Modelling of a large number of electric vehicles (EVs) in the all-island Ireland energy system

May 9, 2018

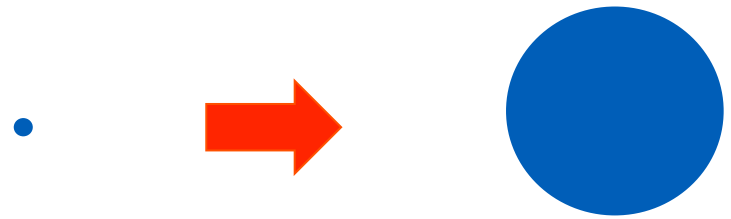
Overview of the model

All-Island Ireland electricity system has ca. 13 GW capacity and limited interconnection with Great Britain

All-Island Ireland power system overview:

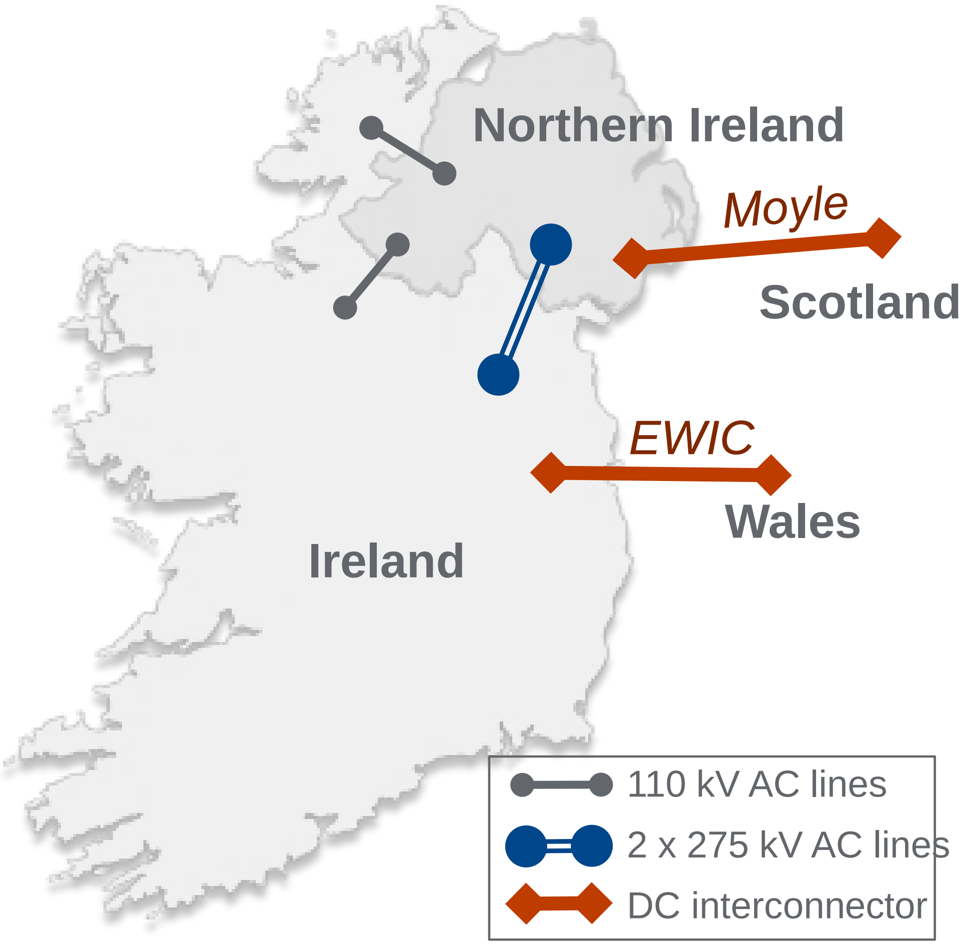
- The installed **net capacity** in the SEM was **13 GW in 2016** with 23% of wind penetration.
- The **interconnection with Great Britain is realised through** two interconnectors: **Moyle Interconnector**, connecting Northern Ireland with Scotland, **and the East-West Interconnector (EWIC).** Both are limited to ca. 500 MW.
- **There are a number of proposed interconnection projects** to Great Britain and mainland Europe (France), however all of these are currently at a preliminary stage.

Number of Electric Vehicles in Ireland:



2017
(Irish EV owners Association[1])

Projected for 2030
(EirGrid Group Consumer Action energy scenario[2])



