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Influences on dispatch of power generation when introducing electric drive vehicles in an Irish power system year 2020

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Abstract (max. 2000 char.):
Increased focus on global warming and CO_2 emissions imply increased focus on the energy system, consisting of the heat, power, and transport systems. Solutions for the heat and power system are increasing penetrations of renewable heat and power generation plants such as wind power and biomass heat plants. For the future transport system, electric drive vehicles are expected to be one of the solutions. Introducing different electric drive vehicle penetrations in a power system with a large amount of wind power, changes the usage of the predefined power system. This work presents investigations of different charging regimes' influence of the power dispatch in the Irish power system. Analyses show an overall cost decrease and CO_2 emission increase in the heat and power system with the introduction of electric drive vehicles. Furthermore, increased intelligence in the electric drive vehicle charging results in larger decrease of overall cost and smaller increase in CO_2 emissions. With the charging regimes presented in this analysis, the cost decreases range from 23.2M€ to 165.5M€, whereas the increase in CO_2 emissions are in the range 1.16Mton to 0.69 Mton.

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Contents

1 Introduction

The energy system faces a large change towards renewables in terms of both heat and power generation and a sustainable transport system. A challenge for the power system is the fluctuating nature of many renewables, e.g., wind power. Larger penetrations of wind call for more flexibility in the system. Flexibility comes from, e.g., storage, and flexible demand. Introducing electric drive vehicles (EDVs) brings along not only a possibly flexible demand, but also storage possibilities if charging is done in times with e.g. excess wind power. Although, electrifying transport also brings along an increased demand to be covered. The contribution of this work is analyses of how different charging regimes change the operation of an all-island power system predefined for the year 2020 – a power system configured for power demand excluding transport.

In a CO_2 perspective, electrifying the transport system makes sense as long as the increased power demand is supplied from power units having a lower CO_2 emission per kilometre driving distance than the corresponding CO_2 emission from a conventional diesel vehicle. Hence, the efficiency of the EDVs compared to the conventional vehicles is very important. Assuming electric vehicle energy efficiency in the range of 4-6 km/kWh and diesel vehicle efficiency of 20 km/l, this applies to high efficiency combined cycle gas turbine plants, nuclear power and renewable power, but not for coal fired power plants. Using gasoline vehicles instead of diesel vehicles will increase costs as well as CO_2 emissions due to lower efficiencies.

Many researchers have focused on the fields of introduction of EDVs, i.e., infrastructure, potential benefits, and quantifying the impacts in the power system. EDVs are capable of providing different services to the power system. The economics of providing different services have been analysed in Kempton et al. (2001). Kempton and Kubo (2000) studies the services of peak load shaving, concluding that it is not profitable for the EDVs, unless the rate schedules change. Regulation and ancillary services have been studied in (Tomic and Kempton, 2007) and Brooks (2002) has looked on the integration of battery electric vehicles (BEVs) with particular focus on the vehicles providing ancillary services. Moura (2006) has made costs comparisons of providing the different services, comparing the different kinds of EDVs to the technologies providing the services today. In general, the papers find that it is beneficial to introduce EDVs except for the peak load shaving.

Integrating the heat, power, and transport systems influences the power production. Lipman (2005) has provided an overview of the potentials of the grid-to-vehicle (G2V) and vehicle-to-grid (V2G) capabilities. A simplified dispatch model of California's energy market has been developed by McCarthy et al. (2008) in order to investigate the impacts of EDVs being part of the energy system. Analyses of the flexibility contributions provided by EDVs and heat pumps to the Danish energy system are provided in (Østergaard, 2010), focusing on forced export.

Consequences of having flexibility provided by plug-in hybrid electric vehicles (PHEV) on power system investments have been analysed in the energy system analysis model, Balmorel, by Kiviluoma and Meibom (2010). They use an exogenously given EDV fleet and optimise investments in the power system accordingly. Juul and Meibom (2011) have developed a road transport model for analysing the optimal configuration and operation in the integrated power and road transport system in Balmorel, including investments in vehicles. Lund and Mathiesen (2009) have analysed the power system needs for reaching a 100% renewable energy system, including transport on non-fossil fuels. In the paper they set up a scenario for Denmark to reach 100% renewables, finding that it is possible even on domestic resources.

