biofuels at 17%. Solar PV has also been steadily increasing, reaching 3% in 2019.

The average carbon intensity of the Danish electricity mix is around 155 gCO_2/kWh[3]. Over a third of the 8,784 hours in the year 2020 had a carbon intensity between 100 and 150 gCO_2/kWh[4], while roughly one in five hours saw the carbon intensity fall below 100 gCO_2/kWh[5]. The carbon intensity of Denmark's electricity grid exceeded 300 gCO_2/kWh for only 3% of the hours in the year.

[3] 152.9 gCO_2/kWh in DK1 and 157.6 gCO_2/kWh in DK2
[4] 35% in DK1 and 33% in DK2
[5] 21% for DK1 and 17% for DK2

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At an hourly resolution, only 243 (West Denmark) and 101 (East Denmark) hours a year would have been clean enough to produce hydrogen at 3tCO_2/tH_2, the threshold established in the sustainable taxonomy. Producing electrolytic hydrogen that is equivalent or cleaner than grey hydrogen (10.9 tCO_2/tH_2) would have been possible for 7,943 (West Denmark) and 7,984 (East Denmark) running hours.

Under the system-level matching regime, in 2020, a hydrogen electrolyser in West Denmark could have operated for 7,943 hours, producing green-labelled hydrogen. The average hourly carbon intensity would have been 140gCO_2/KWh, thus the green-labelled hydrogen would have had a carbon intensity of 6.6 tCO_2/tH_2, more than double the threshold for green hydrogen defined in the sustainable taxonomy.

The very high running time is permitted by the high uptake in renewable energy over recent years in Denmark, allowing for hydrogen production on the grid 9 hours out of 10. The most carbon intensive hour at which green-labelled hydrogen could have been produced on the Danish grid would have been the 5th of February at 8 am, when the carbon intensity was 309 gCO_2/kWh in the West Denmark, while in East Denmark it would have been the 27th of February at 1 am, with a carbon intensity of 336 gCO_2/kWh.

The rapid deployment of wind and solar makes Denmark a good candidate for the production of hydrogen. However, if the "System-Level Matching" is applied, 429 (West Denmark) and 591 (East Denmark) of the running hours would produce 'green-labelled' hydrogen with a carbon intensity higher than that of grey hydrogen (10.9 tCO_2/tH_2).

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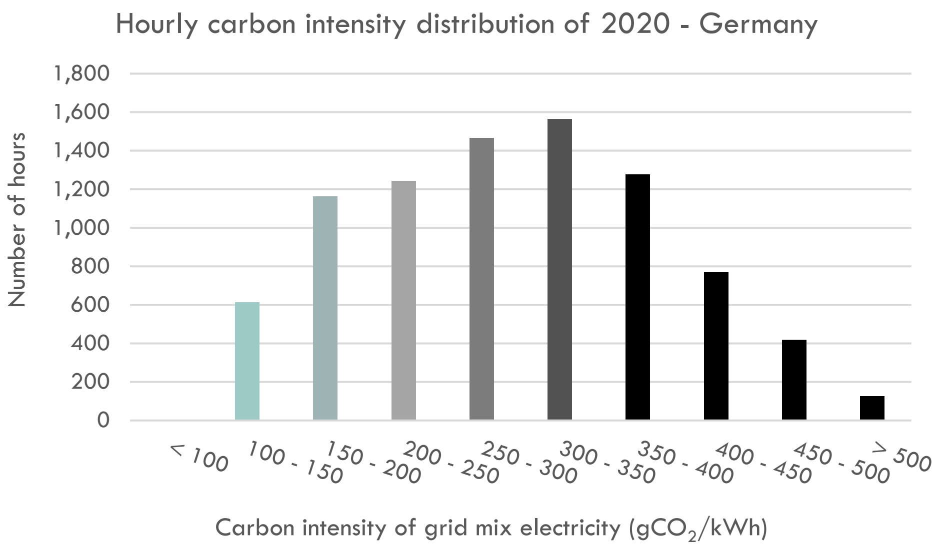
Germany



The German electricity grid has an average carbon intensity of 294 gCO_2/kWh. This high intensity is driven by the large share[6] of carbon-based electricity that remains in the German grid. Although in the past ten years, wind and solar PV have increased substantially, covering 28% of the electricity production collectively in 2019, this has not resulted in a direct substitution of fossil fuel electricity because of the parallel reduction of nuclear electricity production happening in the country. In 2019, all fossil fuels combined supplied 46% of Germany's electricity, while renewables reached the quota of 40%.