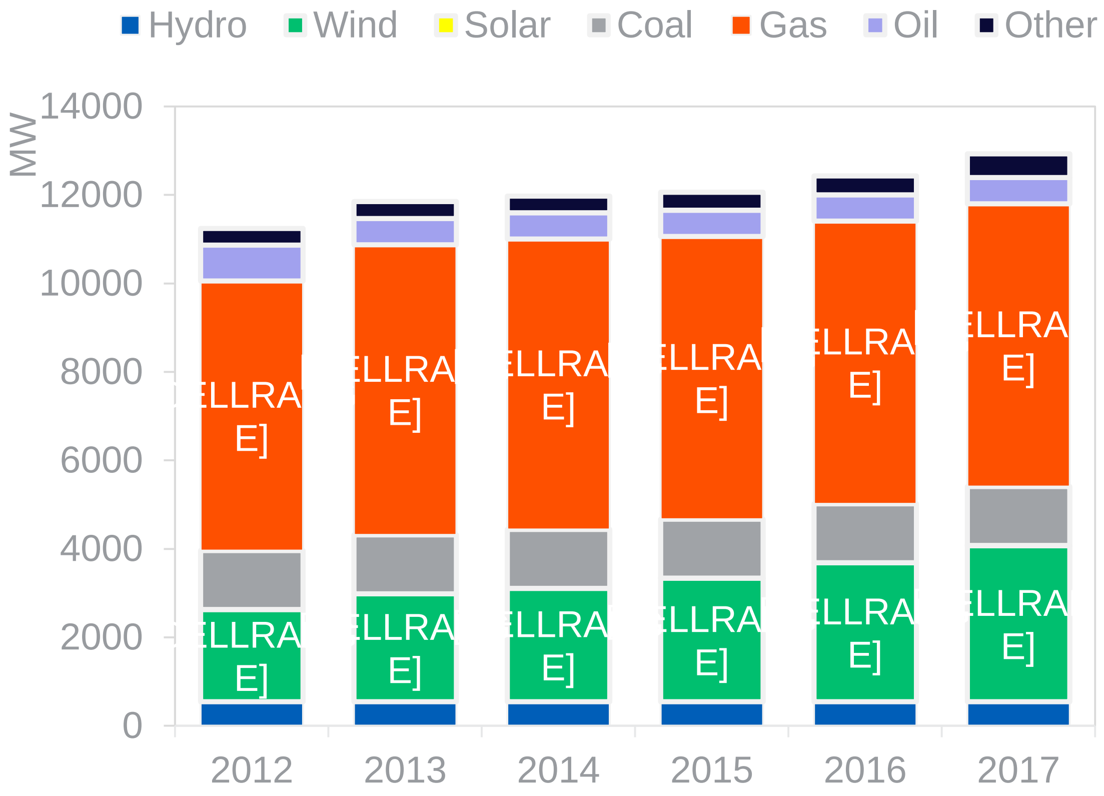
[1] http://www.irishevowners.ie/2017-irish-ev-sales-better-than-you-might-think/
[2] EirGrid, "Tomorrow's Energy Scenarios 2017," 2017

For this analysis, all dispatchable thermal and hydro power plants in Ireland are modelled as individual units

The analysis is performed by utilising a modelled with a detailed plant-level power dispatch model of Ireland:

- All dispatchable thermal and hydro power plants in Ireland are modelled as individual units, while wind and solar farms are aggregated.
- To capture the power flows between Ireland and Great Britain, the latter is also included in the model with all generators aggregated by owners.
- Transmission between Ireland and Great Britain is modelled through Moyle and East-West interconnectors using the physical capacities of these transmission lines.
- The model dispatches thermal and hydro units considering system constraints. The constraints that ensure synchronization between Republic of Ireland and Northern Ireland, as well as overall system stability

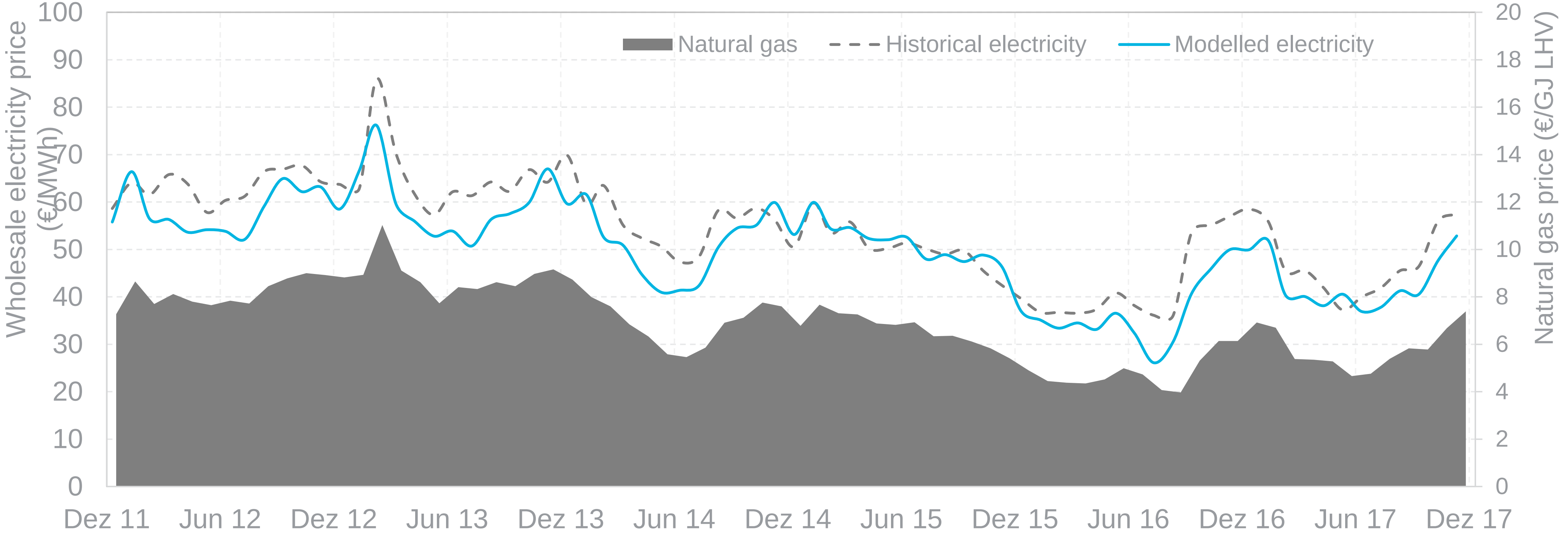
Net electricity generation capacity by type[1]:



[1]Basded on ENTSOE-E data

The model has been calibrated using historical electricity prices sourced from SEM-O

Calibration of the modelled electricity prices with historical values[1]:



- Fuel price dominate the cost of thermal power plants as is therefore crucial to power market modelling. Wholesale electricity prices in Ireland have **a strong correlation with natural gas commodity prices** due to high penetration of gas power plants.
- **Seasonal fluctuations** in electricity demand is another factor affecting the wholesale electricity prices.