The transition path from today towards a sustainable transport system has been studied in (Tomic and Kempton, 2007), where the focus is how to ensure a smooth transition path going from today's vehicle fleet to PHEVs and BEVs. The main focus in these papers is when and in which penetrations to include the EDVs in the respective years. However, none of the above has focused on how to include the EDVs in an existing power system and analysed the consequences on this power system, thus how to make the transition work. Thus, they do not focus on how to integrate EDVs in a power system not configured to include the transport system. This paper contributes with analyses of the influence on the power system when introducing different penetrations of EDVs with different charging regimes, focusing on a predefined 2020 Irish power system.

The methodology used for the analyses is described in the next section. A base case and four scenarios has been defined in order investigate the influences on the power system from introducing EDVs. These are all described in section 3. Section 4 elaborates on the results from running the model. Finally, discussions are found in section 5 and section 6 concludes.

2 Methodology

An advanced hourly dispatch model is used to investigate the operating of the all-island power system for the entire 2020 with an assumed CO_2 price of €30/ton. A base case is set up as in (Denny et al., 2010). To investigate effects of different EDV charging schemes on the base load, mid merit and peak load plants, 4 scenarios have been developed and run in the unit commitment and dispatch model, Wilmar. The system impact of various EDV penetrations is examined by examining various system metrics relative to a base system configuration. A superficial description of the Wilmar model is provided in this section. For a more thorough description see (Meibom et al., 2007) and (Meibom et al., 2010). Presentations of the base case and the 4 scenarios are given in the next section.

2.1 Wilmar

Wilmar is a stochastic unit commitment and dispatch model optimising the operation of a given power system. The model is stochastic in three elements; the forecasts of electricity demand, wind power production, and demand for replacement reserves. Thus, a scenario tree representing these three elements is implemented. Replacement reserves represent reserves with activation times longer than five minutes. They can be provided by online power plants and offline power plants that are able to start up in time to provide the reserves in the hour in question.

The model is a stochastic multistage linear model with recourse. The model uses an hourly time resolution and rolling planning in 3 hours steps, thus, 8 loops a day (Figure 1). The figure illustrates three stages, stage 1 resembling the first three hours, stage 2 hours 4-6, and stage 3 the remaining period in the planning horizon. Perfect foresight is assumed for the first three hours, but to get a more realistic picture, forecast errors are introduced in terms of replacement reserves.

The root decision is the production plans for the day-ahead market (stage three), where the forecast of electricity demand, wind power production, and replacement reserve demand are all uncertain. The recourse decision is taken after knowing the uncertain outcome, thus, when planning the first three hours. Hence, the recourse decision consists of up and down regulations of power production relatively to the production plan determined day-ahead.

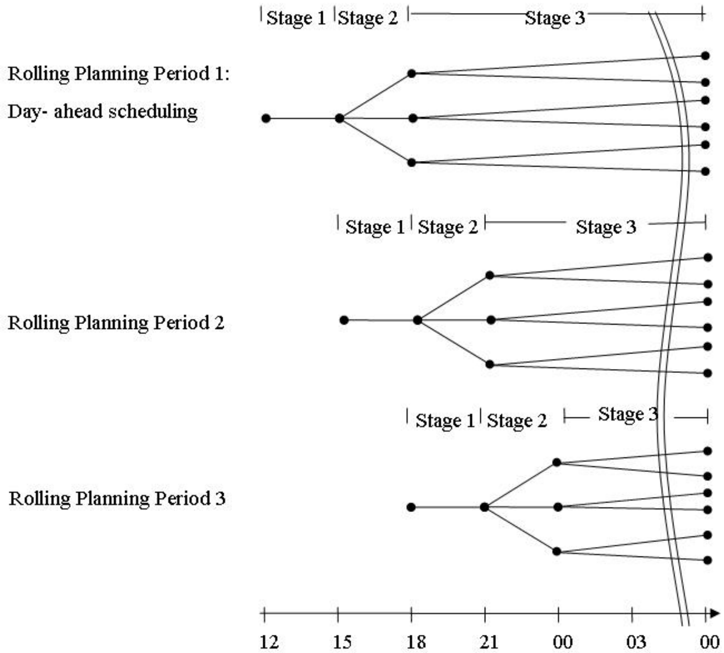


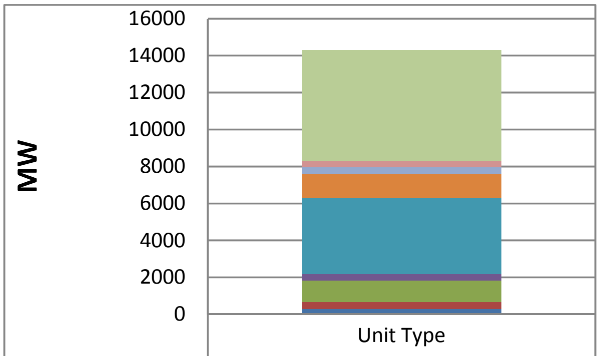
Figure 1 Illustration of the rolling planning and decision structure in each planning period (Meibom et al., 2007).

