EWI EV PREPAREDNESS INDEX

European benchmark of electricity system preparedness to accommodate large-scale EV Adoption

On behalf of the Society for the Promotion of the Institute of Energy Economics at the University of Cologne e. V.

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Executive Summary

- Electric vehicle (EV) adoption is accelerating – in the EU, the passenger car electric vehicle (EV) fleet is targeted to reach up to 30 millions by 2030. In line with growing EV penetration and vehicle fleet electrification, investments in charging infrastructure has picked up speed, as well. The electrification of transportation has immediate and significant repercussions for national electricity networks (sector convergence), leading to several challenges. These are: providing sufficient green electricity generation (and storage) to satisfy additional demand from mobility sector, ensuring reliable electricity distribution under intensifying grid capacity constraints and aligning increasingly intermittent non-dispatchable supply with dynamic charging needs. We refer to these interrelated challenges as the **EV Charging Trilemma**.

- EWI has developed an index to systematically assess **energy system preparedness** along three **Challenges (C1, C2 and C3)** of the EV Charging Trilemma. Specifically, we look at **C1 Electricity Supply**, **C2 Charging & Grid infrastructure** and **C3 Flexible Charging**. In total, **8 specific quantitative indicators** build our **EV Preparedness Index**.

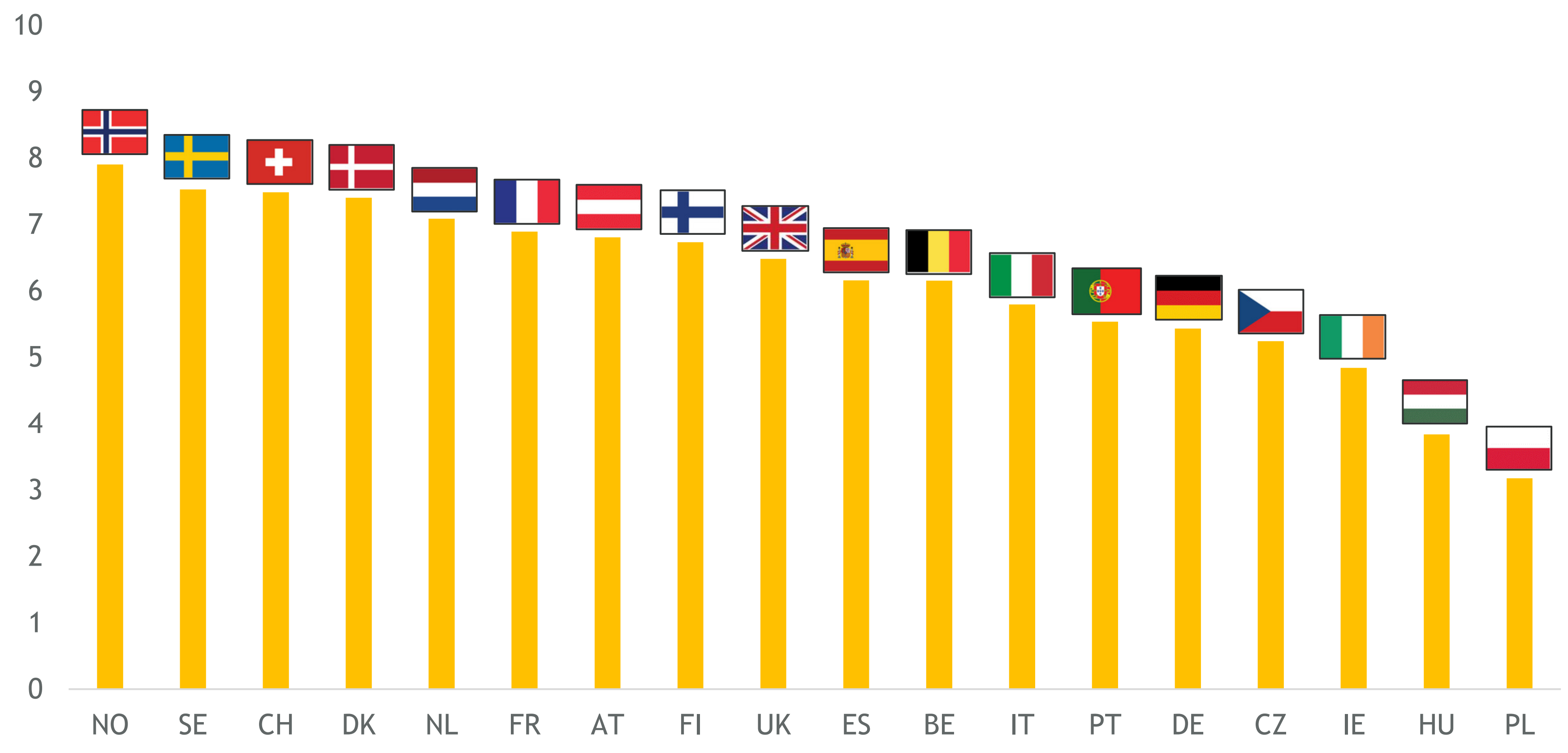
Executive Summary

- Our **analysis of 18 major European energy systems** reveals a **diverse picture of EV Preparedness across Europe**. We find that countries approach the three challenges with different emphases. Scoring high in one challenge could reduce the demand for investment in other challenges. High scores in flexible charging for example could reduce the need for peak load generation capacities. Still, overall EV Preparedness is best when all challenges are met.
- The countries with the **highest EV Preparedness Score include Norway, Sweden and Switzerland**. Leading countries typically have a strong renewable energy sector (with a focus on wind and hydro) including storage, generally a very capable grid and charging infrastructure and oftentimes a strong focus on smart metering and flexibility regulation. The **bottom three countries** include (from lowest to highest) **Poland, Hungary and Ireland**. Core reason of poor performance is a highly carbon intensive electricity sector that diminishes benefits from EV driving (especially Poland) and low charger coverage as well as relatively poor grid quality. Furthermore, the bottom three countries do not support flexible charging since neither the technical preconditions (smart meters) nor the economic incentives stimulate demand side flexibility.

Executive Summary

Nordic countries ahead, Germany among bottom three

Combined EV Preparedness Ranking [2021]