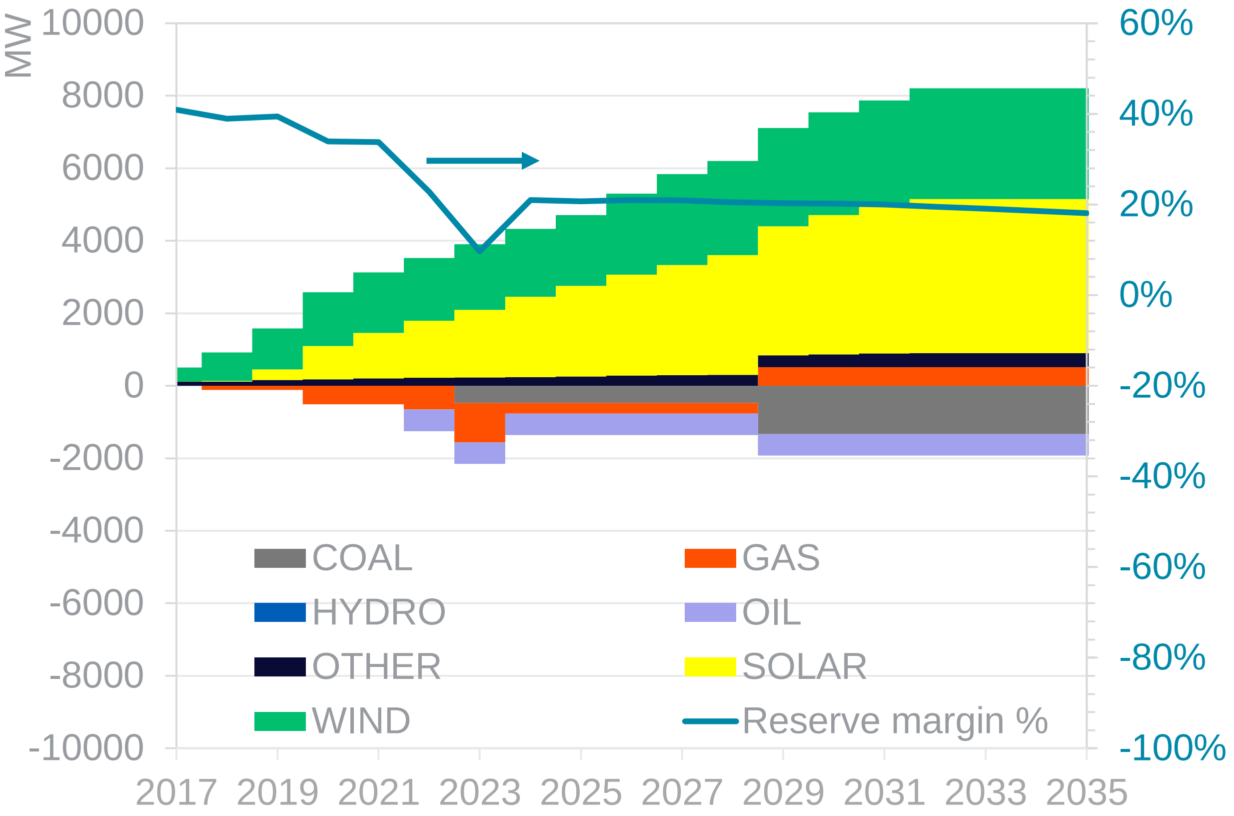
[1] Historical electricity prices sourced from SEM-O

The model captures planned generation capacity additions and retirements in Ireland

Modelled additions and retirements:

- The Industrial Emissions Directive (2010/75/EU) is the EU instrument for regulating Nitrous Oxide (NOx), Sulphur Dioxide (SO_2) and particulate levels from large power plants (>50 MW).
- Some **conventional generation** plants are expected to be **decommissioned** by 2023 due to poor availability and the **requirement to comply with the IED**.
- The current focus in the Republic of Ireland and Northern Ireland is on the expansion of renewable generation. The wind capacity is expected to increase further to around **4.4 GW by 2020** and up to almost **8 GW towards 2030.**
- **Reserve margin** is expected to decrease due **to low firm capacity factors** for Solar (ca. 5%) and Wind (ca. 25%).
- Thermal unit additions are modelled to meet 20% reserve margin in the region (not considering the load from EVs). On that basis, a CCGT and an OCGT units are added to the model in 2024, following the expected retirement of several older OCGT units.

Net changes to capacity and the reserve margin[1]:



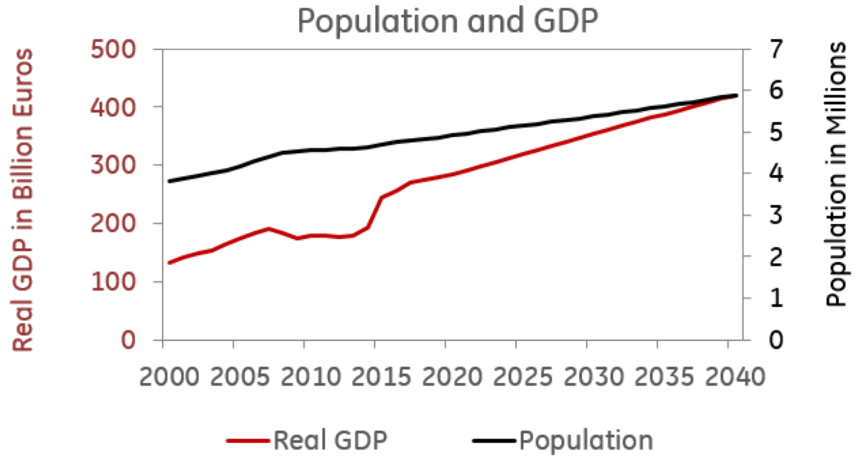
[1]Basded on EirGrid and IHS Markit data