3 Application

In this section the base case is defined, followed by the definition of the 4 scenarios. The analyses are made on the all-Island power system, including both Great Britain and Ireland, although, the main focus is on the introduction EVs and different charging regimes supporting these in the Irish power system.

3.1 Base Case

A 2020 power system with a high penetration of wind capacity - 6000MW - has been defined for the Irish power system. This is based on portfolio 5 used in the All Island Grid study (Meibom et al., 2010). The portfolio consists of a total of 47% renewable share of total capacity. The total capacities of the various units used in the base case are shown in Figure 2. Base load gas and mid merit gas are different types of gas using plants, producing either as base load or mid merit.



Unit Type	
WIND	6000
BIOGAS	360
WATER	346
COAL	1324
BASELOADGAS	4119
PEAT	343
MIDMERITGAS	1155
GASOIL	383
PUMP	292

Figure 2: Ireland unit capacities by type

An interconnection with Great Britain of 1000MW is assumed to exist. The total conventional generation assumed in the Great Britain system is shown in Figure 3. It can be seen that base load gas, coal and nuclear comprise the vast majority of conventional generation in Great Britain. The power systems in Ireland and Great Britain are kept fixed for 2020 for all the scenarios.

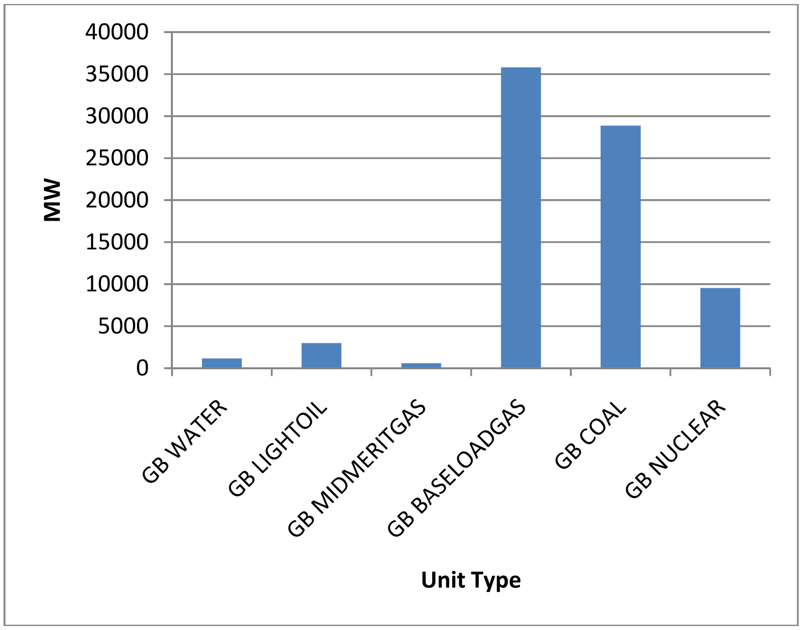


Figure 3: GB unit capacity by type

Fuel prices differ depending on the area. The fuel prices used for this study are seen in Table 1.

Table 1: Fuel Prices used in the study

Area	Fuel	Price (€/GJ)
Great Britain	BASELOADGAS	6.71
	COAL	1.75
	GASOIL	9.64
	LIGHTOIL	5.22
	MIDMERITGAS	6.90
	NUCLEAR	0.4
Northern Ireland	BASELOADGAS	7.06
	COAL	2.11
	GASOIL	8.33
	LIGHTOIL	4.83
	MIDMERITGAS	7.27
	PEAT	3.71
Republic of Ireland	BASELOADGAS	7.06
	COAL	1.75
	GASOIL	9.64
	LIGHTOIL	5.22
	MIDMERITGAS	7.27
	PEAT	3.71
Ireland	DIESEL	14

The Irish vehicle fleet

Table 2Table 2 shows the three classes of vehicles that were identified as realistic candidates for future replacement by equivalent PHEVs and/or BEVs (SEI2004).

