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Decarbonising Passenger Cars

Gap to target, revenue to the exchequer, and distributional impact

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Executive Summary

This paper provides an analysis of the decarbonisation of passenger cars using an agent-based model (ABM) to simulate the adoption of battery electric vehicles (BEVs). The model allows for individual preference based on cost, non-financial barriers and social influence. Some of the key findings from the report include:

- A target of 845,000 electric vehicles (EVs) can be met assuming moderate fleet growth (from 2.15M in 2019 to 2.4M in 2030) and a 10% reduction in vehicle kilometres per vehicle. With some further assumptions described in this report, this scenario can deliver a 55% reduction in emissions for passenger cars by 2030.
- Measures to lower emissions by reducing average car kilometres also have the unwanted effect of lowering the uptake of EVs.
- There is a sharp uptake of second-hand battery electric vehicles (BEVs) from mid-decade, implying the need for a robust second-hand market in Ireland.
- There is a marked downward trend in total tax revenue per passenger car, projected to fall by 14% between 2019 and 2030 under the current taxation system. In 2030, BEVs account for 28% of total tax revenue and revenue per car for BEVs is similar to that for diesel or petrol vehicles.
- There is no evidence in the simulations that the CO_2-based tax system is regressive over the longer term. Higher-income groups pay higher taxes. All income groups have a declining tax burden, but with the steepest declines for middle and low-income groups as they are more likely to purchase second-hand BEVs.

More detail on these findings is available within the relevant sections of the report as outlined below:

- Section 2 provides an overview of the agent-based modelling framework used for the analysis, including an overview of the main assumptions and the dynamic modelling technique used. A more detailed list of input parameters is also provided in Appendix A.
- Section 3 uses the modelling framework to assess the interaction of some of the transport targets outlined in the 2021 Climate Action Plan with a particular focus

on those actions relating to the decarbonisation of the passenger car fleet.

- Section 4 considers the implications of the decarbonisation policy on the current vehicle taxation model and the sustainability of public finances.
- Section 5 focuses on the distributional impacts of decarbonisation policy with a focus on how the taxation measures affect the relative welfare of different social groups.

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1 Introduction

The 2021 Climate Action Plan [1] specified an ambitious emissions reduction target range of 42%-50% for transport. This implies an even more ambitious sub-target for passenger cars because few decarbonisation options are available at present for sub-sectors such as heavy goods vehicles (HGVs). To illustrate this, Table 1 shows a scenario where an overall emissions reduction of 46% is achieved by reducing emissions from cars by 55% while other road transport emissions (vans, buses, HGVs) reduce by 25%. Achieving an outcome within the Climate Action Plan (CAP2021) target range will be a challenge, particularly because population growth [2] will increase aggregate travel demand.

Table 1: A transport emissions ($MtCO_2$) scenario.

	2018	2030	%
Cars	6.1	2.9	-55%
Other Road[a]	5.2	3.9	-25%
Non-road[b]	0.5	0.5	0%
Sub-total	12.1	7.3	-40%
Fuel Tourism		-0.7[c]	
Total	12.1	6.6	-46%

[a] Goods vehicles, buses etc
[b] Rail, domestic aviation and navigation
[c] NTA

This report focuses on the deep emissions reductions (>50%) necessary for passenger cars. A key fact is that the time remaining to 2030 ($\approx$ 8 years) is shorter than the average service life of passenger cars. This makes it harder for electrification measures alone to deliver on the required timeframe, despite the generous incentives for electric vehicles (EVs) and the greater maturity of Lithium-ion battery (LiB) technology. To help bridge this gap, the Climate Action Plan (CAP21) introduced additional measures and targets, including increased blending of biofuels and direct passenger car travel demand reduction. Of course, such policy interventions are not without trade-offs. Questions that arise include:

1. How do strong interactions between policy measures [3] impact emissions and costs?
2. What is the impact of decarbonisation on exchequer revenue [4]?
3. Are there adverse Just Transition and distributional effects that could lower the social acceptability of climate policy [5]?