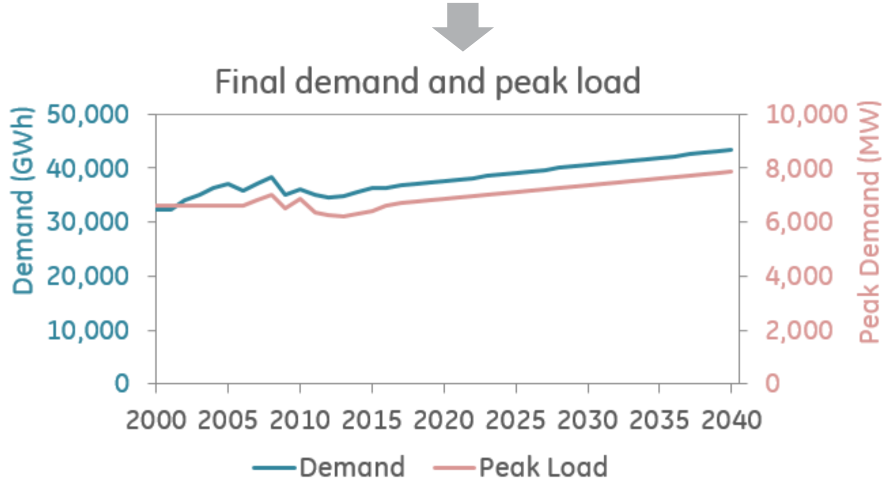
Demand growth, based on economic indicators, is one of the key underlying assumptions used in the model

The following methodology is used to calculate future demand and peak load:

- relationship between the historic demand (Eurostat) in each of three sectors (industry, households & services and transport) and the economic indicators (Oxford economics) and temperature (WBG) are established via linear regression. Historic demand (Entsoe) is used to account for transmission losses.
- Future annual demand is forecasted using forecasts of the population growth and GDP (Oxford economics).
- Historic hourly load profile is combined with future demand and peak load to produce hourly load forecast.

Demand forecast for Ireland:





EV parameters are based on Nissan leaf and the uptake is assumed to follow an S-shaped curve

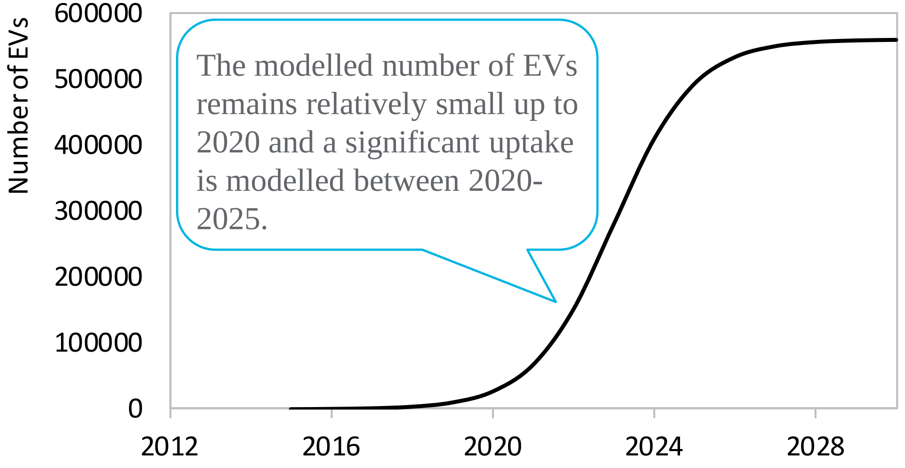
It is assumed that all EVs are charged to 100% by 7am and are depleted to 20% every working day[1]

Two charging strategies are modelled:

1. In the case of Standard charging, **EVs can charge from 5pm to 11pm** emulating the situation when they are plugged in the evening and start charging at once.
2. In the case of Managed charging, the **window available for charging is** increased to **5pm till 7am** and the model optimises charging patterns to achieve the minimum total system cost solution.

Charging can be paused and then resumed within the allowed timeframe for charging.

The uptake of EV is Ireland is assumed to follow the S-shaped curve:



Nissan Leaf was the best selling EV in Ireland in 2017.[2] Therefore, the modelled battery pack is based on the 1st generation Nissan leaf – **energy capacity of 24 kWh.**

Charging power is based on a typical single-phase domestic charger with the **power of 7.4 kW.**

[1] Such a situation represents the worst-case scenario and this assumption is appropriate for demonstrating the maximum impact that EVs can have of the grid.