Table 2: Irish vehicle fleet, 2007 (Department of Transport, 2007)

Vehicle Type	*Number*
Private car fleet	1,882,901
Goods Cars/light vans < 3.5T fleet	292,604
Bus fleet	6,480

Table 3: PHEV battery and charging data (capacities based on Kalhammer et al.)

	PHEV Battery kWh	*PHEV charging capacity kW*	*Charging point*
Private car	10	3	Single phase 15A supply
Goods Cars/light vans < 3.5T	25	3	Single phase 15A supply
Bus	120	12.5	3 Phase 32A supply

Table 4: BEV battery and charging data (capacities based on Kalhammer et al.)

	BEV Battery kWh	*BEV charging capacity kW*	*Charging point*
Private car	40	3	Single phase 15A supply
Goods Cars/light vans < 3.5T	100	12.5	3 phase 32A supply
Bus	480	60.0	Required capacity exceeds standard 3 phase supplies

Table 5: Diesel data and assumed energy consumption of a private car driven on diesel.

Diesel	
CO_2 emission (kg/GJ)	76.5
km/litre (passenger veh.)	20
km/litre (others)	12
MJ/l	38.6

It can be seen from Table 3Table 3 and Table 4 ***Table 4****that the proposed PHEVs and BEVs may be charged at standard residential/commercial and industrial outlets. The 60kW charging requirement of the BEV bus was assumed to exceed the electrical electrical capacity of standard installations, thus, BEV buses are not considered. Table 5*

considered. Table 5

Table 5 shows the data for diesel used to calculate the effect on CO2 emissions and total system cost increase of moving from a diesel to an EDV fleet. The usable part of the battery is assumed to be 60%. The average use of energy is 4 km/kWh when driving on electricity.

3.2 Scenarios

Each of the four scenarios defined can be characterized as consisting of either a low or high EDV fleet. The composition of the total Irish vehicle fleet is assumed to be driven by the consumers as part of moving towards sustainability in the transport sector. Thus, the EDVs are invested in for driving and the analyses below focus on the influence of the changes in means of transport and on the interaction between the vehicle fleet and the power system.

Low EDV fleet

The low fleet assumes the percentages of PHEVs and BEVs along with the total daily electrical consumption for each vehicle class shown in Table 6.

Table 6: Low vehicle fleet

	PHEV %	*EV %*	*# PHEV*	*# EV*	*Total daily consumption (MWh)*
Private car fleet	5	1	94,145	18,829	1,016.77
Goods Cars/light vans < 3.5T fleet	20	1	58,521	2,926	1,053.38
Bus fleet	6	0	389	0	28.01

High EDV fleet

The high fleet assumes the percentages of PHEVs and BEVs along with the total daily electrical consumption for each vehicle class shown in Table 7.

Table 7 High vehicle fleet

	PHEV %	*EV %*	*# PHEV*	*# EV*	*Total daily consumption (MWh)*
Private car fleet	15	5	282,435	94,145	3,954.09
Goods Cars/light vans < 3.5T fleet	40	5	117,042	14,630	2,633.43
Bus fleet	10	0	648	0	46.66

Furthermore, the scenarios have different charging regimes. The four scenarios, EV1-EV4, are described in the following. The scenarios are based on the assumption that intelligence is built into the vehicles making sure that the batteries are loaded when needed. This intelligence could be in terms of a computer monitoring the driving patterns and fitting the loading of the battery to meet this demand (plus a buffer). The possibility to overrule the computer should exist in case of extraordinary trips are planned.

EV1

The demand in the base case is modified to introduce the low EDV fleet having a daily charging target of 2,098 MWh. Fleet charging is spread over the night hours of 9pm – 3am, thus, no daytime charging takes place. The extra demand during charging hours is 300 MW per hour.

EV2

The demand in the base case is modified to introduce the high fleet having a daily charging target of 6,634 MWh. Fleet charging is spread over the night hours of 9pm – 3am. The extra demand during charging hours is 1,000 MW per hour.

EV3

In EV3, the demand is modified to introduce the high fleet. Fleet charging is set to begin at 7pm but is configured to ensure that 1,200 MW of spare conventional and wind capacity is available during all charging hours. Modelling the charging in this manner has the effect of ensuring that the EDVs will be charged at times of high wind. This results in a reduction of the night time consumption (relative to EV2) and a spreading of the extra demand into the early morning hours. The connection between wind and vehicle charging is illustrated in Figure 4 where it can be seen that during the period of low wind early in the month night time fleet charging is reduced, whereas, during the period of high wind later in the month night time charging increases.