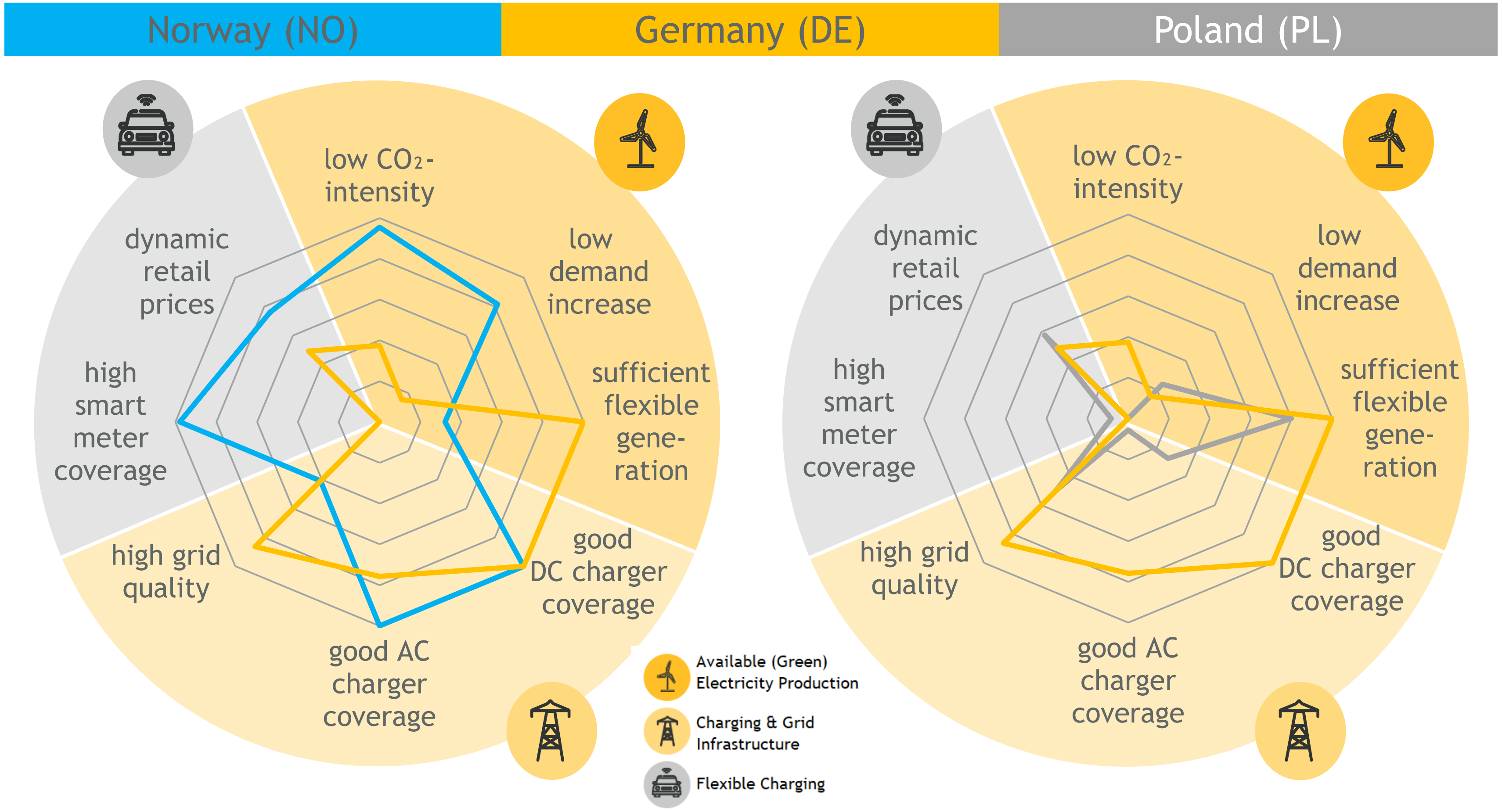


Source: EWI analysis

- Three Nordic countries and CH are among the top prepared European energy systems for the electrification of transport.
- The reasons are especially their low CO_2 intensity of electricity production, the good charging and grid infrastructure as well as their advanced smart meter roll out.
- PL, HU, IE, and the CZ form the bottom cohort.
- Especially the coal-reliant electricity systems and poor flexibility performance lead to their low ranking.

Executive Summary

Best and worst along three Challenges and eight indicators



- A value further out of the circle indicates a better value in the respective indicator.
- NO and DE both have a well-prepared infrastructure for the EV-rollout. While NO is better equipped regarding the charging infrastructure, DE succeeds in a higher grid quality.
- The electricity systems of PL and DE lag behind, both because the EV-rollout could increase the burden of electricity system due to the countries' large automobile fleet and because of the relatively high CO_2-intensity of power generation.
- DE and PL both lag behind NO by neither offering sufficient economic incentives nor the technical means for flexible charging.

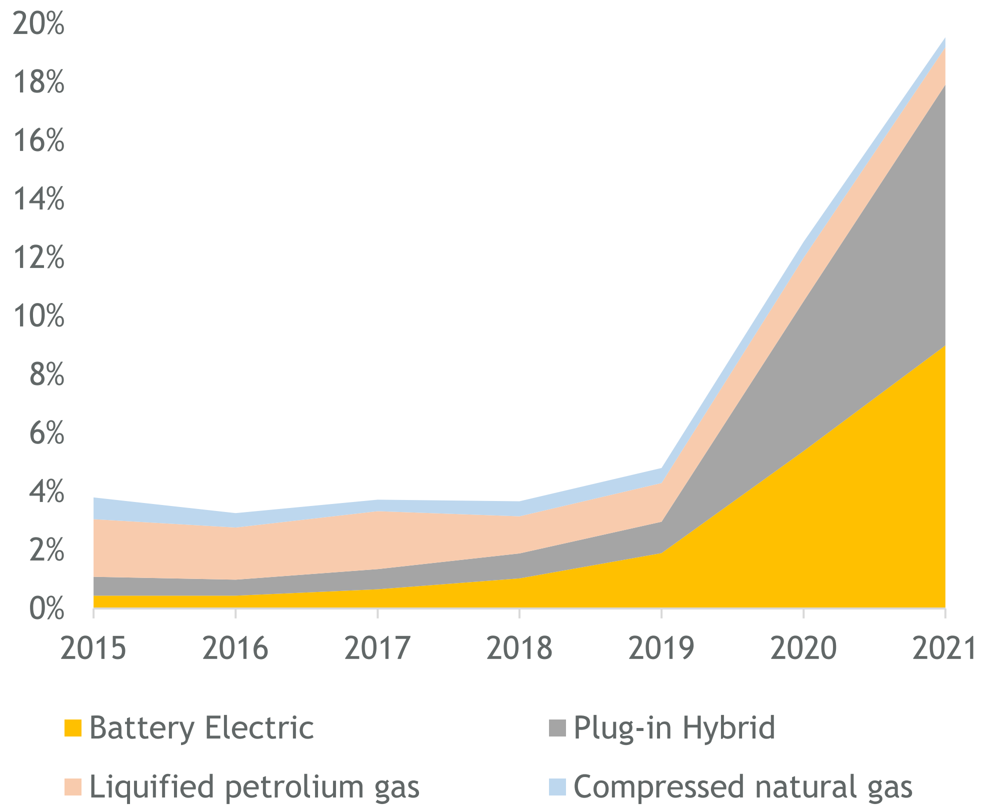
Source: EWI analysis

1 Motivation

Dynamics of EV Adoption

Up to 30 million passenger cars by 2030 in Europe

Market share of alternative fuel vehicles registrations in Europe [2015 – 2021]