Ideally, the answers to questions 1-3 should be quantified within a modelling framework where the emissions target is achieved endogenously. For example, exchequer revenue projections ought to be made in a technical and taxation policy scenario that is consistent with the desired emissions outcomes. This is done here using an agent-based model (ABM) framework based on survey data for Irish drivers.

2 Modelling

This section gives an overview of the main assumptions and dynamic modelling techniques used in this report. Findings are described in Sections 3-5.

2.1 Agent-based model

The rate of diffusion of new technology through a population is controlled by non-financial barriers, social influence and cost [6, 7]. Computer simulation of this process is conceptually simple. A simulation starts with a heterogeneous population of car-owning households or “agents”. At each time step, some agents decide to replace their current vehicle. A group of candidate replacement cars is drawn from the currently available passenger car fleet (different for new and second-hand car buyers). The vehicle selected is the one that maximises an agent’s *choice utility*. The choice utility is a weighted sum of financial, social and barrier terms, with the latter reflecting individual risk-aversion towards unfamiliar battery electric vehicle (BEV) technology, range anxiety and other effects. A high barrier may mean that the financially optimal powertrain is not adopted. However, when a BEV owner appears in an agent’s social influence network, the barrier is lowered. The social network is updated at each time step to keep track of agents who have adopted a BEV, as this influences choices made at the next time step.

This report is based on simulations of 924 agents at monthly time steps from the beginning of 2015 to the end of 2030. Agent characteristics and choice utilities are derived from a representative survey designed at UCD [8, 9] and conducted by Amarach/ESB in 2018. As expected for a survey of this type, "hypothetical bias" is present in the stated likelihood to switch to an electric powertrain. Correcting for this bias sets the primary model tuning parameter λ, determined using the BEV uptake observed in the year following the survey (2019). Once λ is known, future powertrain choices are found endogenously by simulation.

A great advantage of ABMs is that additional rules governing agents’ behaviour can easily be included, adding more realism. For instance, agents always choose cars from their preferred car market segments, set probabilistically at the beginning of each run. This ensures that the observed pattern of Irish passenger car market segmentation [10] is preserved.

An agent's vehicle choice is biased towards their current marque (brand loyalty). Another rule is that there is no barrier to BEV adoption when an agent is an existing plug-in EV (PHEV) owner i.e. PHEVs can act as a "gateway" to full electrification. Furthermore, the links of the social network are reset at the beginning of each run. The various randomisation steps mean that vehicle and powertrain choice is not deterministic, as is the case in standard random choice utility models [11]. All of the results presented in this report are based on averages of 80 simulation runs.

2.2 Assumptions

Large-scale adoption of EVs is fostered by improved offerings from car manufacturers, high pump prices, and supportive government policy. With the assumptions described below, the simulation output shows deep and rapid decarbonisation of passenger car transport.

2.2.1 Growth

Fleet growth sets the context for any climate policy analysis because it has a direct influence on emissions outcomes. Passenger car activity can be expressed as $\mathrm{vkt} \times \mathrm{N}_{\mathrm{fleet}}$ where vkt is average car kilometres ($\sim$ 17,000km) and $\mathrm{N}_{\mathrm{fleet}}$ is fleet size. In the "mid" growth case of Figure 1, $\mathrm{N}_{\mathrm{fleet}}$ grows from 2.15M in 2019 to 2.4M in 2030, in line with population growth projections [2] i.e. nearly constant motorisation $\approx$0.43. On the other hand, the zero growth "lower" and "degrowth" cases imply de-motorisation. Actions that aim to inhibit car use (vkt) by 10% were introduced in CAP2021 [1].