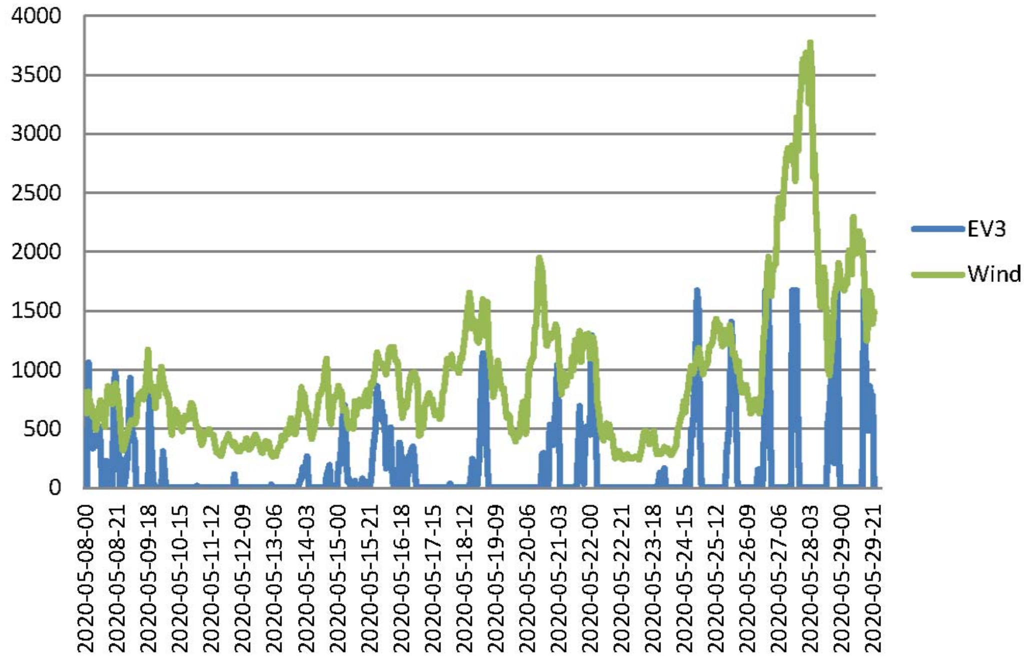


Figure 4 : Hourly wind and fleet charge during May 2020, EV3

EV4

The demand in the base case is modified to introduce the high fleet. The maximum additional demand due to the electrical vehicle fleet is limited to 400MW and the case is configured such that 1,000MW of spare conventional and wind capacity is available at all times. These restrictions have the effect of spreading the additional demand due to the EDVs across the day. The majority of charging takes place during the evening and night hours but significant levels of charging also occur during daylight hours.

The average additional system demands due to the four scenarios chosen for this study are shown in Figure 5.