With this grid mix, at no point during 2020 would Germany have qualified to produce green hydrogen as defined by the sustainable taxonomy (at 3 tCO_2/tH_2). [7] In fact, Germany could only have produced hydrogen with lower associated emissions than grey hydrogen (10.9 tCO_2/tH_2) during 25% of the year.

However, when applying the System-Level Matching, Germany would have been able to produce green-labelled electrolytic hydrogen for 7,249 hours in 2020, with an average carbon intensity of 269 gCO_2/kWh. Such a high number of running hours can be explained by the fact that Germany has improved its renewable share from 32 to 49%, so its hourly penetration of renewables is almost always higher than the average two years prior.

[6] 30%. IEA data.
[7] 2,514 hours

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Applying the system correlation would mean that two thirds of this “green” hydrogen would have a higher carbon intensity than grey hydrogen[8]. The marginal production hour would have been on the 16th of October at 7 a.m. with a carbon intensity of 459 gCO_2/kWh, producing hydrogen at 22 tCO_2/tH_2, twice as high as the emissions from producing grey hydrogen.

Unlike the other countries analysed in the report, Germany’s electricity mix is the least suitable today to produce hydrogen using electricity from the grid. Renewable hydrogen production in Germany would still be possible with direct connection or through a Power Purchase Agreement which ensures strict temporal and geographical correlation.

[8] 4,835 hours

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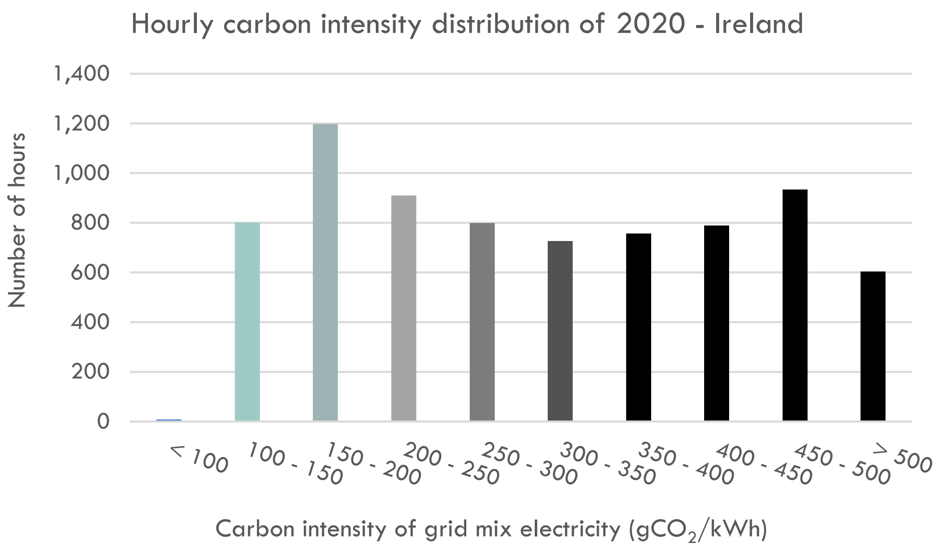
Ireland



The Irish electricity mix relies largely on wind (31%) and natural gas (53%). These, over the past 30 years, have progressively taken over coal- and oil-based power generation, substantially lowering the carbon footprint of the Irish power grid.

The average carbon intensity of the grid in 2020 was 312 gCO_2/kWh. From the distribution of the hourly average carbon intensity, it stands out that these cluster in two categories: lower emissions (150-200 gCO_2/kWh) and higher emissions (450-500 gCO_2/kWh). This two-peaked distribution is inherently linked with the characteristics of the Irish electricity mix. Clearly, when the wind is blowing, it is almost sufficient to satisfy the grid's needs, keeping the carbon intensity fairly low. However, when the wind is not blowing, gas comes in to meet the energy demand, resulting in a very carbon intensive electricity mix during those times.

Given the Irish electricity mix and its average carbon intensity, producing green hydrogen (below 3 tCO2/tH2) directly from the grid, was not possible in any of the hours of 2020. Moreover, connecting an electrolyser directly into the grid would have produced hydrogen with lower associated emissions than grey hydrogen (10.9 tCO_2/tH_2) during less than 30% of the hours in a year[9].