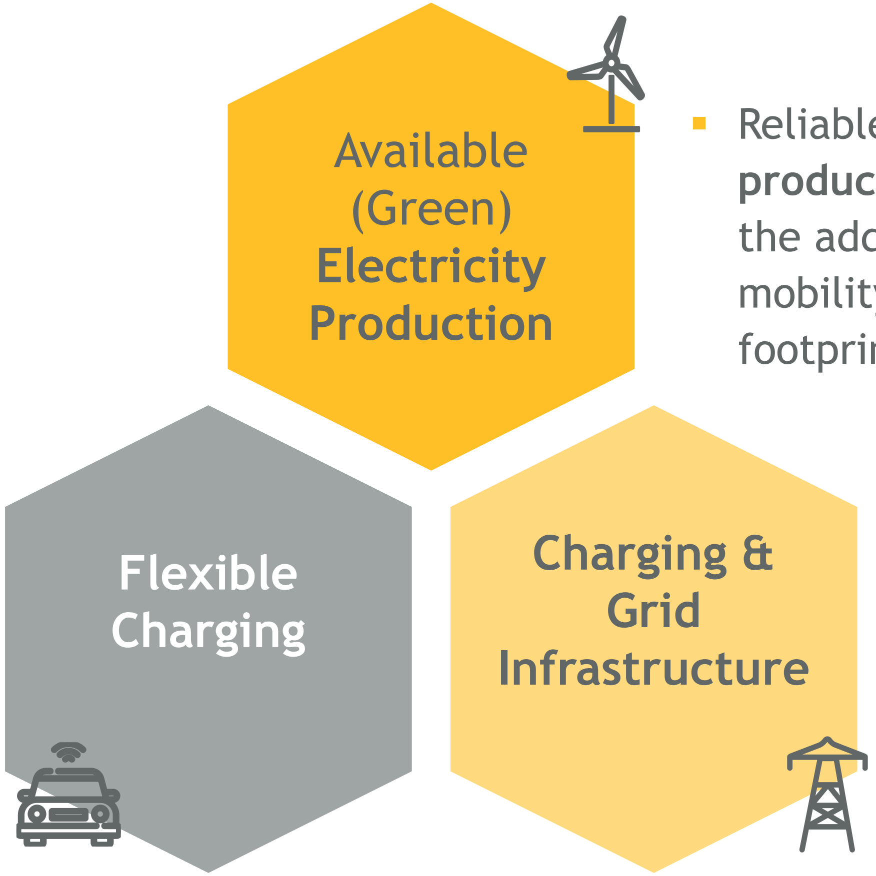


- The share of electric vehicles (EV) in passenger and commercial transportation is increasing rapidly. The market share of new registrations of batterie electric and plug-in hybrid vehicles increased from 1% in 2015 to almost 18% in 2021 in Europe. The perpetually increasing EV sales persisted even with supply shortages during Covid-19 pandemic. Without these shortages the EV market shares might have been even higher.
- For the rollout of electric mobility this market share of new registrations needs to increase in order reach the European target of 30 million electric vehicles in 2030.
- This wide scale EV adoption significantly transforms the transportation as well as the electricity sector. The two sectors will become more intertwined with an increasing EV roll out.
- The transformation of the transportation sector leads to 3 challenges in the electricity sector concerning electricity production, grid infrastructure and system flexibility.

Source: Eurostat (2022a)

Interrelated challenges of EV Integration
We refer to them as the EV Charging Trilemma

The EV Charging Trilemma



- Reliable **green electricity production** can provide the additional load of e-mobility with low carbon footprint.

- **Flexible charging** behavior can avoid higher load peaks compared to uncontrolled charging.

- A reliable **grid infrastructure** and a nationwide **charging infrastructure** are prerequisites for the ramp-up of e-mobility.

2

EWI EV Preparedness Index

EWI EV Preparedness Index: Systematically assess energy system preparedness along the three challenges of the charging trilemma

C1 Available (Green) Electricity Production

- To what degree does the energy system provide **Abundant, Clean and Affordable Electricity?**

3 indicators

C2 Charging & Grid Infrastructure

- Can the energy system rely on a **Capable Charging and Grid Infrastructure** backbone?

3 indicators

C3 Flexible Charging

- Are **Price Signals and Technologies** in place that enable and encourage **Demand Side Flexibility**?

2 indicators

EWI EV Preparedness Index: Eight unique indicators along the three dimensions

C1 Available (Green) Electricity Production

- **1.1** – CO_2 intensity of EV driving
- **1.2** – Demand increase attributable to EVs
- **1.3** – Flexible generation capacities

C2 Charging & Grid Infrastructure

- **2.1** - DC (fast) charger coverage
- **2.2** - AC (standard) charger coverage
- **2.3** - Grid quality (SAIFI)

C3 Flexible Charging

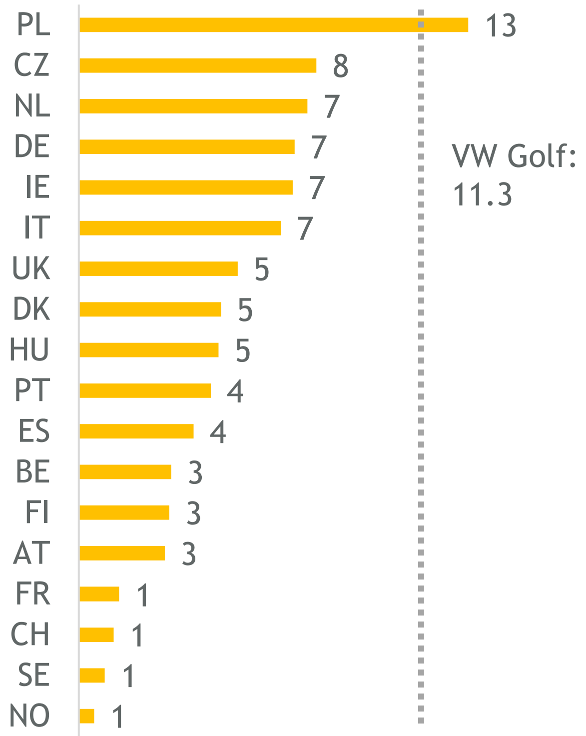
- **3.1** - Smart meter coverage
- **3.2** - Retail price dynamics

C1 Electricity Supply: Three indicators to assess EV Preparedness

	Indicator	Definition	Rationale
Available (Green) Electricity Production	**1.1 CO_2 Intensity of EV driving**	▪ Emissions per 100 km based on countries' generation mix (use phase only, neglecting any vehicle production-specific emissions)	▪ True sustainability footprint of EV over the course of its use cycle depends on the CO_2 intensity of the relevant electricity mix.
	1.2 Demand increase attributable to EVs	▪ Increase in electricity demand that is attributable to EV demand in a 100% adoption scenario	▪ Relatively larger energy systems will likely be able to cope better with increasing demand from the EV sector.
	1.3 - Flexible generation capacities	▪ The share of secured capacity of a countries' generation mix compared to its peak demand	▪ Countries with high amount of secured capacity are well-prepared for possible demand peaks arising from EV-charging.