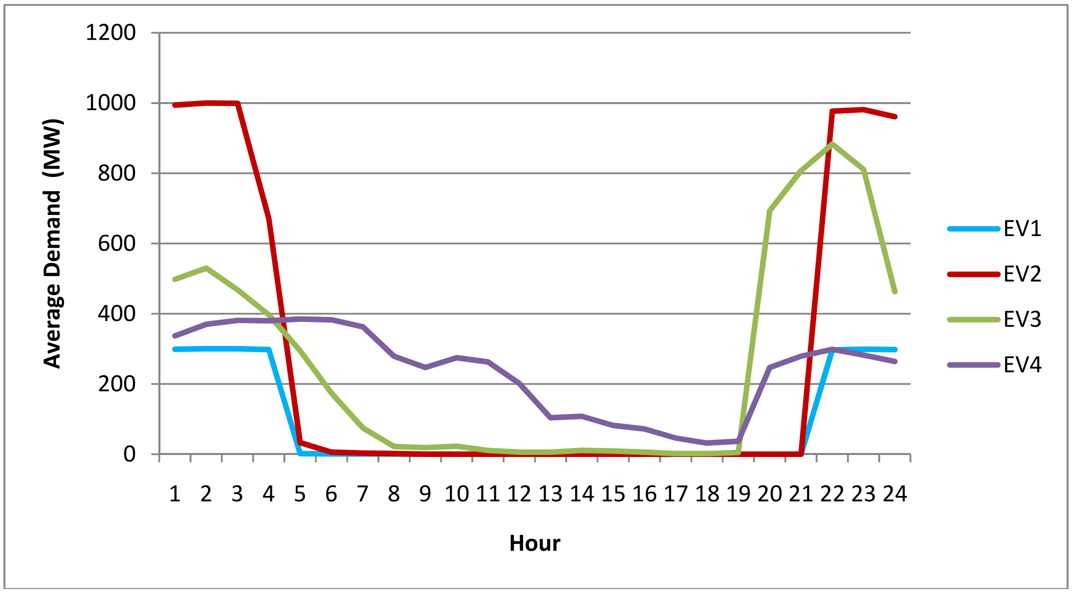


Figure 5: Average additional load (above base case) due to electric vehicles

Figure 6 shows the effect of the additional demand for each of the EDV scenarios on the average daily demand of the Irish system. It can be seen that EV4 has the effect of increasing the demand across the whole day while scenarios EV1-3 have the effect of increasing demand to various degrees during the evening and night hours.

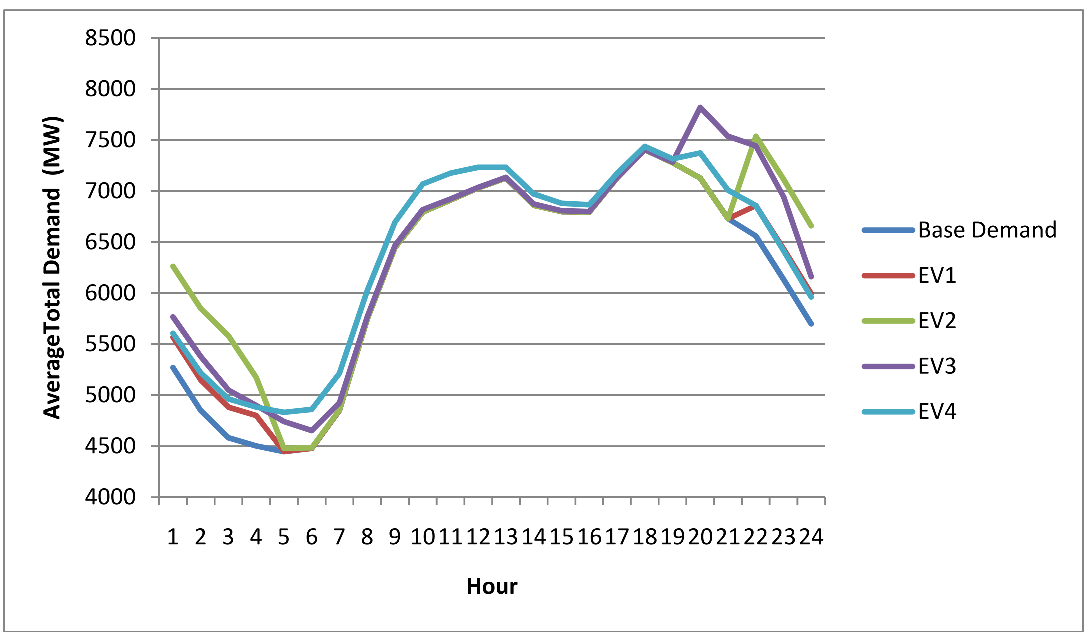


Figure 6: Average Ireland daily system load

Based on the scenarios, the expectations of the results are that the EV4 scenario will be the best of the high EDV fleet scenarios, when it comes to system costs and CO_2 emissions, due to the better correlation with wind power production. The number of start-ups are expected to increase the more fixed the charging of the EDVs are.

4 Results

4.1 Change in unit starts

A key consideration for generator owners and operators is the effect that wind and EDVs have on the dispatch of units. In this regard the number of unit starts per year or the change in the number of unit starts due to EDVs will have a large impact on the operation and maintenance costs of units. The change in the number of unit starts for EV1-EV4 is shown in Figure 7.

It is seen from the figure, that the increased demand in low load periods from the EDV fleet reduces the number of starts required by the base load units (baseload gas, coal, and peat). With the large wind penetration, number of base load starts is quite high in the base case. Therefore, the EDVs could be of great benefit when integrating larger shares of wind power in existing power systems.