[2] http://www.irishevowners.ie/category/news/sales/

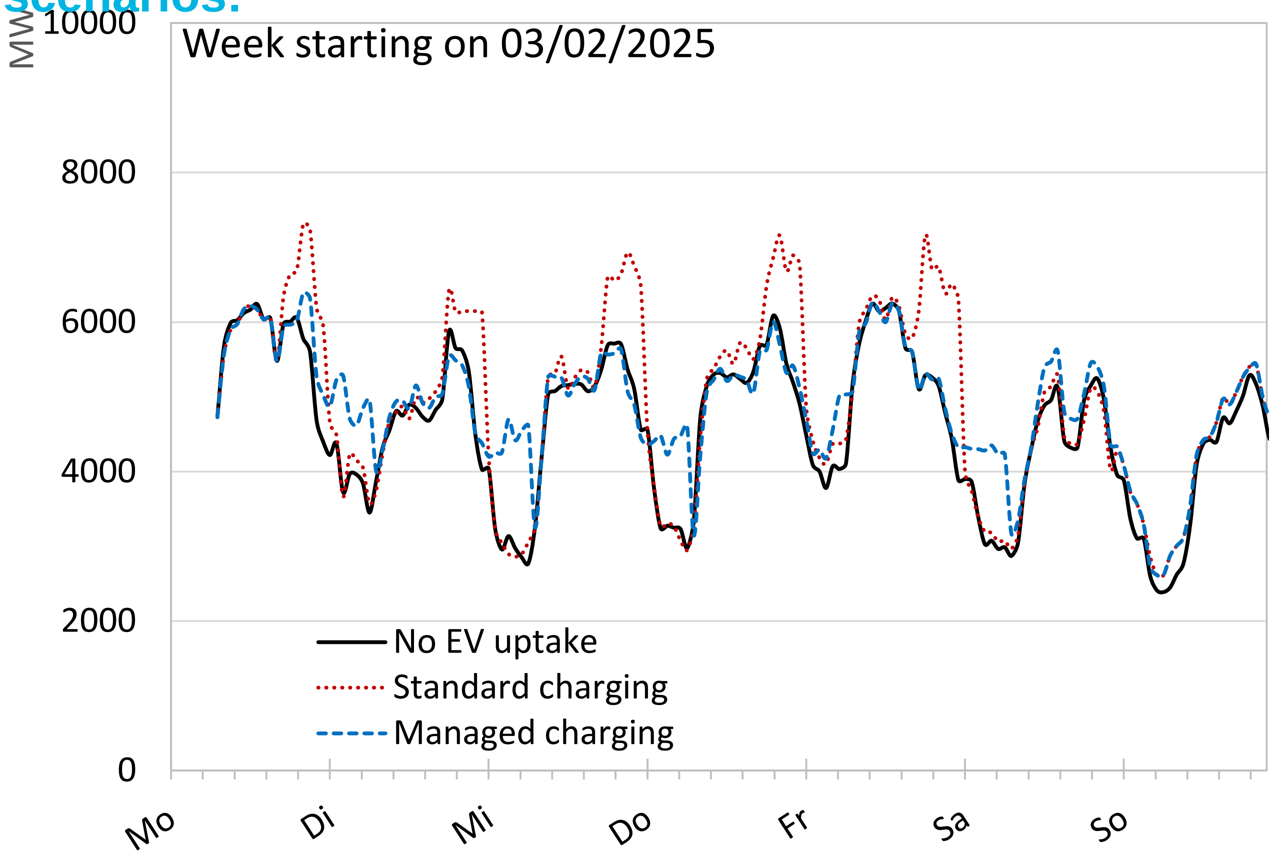
Modelling results

The additional modelled load from a large number of EVs in 2025 has a significant effect on system load

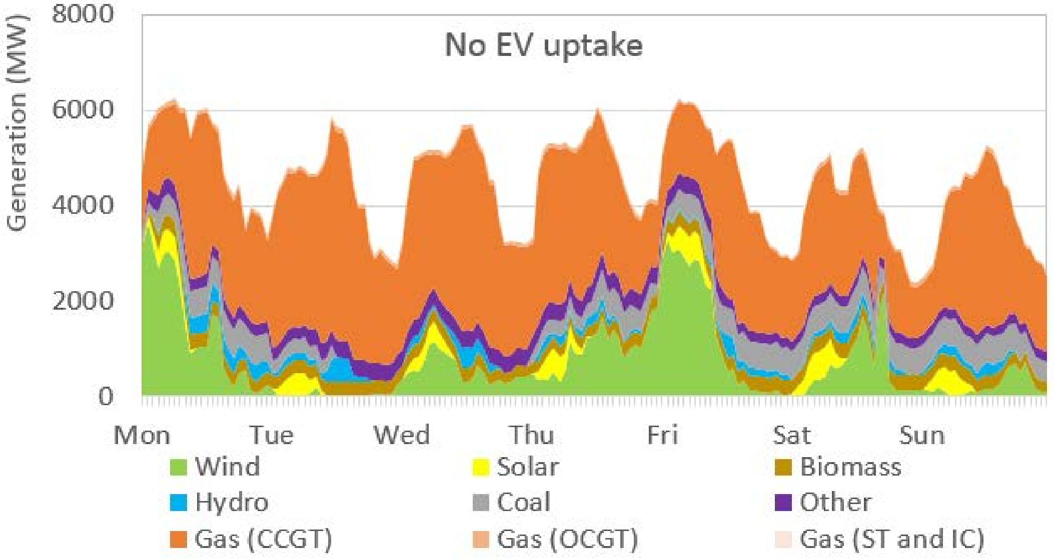
The modelled load with hourly resolution for the week starting on 03/02/2025 demonstrates that:

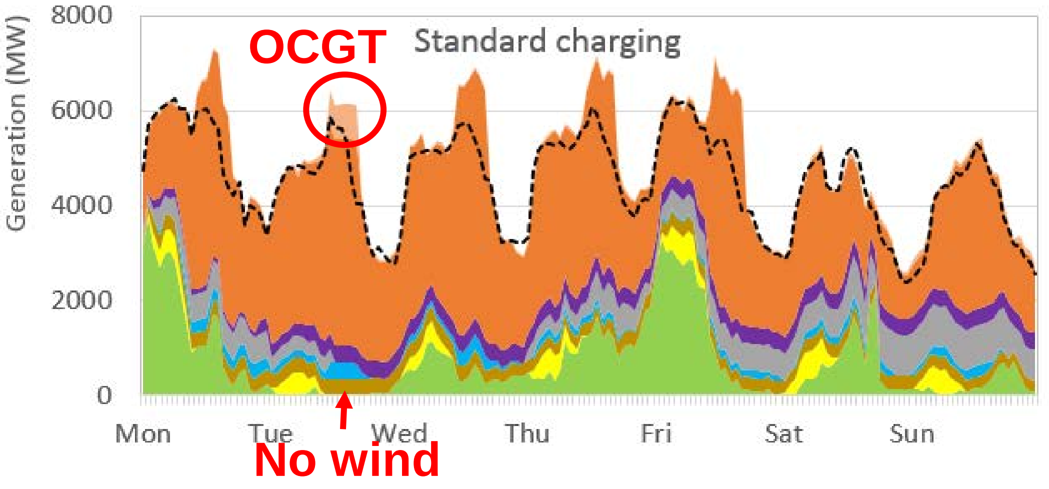
- In the absence of EVs in the Irish power system, the load between 12pm and 7am is reduced to almost half of the daily peak load.
- Standard charging exacerbates the load on the system during peak hours.
- Managed charging approach helps to avoid additional load during peak hours by shifting the EV load to periods of low demand.