1.1 Available (Green) Electricity Production: CO_2 intensity of EV driving

Average of CO_2 Intensity of EV driving in 2021 [kg CO_2/100km]

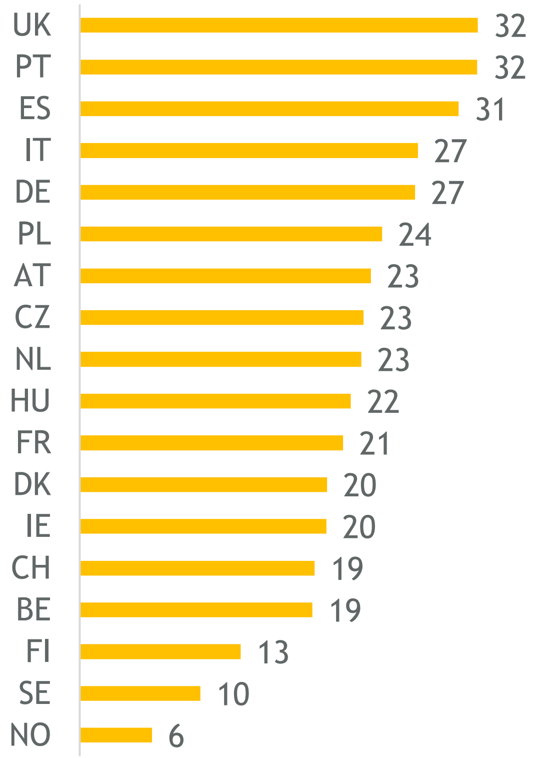


Source: Our World in Data (2022); EV Database (2022)

- The carbon footprint of e-mobility depends on the electricity generation mix in the respective country. A generation mix based on renewable technology can reduce more CO_2 than a generation mix dominated by fossil fuels.
- This indicator measures the emissions of an electric vehicle per 100 km based on the underlying countries' generation mix and assuming a consumption of 19.4 kWh/100km.
- The lowest specific emissions are in Nordic (NO and SE) countries and countries which have zero-emission nuclear power (CH and FR). Energy systems with substantial installed capacity of coal-fired power plants (PL, CZ and DE) rank among the worst. High prices for natural gas in 2021 however shifted electricity generation from gas to coal. Therefore, countries with a smaller share of coal-fired power plants like NL, IE and IT also relied on their coal capacities. PL performs worst in this category, even underperforming the benchmark ICE (internal combustion engine) vehicle (VW Golf).
- An overall downward trajectory in CO_2 intensity can be observed until 2020 due to progressive reduction in CO_2 intensity of the energy mix in most EU countries. In 2021, however, the CO_2 intensity of electricity generation increased on average. The overall downward trajectory is expected to continue due to increasing RES capacity and CO_2-certificate prices, as well as political ambitions to phase out coal generation.

1.2 Available (Green) Electricity Production: Demand increase attributable to EVs

Average demand increase attributable to EV in 2021 [share of total demand in %]

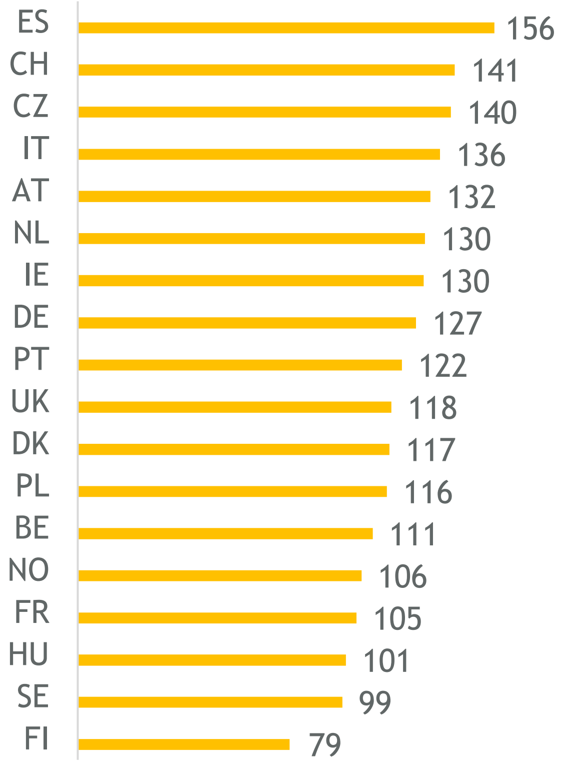


Source: BEIS (UK)(2022); Entso-e (2022); European Commission (2022a); Odyssee-Mure (2019); EWI analysis

- To analyze the electricity systems' preparedness, this indicator assumes a 100% replacement of the (ICE) passenger vehicle fleet with EVs and calculates the increase in electricity demand resulting from this replacement. Countries that already consume high amounts of electricity are likely to absorb the additional load from a replacement of ICE vehicles with EVs better than countries with lower electricity consumption.
- The additional demand from private mobility can amount to approximately 30% at a 100% replacement of ICEs. This is especially the case in countries with large vehicle fleets (DE, UK, IT and ES) and/or relatively small specific base energy consumption (PT).
- Best in class countries (NO, SE and FI) only experience a demand increase of up to 12% from the electrification of private mobility. This is due to an already high specific base consumption (high electricity demand at low population) and/or relatively small vehicle fleets.
- From 2020 to 2021 both the passenger vehicle fleet and the electricity demand increased by approximately 4%. Therefore, the increase in demand attributable to EV remains on the same level between 2020 and 2021.

1.3 Available (Green) Electricity Production: Flexibility of Generation Capacities

Coverage of peak demand with secured capacity in 2021 [% of secured capacity/peak demand]