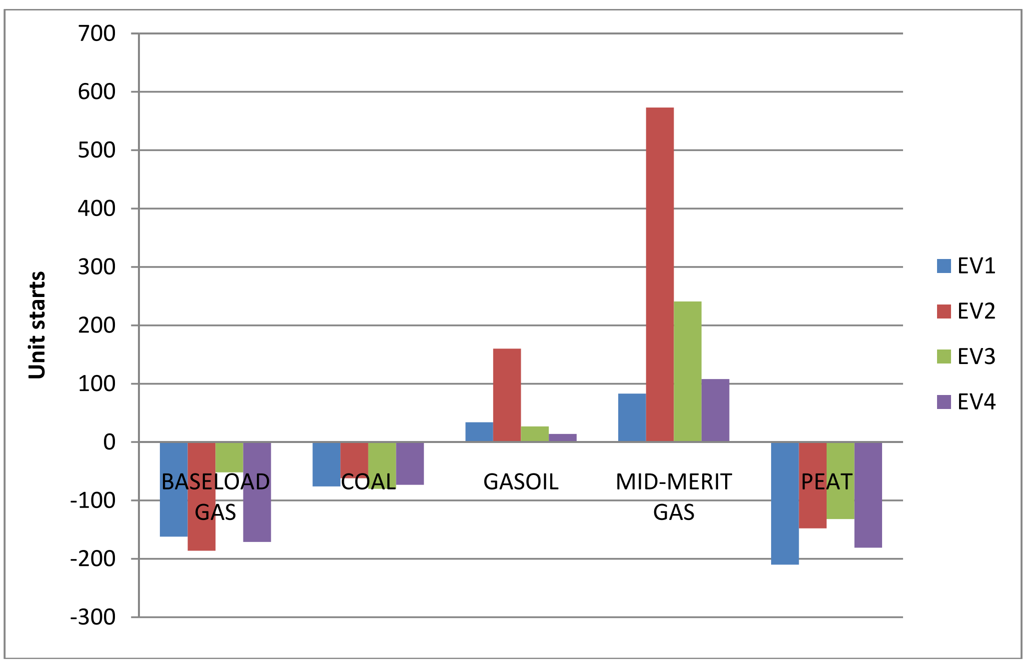


Figure 7: Change in number of starts per year relative to base case for Ireland

The number of start-ups required by mid-merit and peaking units to accommodate the EDV fleet is seen to be increasing. This is due to the inflexibility in the charging regimes creating rapid changes in the demand profile as illustrated in the large increase in mid-merit and peak load start-ups in EV2 compared to EV3 and EV4. From these results it is evident, that some kind of intelligence in the charging of the vehicles is needed.

4.2 Unit production

Unit production is the amount of electricity produced on a specific power plant. The change in unit production reflects the change in how big a share of the available capacity is used for each power plant, also known as change in the capacity factor. With a predefined power system configuration the unit production will be increasing with the introduction of another load, the EDVs.

Figure 8 illustrates an important finding. It can be seen that the majority of energy required to charge the EDVs comes from coal plant in Great Britain (GB COAL) followed by base load gas in Ireland (BASELOADGAS) and nuclear energy in Great Britain (GB NUCLEAR). For the low fleet scenario, EV1, the charging energy comes predominantly from units in Great Britain. This finding suggests that a growing EDV fleet in Ireland will be powered mainly from Great Britain plants and it is only at higher fleet penetrations that base load gas plants on the all-island system will begin to dominate. The primary reason for this is that, in this study, generation is cheaper in Great Britain and the large amount of interconnection is sufficiently flexible to allow import at the appropriate times.