[9] 2,530 hours

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Applying the System-Level Matching rule, the average emissions associated with the hydrogen labelled as green would have been 11 tCO_2/tH_2[10], higher than the emissions from grey hydrogen production. For over 2,300 of the running hours, an electrolyser would have produced green-labelled hydrogen with more associated emissions than grey hydrogen. The most carbon intensive production hour would have been the 31st of May at 7 p.m., when the average hourly carbon intensity of the grid was 409 gCO_2/kWh, which would have resulted in hydrogen production at almost 20 tCO_2/tH_2 (almost twice the emissions from producing grey hydrogen).

The rapid uptake of wind in Ireland over the past decades, makes the country a potential candidate for hydrogen production. Aiming for high penetration of one intermittent renewable energy source, Ireland will likely be one of the countries facing excess production, which could be channelled towards hydrogen production. **However, for this to be sustainable, a very careful pairing between electricity supply and hydrogen production needs to happen. If not, as the System-Level Matching shows, hydrogen risks being produced when gas-fired power plants come in, so the grid can match the demand that cannot be met by renewable energy generation.**

[10] average hourly carbon intensity of the electricity mix at 233 gCO_2/kWh

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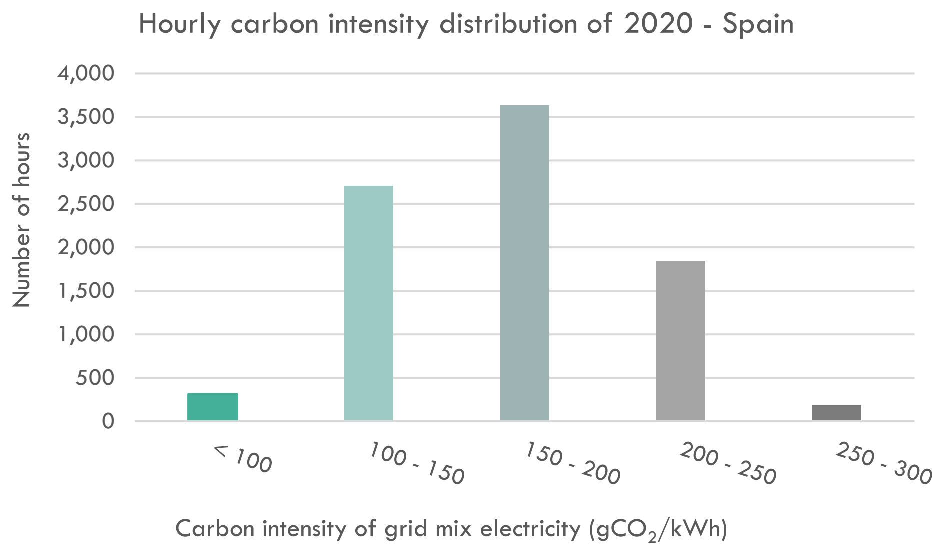
Spain



The electricity mix of Spain is very diverse. In 2019, natural gas was the primary source (31%) followed by nuclear (21%) and wind (20%)[11]. Over the past three decades, coal has been progressively displaced by natural gas and wind, resulting in a progressive reduction of the carbon footprint of the Spanish grid. In 2020 the average hourly carbon intensity was 169 gCO_2/kWh.

Despite the progressive uptake of renewables, in 2020 Spain would not have been able to produce any green hydrogen (less than 3tCO_2/tH_2) directly from the grid. However, for 8,072 hours, electrolytic hydrogen could have been produced with lower associated emissions than grey hydrogen (10.9 tCO_2/tH_2).

Overall, almost half of average hourly carbon intensity of the Spanish electricity grid is between 150 and 200 gCO_2/kWh, with no hour exceeding the 300 gCO_2/kWh threshold. This can be explained by the relatively high share of renewables, coupled with a constant load coming from nuclear production.

[11] IEA data.

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If the System-Level Matching was put into place in Spain last year, green labelled hydrogen could have been produced on the grid for roughly two thirds of the hours in the year[12]. Its average carbon intensity would have been 7.3 tCO_2/tH_2, twice as high as the green hydrogen definition set by the sustainable taxonomy. At the margin, the most carbon intensive production hour would have been on the 1st of September at 9 pm, with an associated carbon intensity of 11.5 tCO_2/tH_2[13]. During that hour, 'green-labelled' hydrogen would have been produced with a higher carbon footprint that grey hydrogen.