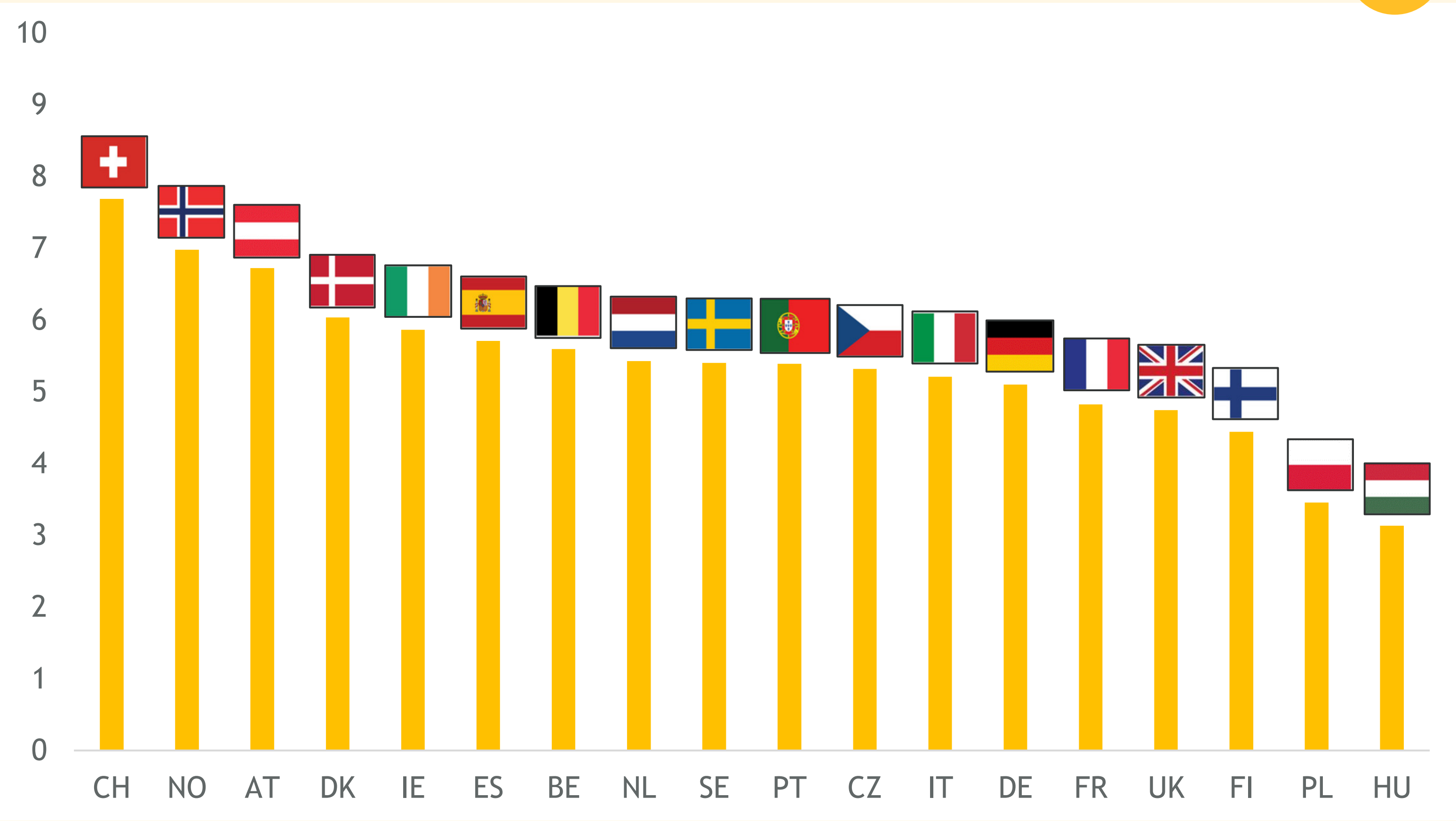


- In order to deal with the potential demand peaks through additional load from electric vehicles, dependable generation technologies are crucial. Therefore, this indicator analyses the share of the guaranteed capacity of a country's generation park in comparison to its peak demand. Countries with sufficient secured generation capacity could cover peak demand hours in situations with low renewable generation.
- There are generally large reserve margins of generation capacities in Europe. ES is the country with the highest margin due to its high installed capacity of gas fired power plants, its hydro pump storages and hydro water reservoirs power plants.
- Many countries perform well in this category, often due to legacy generation capacities. The phase out of some generation technologies like coal and nuclear power in Germany will likely decrease the secured capacity over time, leading to a lower performance in this dimension.
- FI and SE perform worst in this category. This originates from the low secured capacities in combination with high demand peaks. FI had secured capacity of 21% lower than its peak demand in 2021. This leads to high import dependencies in case fluctuating generation and peak demand hours do not correlate. However, the Nordics are well-connected with their neighboring countries, which may reduce the demand for secured capacities.

Source: Entso-e (2022), EWI analysis

C1 Available (Green) Electricity Production: High variability in terms of generation-based EV Preparedness across countries in scope

EV Preparedness Ranking – Electricity Production [2021]



- Hydro-focused electricity systems (CH, AT and NO) are the clear leaders in generation-driven EV preparedness due to their low average CO_2 intensity of generation.
- While the Nordics witness only a small increase of their electricity consumption in case of a complete EV-rollout, their generation systems might not be supplied sufficiently with secured capacity.
- The bottom quartile (UK, FI, PL and HU) consists of coal-based energy systems (PL and HU) with a relatively high CO_2 intensity. FI and UK perform comparatively poor due to the undersupply of secured capacity and the large expected demand increase from an EV-rollout, respectively.

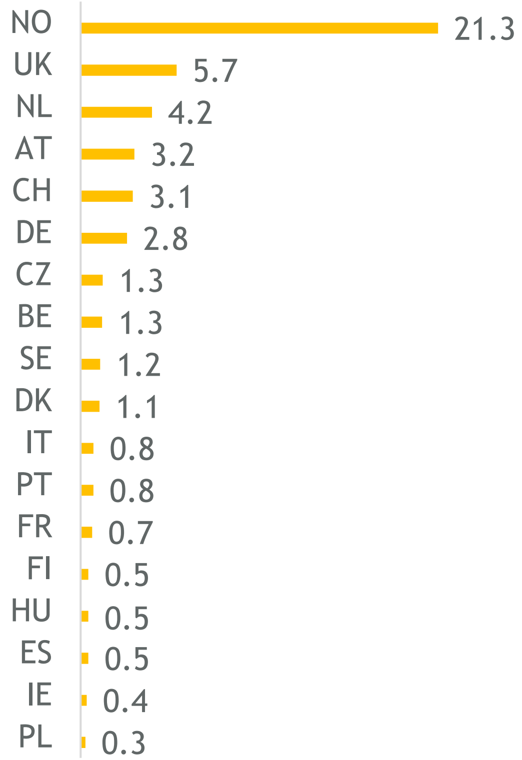
Source: EWI analysis

C2 Grid and Charging Infrastructure: Three indicators to assess EV Preparedness in grid and charging infrastructure

	Indicator	Definition	Rationale
Grid & Charging Infra-structure	**2.1 DC (fast) charger coverage**	▪ Sufficient DC (direct current) chargers per highway kilometer for the e-mobility rollout	▪ Highway charging is seen as an important enabler of (long-distance) e-mobility.
	2.2 AC (standard) charger coverage	▪ Sufficient AC (alternating current) chargers for the e-mobility rollout	▪ Comprehensive public and destination AC charging station coverage is key to accommodating EV adoption.
	2.3 Grid quality (SAIFI)	▪ Counts electricity supply outages with SAIFI (System Average Interruption Frequency Index)	▪ High quality (distribution) grid infrastructure is required to ensure local supply of EVs and ability to connect new chargers (private and public).

2.1 Grid and Charging Infrastructure: DC (fast) charger coverage

DC fast charger coverage in 2021
[#charger/ target value]

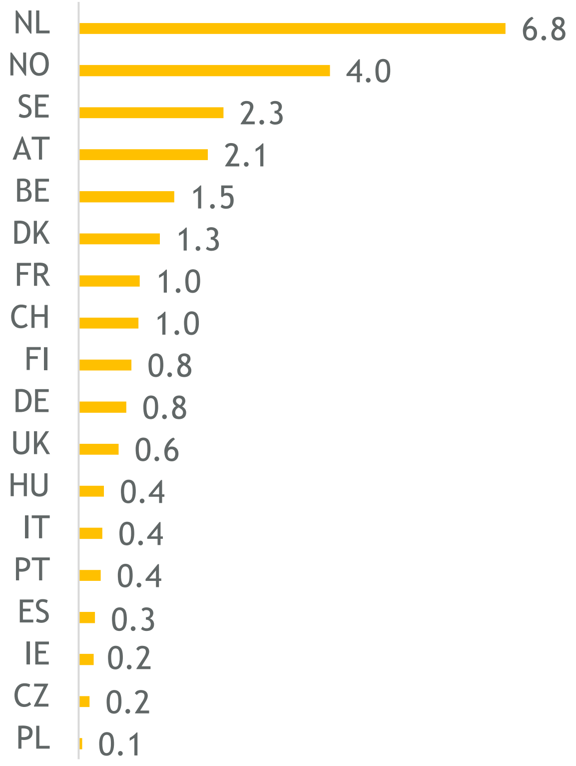


- DC charging allows for fast charging of vehicles at a rate of typically 50kW and higher, often up to 150 – 300 kW. Thus, it compares better to a standard refueling cycle of a petrol vehicle compared to AC charging. A good DC charging infrastructure on highways is a prerequisite for the EV rollout.
- NO is best in class in terms of DC charger coverage per kilometer of highway. This is due to the country's relatively small highway network as well as the relatively large number of DC charging stations.
- The share of newly registered EVs outweighs ICE cars in NO, partly explaining the relatively fast DC charging infrastructure growth. Second in this indicator is UK, which also seems to set its focus on DC charging rather than AC charging.
- To be well-prepared for the e-mobility roll out, PL and IE have the biggest gap of DC charging coverage among the analyzed countries. Low coverage of charging stations on PL's and IE's highways in combination with the adoption of EVs could lead to congestion at fast charging stations.
- The target value computes as the necessary increase in installed DC chargers compared to publicly stated EV registration targets.