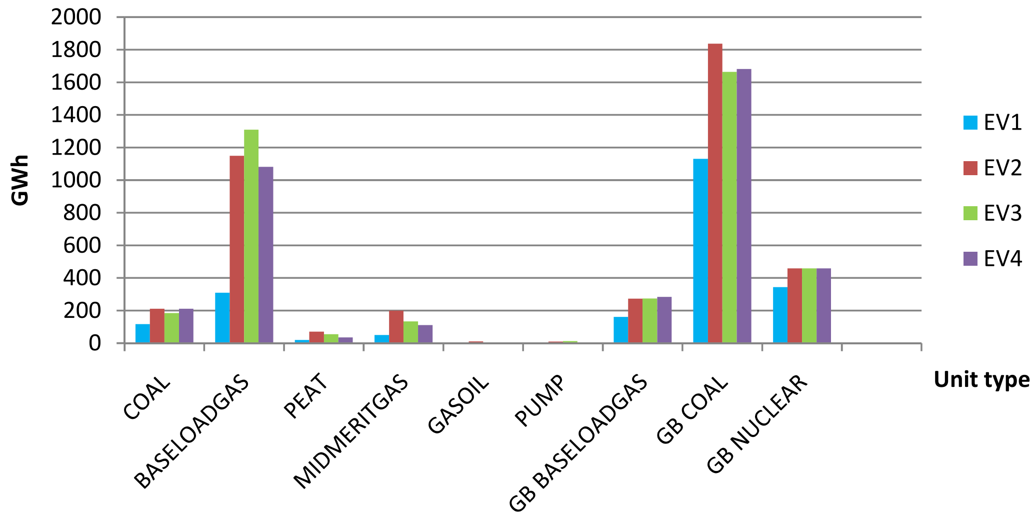


Figure 8: Total change in yearly production relative to base case by unit type

4.3 Costs

The change in system costs of operating the all-island power system for the four EDV scenarios is shown in Table 8. The table shows an increase in operating cost with increasing fleet size and a reduction (relative to EV2 & EV3) in the operating cost of the high fleet scenarios when charging is spread throughout the day in EV4.

In order to compare the systems, the decrease in diesel costs needs to be taken into account. The system cost savings and emissions savings for EV1-EV4 due to the displacement of a diesel only fleet by a BEV/PHEV fleet are shown in Table 8. The decrease in diesel costs more than exceeds the increase in system costs in power system.

Table 8: Yearly changes in system costs and CO2-emissions

	EV1		***EV2***		***EV3***		***EV4***	
	Cost (M€)	CO_2 (Mton)	Cost (M€)	CO_2 (Mton)	Cost (M€)	CO_2 (Mton)	Cost (M€)	CO_2 (Mton)
Increase Ireland	27.7	0.41	90.8	1.14	91.9	0.95	75.3	0.86
Increase GB	60.3	1.36	97.7	1.79	90.1	1.63	91.4	1.65
Decrease diesel	111.2	0.61	332.2	1.82	332.2	1.82	332.2	1.82
Total GB & Ireland	-23.2	1.16	-143.7	1.11	-150.2	0.76	-165.5	0.69

When comparing the costs of EV3 and EV4 it can be seen that while a decrease in cost is observed in Ireland, the operating cost of the Great Britain system increase by €1.2M.

4.4 CO_2 emissions

An important consideration when evaluating the emissions benefits of moving from a diesel based to an EDV or part EDV fleet may be stated as follows. Do the emissions which are saved by the transport system outweigh the increased power system emissions which will occur when charging the EDVs?

Table 8 shows the levels of decrease of transport system emissions together with the levels of increase in power system emissions (relative to the base case) for each of the EDV scenarios. It is evident, that the decrease in transport system emissions is proportional to the size of the EDV fleet. The increase in power system emissions depends on the charging regime. An increase in overall CO_2 emissions is achieved when moving from a diesel to BEV/PHEV fleet. The magnitude of the increase is, of course, dependent on the emissions characteristics, usage of the existing vehicle fleet, the power system plant mix, and the charging regime of the EDV fleet.

Focusing on the differences between the charging regimes, it is evident that the CO_2 emission increase is smaller the more intelligent the charging. This goas hand in hand with the increase in total savings with increased charging intelligence.

5 Conclusions

This paper investigates the influence of different charging regimes on a predefined power system. A simple analysis of the transport sector was used to provide data inputs while a detailed power system model was used. Despite the simple transport analysis performed, the range of cases examined is sufficient to provide a clear insight to the effects on the cost, emissions and operation of the all-island power system.

The number of base load starts decreases with the introduction of the EDV fleet, probably due to the demand increase during the night. However, the number of mid-merit starts increases with the introduction of the EDV fleet, indicating that load/demand is still fluctuating.

The introduction of a low EDV fleet comprising 174,810 BEVs or PHEVs results in an increase to the all-island power system costs of 88M€ and a decrease in the diesel costs of 111M€. Hence, a total decrease of 23M€ for the year 2020 examined.

Introducing a high EDV fleet comprising 508,900 BEVs or PHEVs results in an increase to the all-island power system costs of between 167M€ - 189M€ depending on the fleet charging regime. A decrease in diesel costs of 332M€ results in a total cost decrease of between 144M€ - 166M€ for the year 2020.

Furthermore, power system CO_2 emissions increase with the introduction of an EDV fleet. The primary contributors to the increased emissions are the base load units. The increase in CO_2 emissions range from 0.69Mton to 1.16Mton, depending on the sensible choice of charging regimes – the more intelligent the charging the lower the increase in CO_2 emissions.

5.1 Future research

The combined effect of increased start-ups due to wind coupled with decreased base-load start-ups due to EDVs was not examined. A detailed investigation of this interaction is of interest for future research.

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