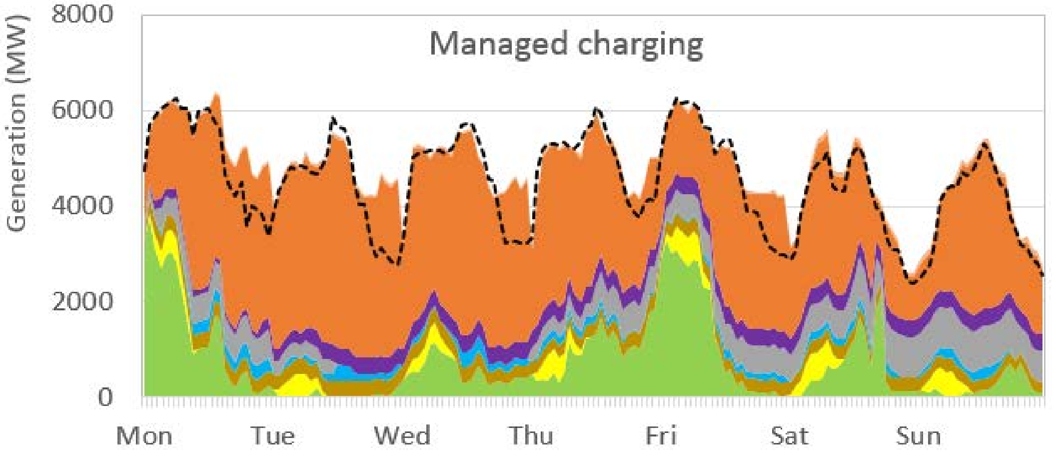
Total system load in Ireland under the modelled scenarios:



The modelled generation with hourly resolution for the week starting on 03/02/2025 for the modelled scenarios





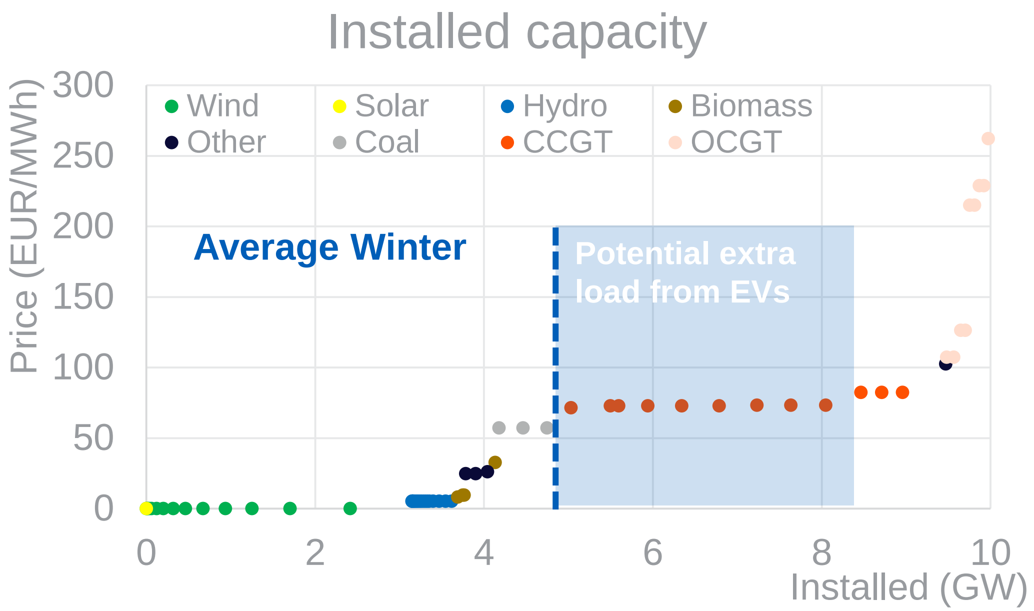


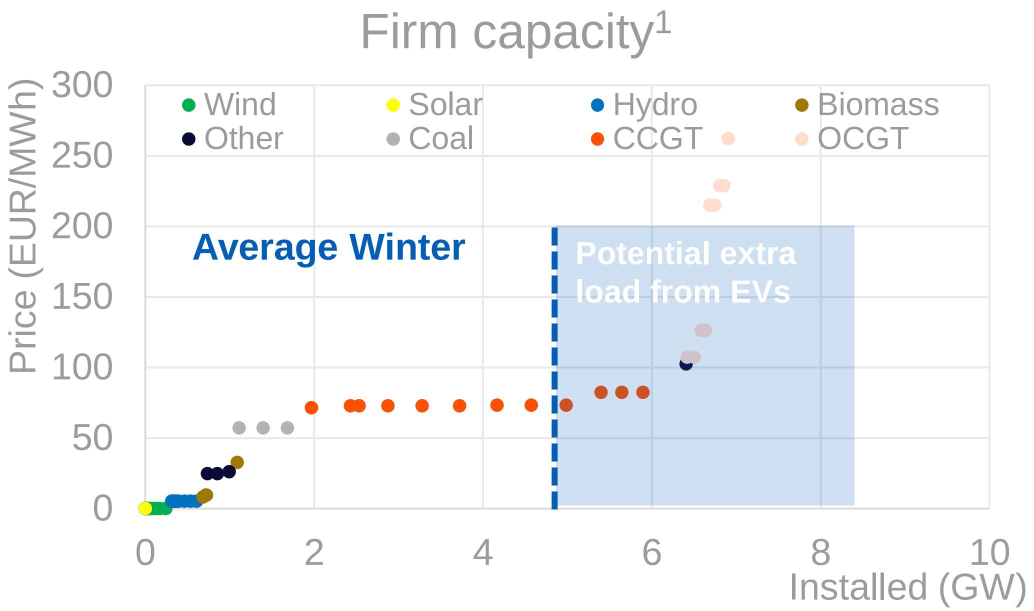
- The additional load from EVs is met mostly with CCGT in the case of Standard charging
- Additional OCGT generation is required is there is low amount of Wind generation in the system