Source: European Commission (2022b), EWI analysis

2.2 Grid and Charging Infrastructure: AC (standard) charger coverage

AC standard charger coverage in 2021
[#charger/ target value]

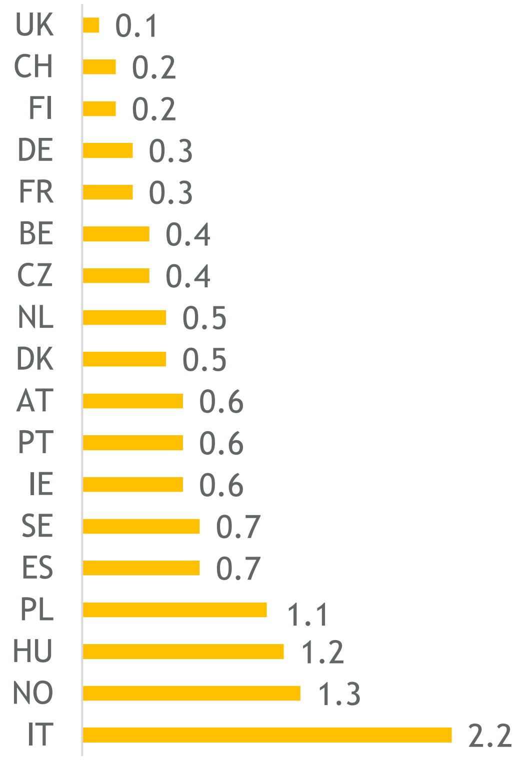


- Public AC charging infrastructure refers to publicly accessible charging opportunities at typical rates of less than 22kW. Countries with a more comprehensive AC infrastructure enable EV drivers to convenient charging while parking. Especially EV drivers without the possibility to charge their EV at home are dependent on public AC charging infrastructure.
- NL public charging infrastructure significantly outperforms other countries. NL has a clear focus on public charging with the highest absolute number of AC chargers. NO's AC infrastructure is also well prepared for an EV rollout due to its relatively small automobile fleet and therefore low demand of AC chargers.
- Worst in class are PL, CZ and IE. This is partially due to the low numbers of AC chargers and partially due to the high demand of charging infrastructure for the EV rollout. In these countries, the growth of public charging infrastructure would need to accelerate for a nationwide EV rollout.
- The target value computes as the necessary increase in installed AC chargers compared to publicly stated EV registration targets.

Source: European Commission (2022b), EWI analysis

2.3 Grid and Charging Infrastructure: Grid quality (SAIFI)

Grid quality (SAIFI) in 2020 [count of interruptions/number of customers]

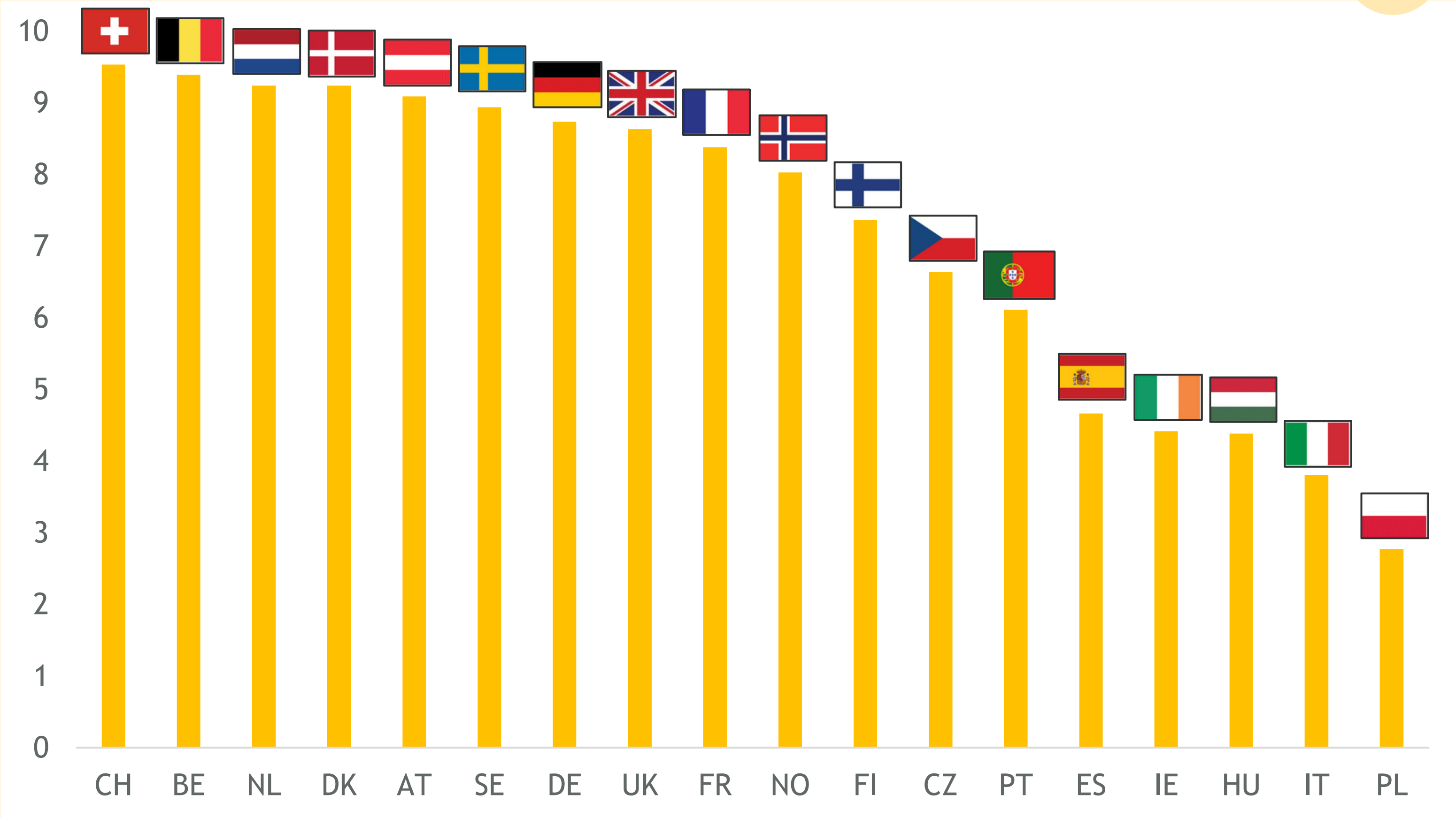


- SAIFI (System Average Interruption Frequency Index) quantifies average annual number of interruptions in the power supply per customer. It is a generally accepted utility reliability measure, specifically regarding grid reliability. Additional load from electric vehicles could stress the grid infrastructure and especially the distribution grid.
- Countries that perform well in this indicator show high grid resilience and are therefore more likely to cope with the increasing load originating from electric vehicles.
- In high performing countries (CH, FI and UK) grids are well-provisioned and can cope with supply and demand-induced pressures.
- In poorly performing countries moderate improvement is seen over the years, which is likely due to much needed grid investments. IT however experienced major outages in 2020 that constituted a set back from previous gains.
- SAIFI is largely stable across the sample with a slight downward trend, i.e., toward better grid performance. However, for the year 2021 there was no available data. Due to shortages of gas supply, the interruptions frequency of electricity supply could have increased.