Overall, Spain with its high and increasing share of renewables (37%) and descending share of fossil fuel-based electricity will be a good candidate for hydrogen production in the coming decades. However, it is important to match hydrogen production with renewable electricity supply, as natural gas and coal are still part of the electricity mix, risking increasing emissions if production happens at the wrong time. The System-Level Matching proposal does not achieve this.

[12] 6,714 hours
[13] Average hourly carbon intensity of the grid at 242 gCO_2/kWh.

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Italy

The Italian energy market is divided into six bidding zones, with different penetration of electricity sources. The table below summarises the penetration of the main electricity sources per bidding zone in 2020.

	IT CNO	IT CSO	IT NO	IT SAR	IT SIC	IT SO
COAL	0%	14%	1%	36%	0%	7%
NATURAL GAS	36%	40%	50%	34%	60%	51%
HYDRO	12%	8%	31%	2%	1%	3%
PV	13%	13%	6%	7%	11%	10%
WIND	2%	14%	0%	14%	20%	20%
OTHER	37%	11%	12%	7%	8%	9%

A few elements are worth noting:

- Coal penetration in electricity production varies widely across bidding zones, reaching 36% in Sardinia.
- Natural gas is the main electricity source in every bidding zone, spanning from 34% to 60%.
- The penetration of renewable energy sources is very different depending on the bidding zone, however fossil fuels still dominate in all of the zones.
- The most prominent renewable source, in the South and on the islands, is wind, while hydropower reaches 31% in the Northern bidding zone.

Overall, Italy is a net electricity importer, importing 12% of the electricity it consumes. Imported electricity from its neighbouring countries (mainly France and Austria) contribute to partially lowering the carbon intensity of the northern bidding zones, compared to the southern and insular ones relying more on local gas-fired and coal-fired generation. The most carbon-intensive grid is the Sardinian one, while the Central North, which is the only one partially relying on geothermal energy, is the least carbon intensive. The table below shows the average hourly carbon intensity in each of the bidding zones.

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	IT CNO	IT CSO	IT NO	IT SAR	IT SIC	IT SO
CARBON INTENSITY (gCO_2/kWh)	276	382	320	505	356	358

The proposed System-Level Matching allows hydrogen to be produced and labelled as green when renewables in a bidding zone are generating at or above average when compared to the country average two years before. Applying this system in each of the bidding zones in 2020, comparing with the Italian renewable penetration of 2018 (36%), the carbon intensity of green-labelled hydrogen would vary (on average) from 12.9 to 18.9 tCO_2/tH_2. The number of running hours would vary from below 2000 to above 8000, as shown in the table below.

	IT CNO	IT CSO	IT NO	IT SAR	IT SIC	IT SO
CARBON INTENSITY (tCO_2/tH_2)	12.9	15.3	13.6	18.9	13.2	13.9
RUNNING HOURS	8,019	4,533	4,534	1,993	3,876	4,410

Of these running hours the great majority would produce hydrogen with an associated carbon intensity higher than that of grey hydrogen. The table below shows how many hours an electrolyser would be producing hydrogen with higher emissions than the grey hydrogen threshold (10.9 tCO_2/tH_2), in absolute terms and as a percentage of the total running hours had the System-Level Matching rule been applied.

	IT CNO	IT CSO	IT NO	IT SAR	IT SIC	IT SO
TOTAL RUNNING HOURS	6,489	4,381	4,173	1,993	3,170	3,365
% IN THE YEAR	81%	97%	92%	100%	82%	76%

During the most carbon intensive production hour permissible under the proposed rules, hydrogen produced in Sardinia would have a carbon intensity up to 2.5 times greater than that of grey hydrogen. The table below shows the associated carbon footprint of the hydrogen produced during the most carbon intensive hour permissible had the System-Level Matching rule been applied in the six Italian bidding zones in 2020.

	IT CNO	IT CSO	IT NO	IT SAR	IT SIC	IT SO
CARBON INTENSITY (tCO_2/tH_2)	17.7	21.9	17.6	24.3	19.1	19.6
WHEN	30/10/20 01:00	26/04/20 19:00	21/09/20 19:00	03/05/20 20:00	12/04/20 18:00	19/04/20 09:00

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Overall, the Italian grid currently does not appear ready to produce electrolytic hydrogen on a large scale. Being a net importer of electricity, Italy clearly does not have oversupply to channel into electrolysis. Moreover, natural gas remains the main source of power across the six bidding zones, with high level of coal penetration in some of them.

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