- The additional load from EVs is met mostly with CCGTs in the case of Standard charging

The additional load from EVs can cause a step change in price as OCGTs come online

Merit order in 2025:





[1] Assumed factors for Wind - 26%, Solar - 5%

- Merit order curve in Ireland is relatively flat until less efficient OCGT power plants need to go online
- Additional load from EVs on the days with low renewable generation or/and significant outages, will move the price of electricity significantly higher along the Merit order curve

The additional load from a large number of EVs results in the increase of electricity prices and cost to load

There is an increase in the wholesale electricity prices with both the Standard and Managed charging:

The price in 2025 is

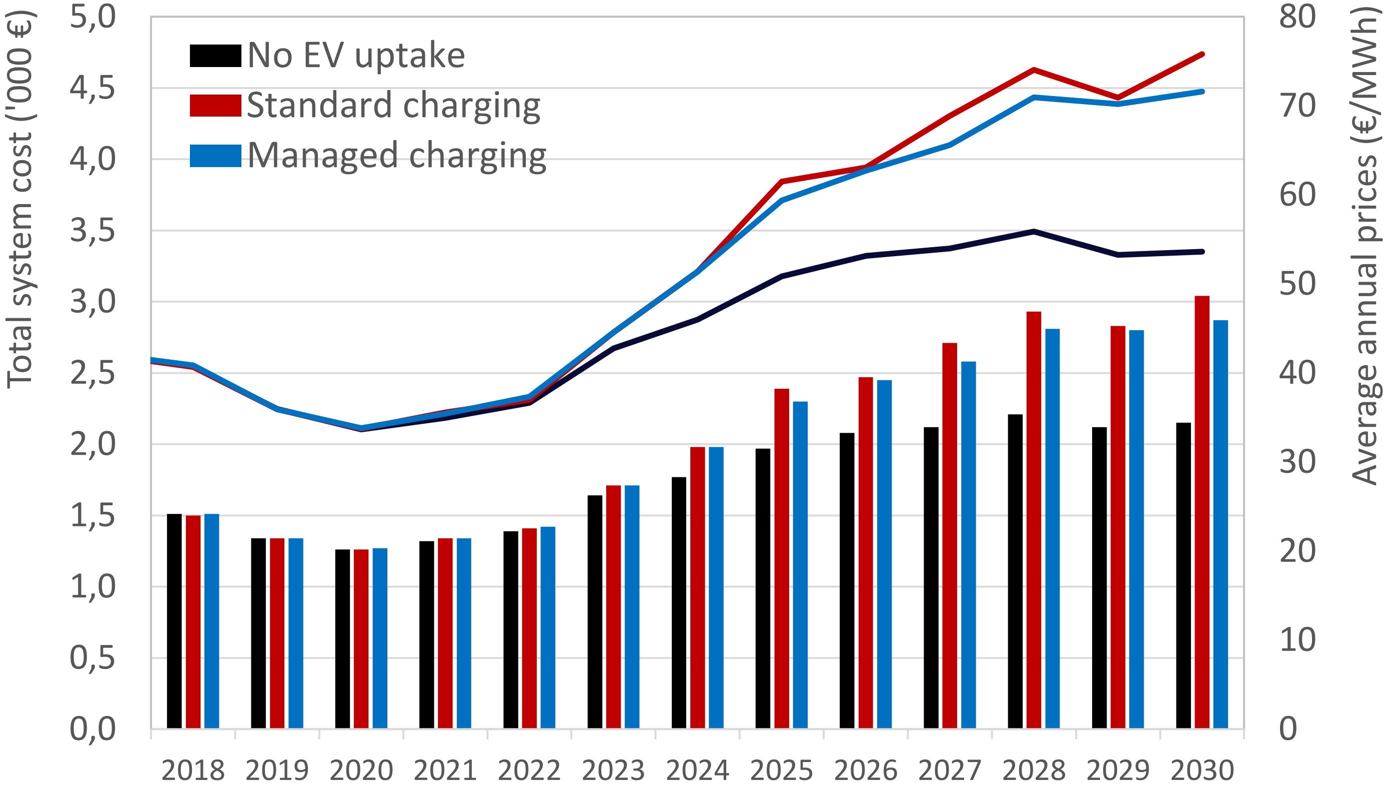
- €50.8/MWh without EV uptake
- €61.5/MWh in the case of Standard charging
- €59.4/MWh in the case of Managed charging

The total cost to load in 2025 is

- €1.97bn without EV
- €2.39bn in the case of Standard charging
- €2.30bn in the case of Managed charging

These numbers exclude the cost of EV charging and demonstrate the repercussions of additional load from EVs to the customers.