Source: The World Bank (2020), EWI analysis

C2 Grid and Charging Infrastructure: Many countries are well prepared while other countries lag in grid quality and charging infrastructure

EV Preparedness Ranking – Infrastructure [2021]



Source: EWI analysis

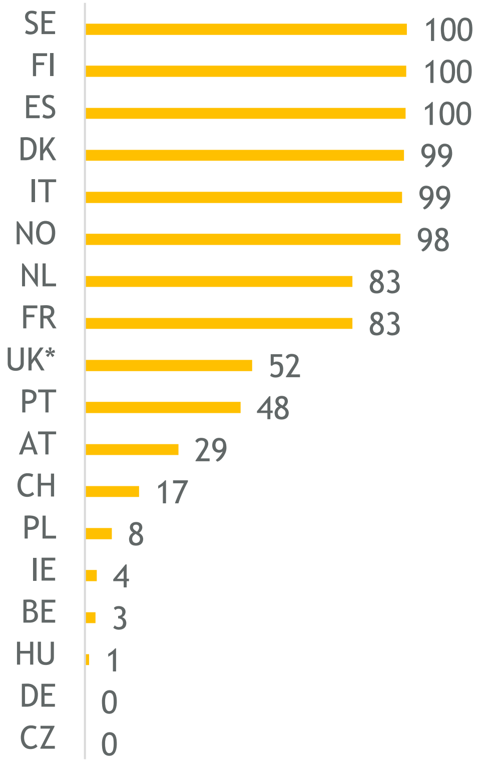
- The top quartile of countries consists of a diverse set that are characterized by good DC and AC charging infrastructure coverage (NL) and/or a good grid quality (CH and BE).
- Other large European and Nordic countries perform equally well due to an already well-prepared charging infrastructure and stable electricity system.
- IT and PL perform badly, partly due to poor grid quality (IT) and/or due to a poor charging infrastructure (PL).

C3 Flexible Charging: TWO indicators to assess EV Preparedness regarding flexible charging

	Indicator	Definition	Rationale
Flexible Charging	**3.1 Smart meter coverage**	▪ Percentage of households equipped with smart meters	▪ Smart Meters are core to measuring and managing demand flexibility in real time and are required to implement time-of-use (TOU) tariffs.
	3.2 Retail price dynamics	▪ Share of electricity wholesale price (i.e., variable portion) in retail electricity price	▪ TOU tariffs only work if price variability is meaningful. If the variable portion on the final retail price is small, incentives for flexibility are insufficient.

3.1 Flexible Charging : Smart Meter Coverage

Share of households with installed smart meters in 2020 [%]



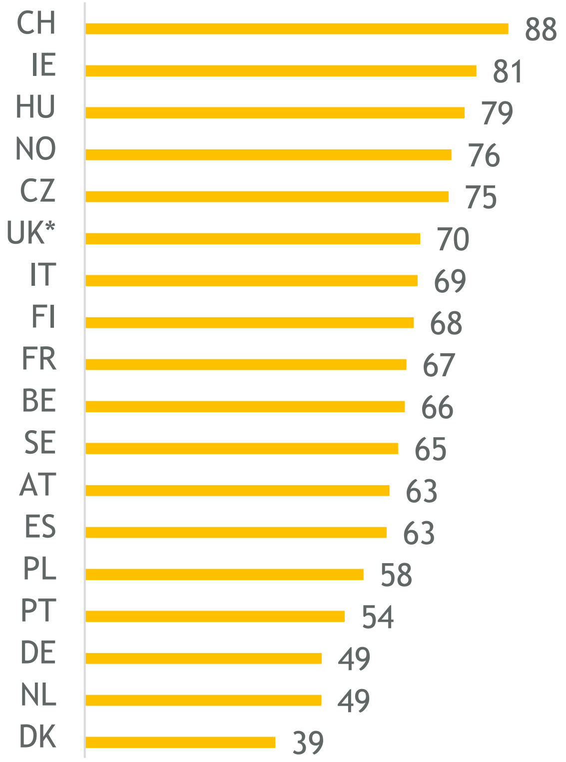
*observation for 2021

Source: European Commission et al. (2020), ACER & CEER (2021), EWI analysis

- Overall, a significant increase has been achieved in smart meter penetration during the last years in many of the considered countries. Smart meters are considered a technical prerequisite for Time-of-Use (TOU) tariffs, which incentivize customers to employ flexible charging patterns. Flexible charging would relieve stress from the electricity system because load could be shifted, and peaks could be reduced.
- Nordic countries (DK, NO, SE, FI) as well as Spain and Italy have already completed the smart meter roll-out. NL and FR are in the final stages of their roll-outs with a share of smart meters of more than 80%.
- In Germany, the largest EV market considered in this analysis, the smart meter roll out has not started yet. Other markets (CZ, PL, HU, IE and BE) are at similar stages of low penetration under 8%.
- Data for the smart meter rollout is only available for 2020. Improvements from 2020 to 2021 were therefore not considered. Especially the score for poor performing countries could have increased between these years.

3.2 Flexible Charging : Retail Price Dynamics

Share of procurement price and network tariffs in retail price in 2021 [%]



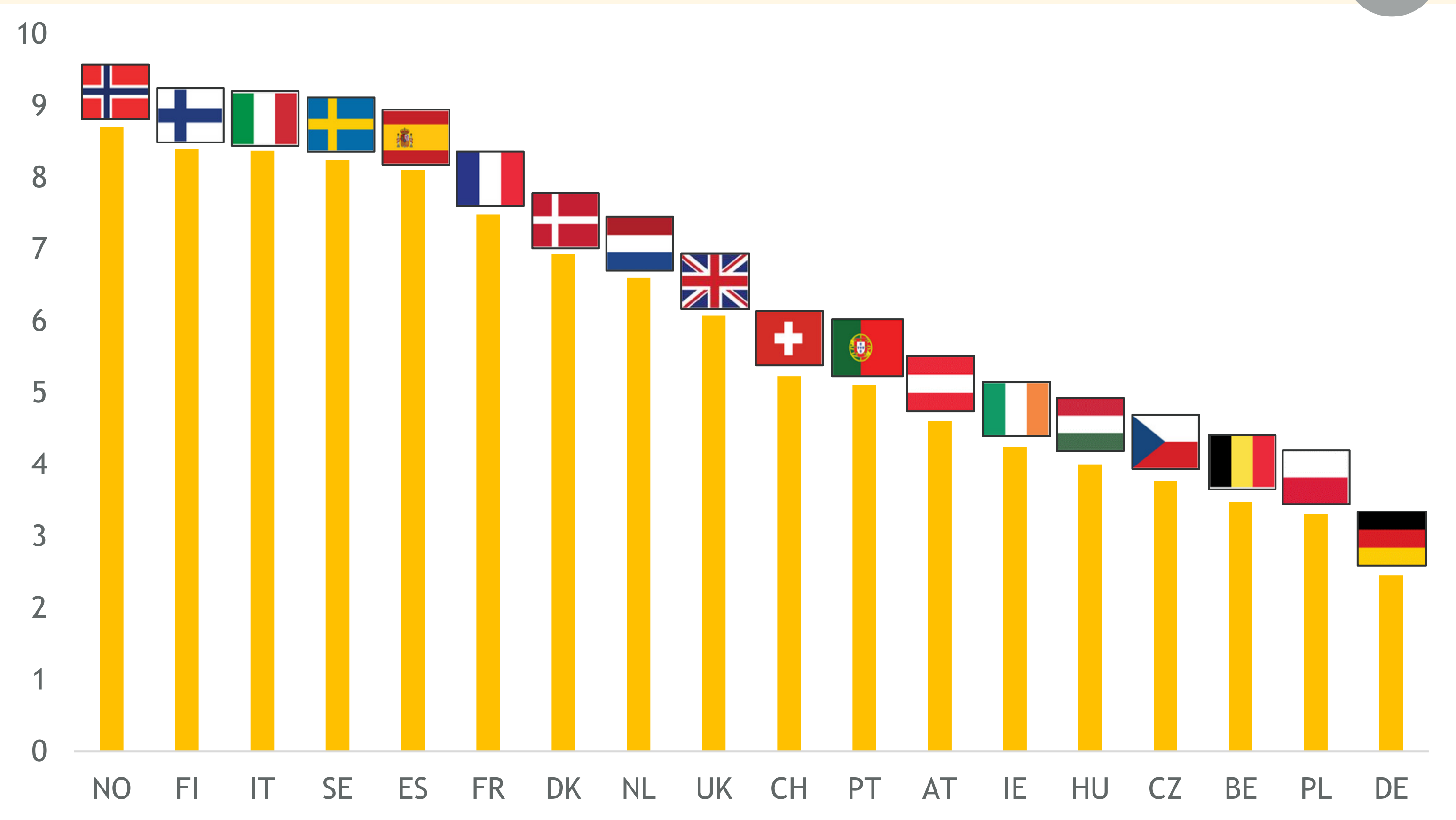
- The retail price of electricity is subject to a range of taxes, fees, and surcharges that result in largely stable prices, even if time-of-use (TOU) electricity and grid tariffs were introduced. The reason being is that the actual procurement of electricity and grid fees often constitute only a small share of the retail price.
- This is especially problematic in countries with high fixed fees and taxes such as PT, DE, NL and DK. Here, the variable portion of the final price is only 39% to 54%. Potential TOU tariffing could create fewer incentives to shift electricity consumption in these countries.
- CH, IE and HU seem to be better prepared for flexible retail tariffs due to lower fixed price components. 79% to 88% of their retail price is based on the costs for electricity procurement and network tariffs.
- To counter increasing electricity prices in 2021, some countries introduced subsidies and reduced their value added taxes (VAT) for consumers, e.g., NL. Since these price components could distort the price signals from electricity providers or signals from grid operators, they were disregarded in this analysis.

*observation for 2020

Source: Belastingdienst (NL) (2022), Centraal Bureau voor de Statistiek (NL) (2022), Eurostat (2022a), EWI analysis

C3 Flexible Charging: Preparedness generally at low levels throughout sample; DE performs especially poorly.

EV Preparedness Ranking – Flexibility [2021]



Source: EWI analysis

- The top quartile is shaped by a diverse set of countries with a high smart meter penetration and a relatively high share of flexible energy cost proportion. In countries like IT, FI and NO, flexible charging is both enabled by the existing technical prerequisites and economic incentives.
- The bottom quantile is dominated by countries with a low smart meter penetration (BE, HU, DE, CZ, etc.) and a low share of potentially flexible components in the electricity retail price (DK, NL and DE). Implementing demand response systems for end-users may be more difficult in these systems.
- Germany performs especially poor due to its low smart meter penetration and low retail price dynamics. Thus, there are neither incentives nor the technical requirements for households to engage in demand response.

Appendix

Appendix A: Definition of Upper and Lower Boundaries per Indicator

Indicator	Boundaries	Rationale	Sources
1.1 - CO_2 Intensity of EV driving	**11.0** [kg CO_2/ 100km] 0 — 10 **0** [kg CO_2/ 100km]	▪ 0 points for performance equal or worse than benchmark ICE vehicle (VW Golf 2018), full points for full CO_2 neutrality	Our World in Data (2022); EV Database (2022)
1.2 - Demand increase attributable to EV	**32%** [% of tot demand] 0 — 10 **0%** [% of tot demand]	▪ 0 point for increase >= 32%, which is approx. the highest value observed in 2021, 10 points for no demand increase at all.	BEIS (UK)(2022); Entso-e (2022); European Comission (2022a); Odyssee-Mure (2019)
1.3 - Flexibility of Generation Capacities	**100%** [% of peak load] 0 — 10 **120%** [% of peak load]	▪ 0 point for capacity margin of 100% or less, 10 points for capacity margin of >= 100%	Entso-e (2022)

Appendix A: Definition of Upper and Lower Boundaries per Indicator

Indicator	Boundaries				Rationale	Sources
	Lower	0	10	Upper		
2.1 - DC fast charger coverage	**0.0** [# charger/ target value]	0	10	**1.0** [# charger/ target value]	▪ Goal of 8 DC charger per highway km in 2050. Full points for being on track of installing 1 DC charger per 8 Highway km, 0 points for no charger	European Commission (2022b)
2.2 - AC ordinary charger coverage	**0.0** [# charger/ target value]	0	10	**1.0** [# charger/ target value]	▪ Goal of 1 AC charger per 25 EV cars in 2050. Full points for being on track of installing 1 AC charger per 25 EV cars, 0 points for no charger	European Commission (2022b)
2.3 - Grid quality	**2.2** [SAIFI]	0	10	**0.0** [SAIFI]	▪ 10 points for no supply interruptions at all. 0 points for SAIFI score of 2.2 (highest score in our sample) and higher	The World Bank (2020)

Appendix A: Definition of Upper and Lower Boundaries per Indicator

Indicator	Boundaries	Rationale	Sources
3.1 - Smart meter coverage	**0** [% of HH] 0 – 10 **100** [% of HH]	▪ 10 points for full coverage (achieved by some countries in sample), 0 points for no coverage at all	European Commission et al. (2020); ACER & CEER (2021)
3.2 - Retail price dynamics	**0** [% of retail price] 0 – 10 **100** [% of retail price]	▪ 10 points for 100% variable portion (network fees and electricity procurement price), 0 points for no variable portion at all	Belastingdienst (NL) (2022); Centraal Bureau voor de Statistiek (2022); Eurostat (2022b)

Appendix B: References

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