The total cost to load (net of EV load) and average load-weighted wholesale electricity prices modelled in each scenario:



The additional load from EVs causes only a slight increase in the average CO_2 intensity of the grid

The potential impact of the EVs on the grid CO_2 intensity is marginal:

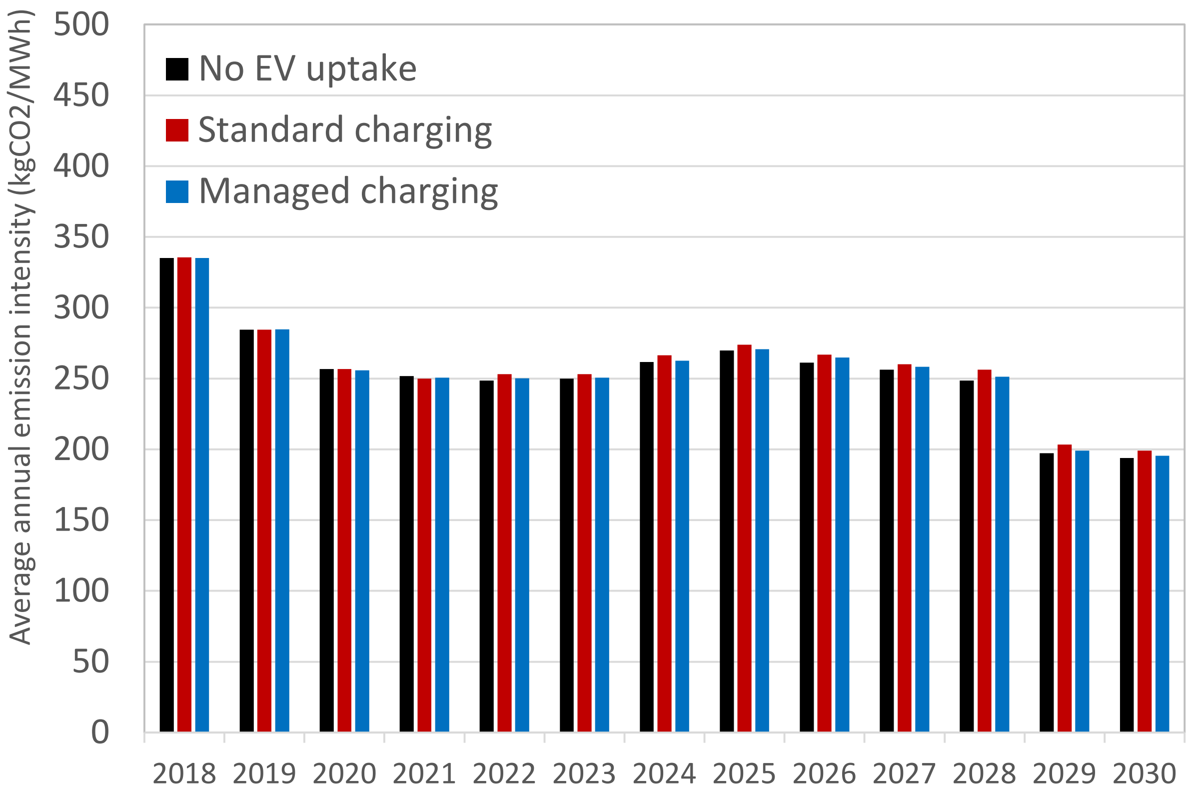
In 2025, the grid CO_2 intensity increases from

- 269 $kgCO_2/MWh$ in the scenario without EVs
- to 273 $kgCO_2/MWh$ in the case of Standard charging
- to 271 $kgCO_2/MWh$ in the case of Managed charging

In general, the CO_2 intensity of the grid in Ireland decreases as Gas displaces some of the Coal generation in a short term.

Equally, there is a step-change in CO_2 intensity in 2029 as Moneypoint coal power plant is assumed to reach its end of life.

Average intensity of the all-island electricity grid in kgCO2/MWh:



Conclusions

- The effect of EVs on the grid becomes noticeable when the load from EVs is relatively large compared to the total load on the system, at around 300000 EVs in the case of Ireland.
- It has been shown that the EV uptake has a potential to substantially increase the wholesale electricity prices and the cost of electricity to load in Ireland.
- All power system customers will bear the increased cost of electricity and therefore any policies around the integration of EVs into the power system need to take this into account.
- The increase in the cost to load was found to be reduced when Managed charging strategy was employed. This is achieved by shifting EV load to the night hours when the demand on the network is lowest.
- The effect on grid CO_2 emissions was found to be marginal with both Standard and Managed charging.

It is acknowledged that EV have the potential to reduce the cost of generating electricity if used for system balancing. Thus, Vehicle to Grid (V2G) operation should be the next step in analysing the impact of EVs on the power system in Ireland.

Thank you!

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May 18, 2018

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In this document, we sometimes use information derived from consolidated financial data but not presented in our financial statements prepared in accordance with U.S. generally accepted accounting principles (GAAP). Certain of these data are considered “non-GAAP financial measures” under the U.S. Securities and Exchange Commission rules. These non-GAAP financial measures supplement our GAAP disclosures and should not be considered an alternative to the GAAP measure. The reasons we use these non-GAAP financial measures and the reconciliations to their most directly comparable GAAP financial measures are posted to the investor relations section of our website at www.ge.com. [We use non-GAAP financial measures including the following:

- Operating earnings and EPS, which is earnings from continuing operations excluding non-service-related pension costs of our principal pension plans.
- GE Industrial operating & Verticals earnings and EPS, which is operating earnings of our industrial businesses and the GE Capital businesses that we expect to retain.
- GE Industrial & Verticals revenues, which is revenue of our industrial businesses and the GE Capital businesses that we expect to retain.
- Industrial segment organic revenue, which is the sum of revenue from all of our industrial segments less the effects of acquisitions/dispositions and currency exchange.
- Industrial segment organic operating profit, which is the sum of segment profit from all of our industrial segments less the effects of acquisitions/dispositions and currency exchange.
- Industrial cash flows from operating activities (Industrial CFOA), which is GE’s cash flow from operating activities excluding dividends received from GE Capital.
- Capital ending net investment (ENI), excluding liquidity, which is a measure we use to measure the size of our Capital segment.
- GE Capital Tier 1 Common ratio estimate is a ratio of equity