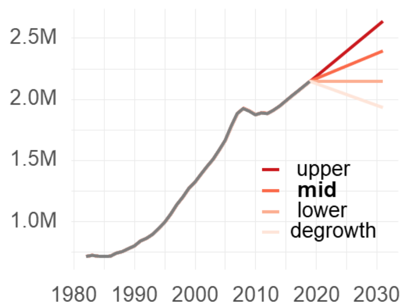

Figure 1: $\mathrm{N}_{\mathrm{fleet}}$ **growth scenarios.**

2.2.2 Policy

The current vehicle taxation system is assumed to be maintained until 2030 i.e. the steeply increasing CO_2-based vehicle registration tax (VRT) and motor tax rates of Budget 2022 are unchanged. However, purchase grants and VRT rebate incentives for battery electric vehicles (BEVs) are phased out around mid-decade. Additional measures outlined in CAP2021 are implemented, with a B20-E10 biofuel blend and a 10% reduction in vkt (car kilometres) by 2030. vkt measures are assumed to affect all powertrains equally. Carbon taxes are raised to €100/tCO_2 in 2030, and excise duty on diesel and petrol is equalised at €0.54/l. In all cases, the measure is implemented in linear increments to 2030.

2.2.3 Technology

The technical parameters of the passenger cars are derived from new car models available to Irish consumers in 2021 and 2022. This includes WLTP type-approval emissions for ICEVs and PHEVs, all-electric range (AER) for EVs and kWh battery capacities. 343 distinct models are present in the 2022 new car fleet dataset, for example, including 61 BEVs. Future new car models correspond to the 2022 fleet but with incremental technical improvements in EV efficiency (km/kWh) and ICEV emissions (gCO_2/km). Battery range degradation (important for second-hand buyers) is assumed to be 3% per year. (Appendix A).

2.2.4 Market

A key assumption used in this report is that *pump prices remain high*, increasing to €2.30 in 2030. Of course, pump prices reflect the market and forex developments as well as tax policy. Table 2 illustrates how a €2.30/l diesel price might arise from the tax policy assumptions of Section 2.2.2, a high €100/bbl oil price and a very high $\gtrapprox$ €200/bbl biodiesel price. Electricity price increases, on the other hand, are assumed to be modest, 25¢/kWh in 2030.

Table 2: €2.30/l diesel.

	€/l
Oil	0.50
Crack	0.10
Margin	0.15
B20	0.29
Excise	0.54
Carbon Tax	0.26
VAT	0.43
TOTAL	2.30

Car prices are derived from dealer quotes for the 2021 and 2022 model years. New ICEV prices are static for future model years, but future new BEV prices decline in line with BNEF battery pack projections e.g. €100/kWh in 2026. These assumptions lead to price parity in 2030 in the important "C" segment (Appendix B). Vehicle depreciation rates are assumed to be 16% per year [12] for all cars. No special allowance is made for inflation. It is also assumed that demand calculated in the model is met by supply i.e. there are no adverse supply-chain effects.

2.2.5 Agents

Most agent characteristics are available from the survey data and remain fixed during a simulation run. For example, agents are classified as new (32%) or second-hand (68%) buyers. Agents are also classified by preferred segment that reflects Irish ownership patterns [10]. PHEV charging frequency is described by a single exogenous parameter ξ. For example, $\xi = 1$ (willingness to charge once per day if required) corresponds to the type-approval assumption for PHEVs. Another exogenous parameter ϵ describes the short-run fuel price elasticity of vkt. Fuel price elasticity acts in addition to vkt reduction measure for ICEVs. Further details are provided in Table 13 (Appendix A).

3 Transport Targets

This Section describes the decarbonisation transition ($\lesssim$ 3 $MtCO_2$ in 2030) observed in the microsimulation output generated using the model and assumptions described in Section 2

3.1 Main features of the ABM output.

Table 3 shows the projected number of EVs in 2030 i.e. simulated uptake of BEVs plus PHEVs as a function of fleet growth and car kilometre reduction (δvkt). Higher overall activity favours higher EV numbers, with the shaded region showing where the CAP2021 target is met. "Mid" fleet growth with δvkt = -10% is just compatible with the target. With degrowth or no growth in fleet size, it is not possible to meet the CAP21 target for EV uptake regardless of δvkt, as there are insufficient EVs purchased.

Table 3: EV numbers at the end of 2030.

δvkt	degrowth	lower	mid	upper
0%	716k	788k	871k	954k
-5%	686k	755k	834k	914k
-10%	674k	743k	**821k**[a]	899k
-15%	649k	715k	790k	865k

[a] The CAP2021 target of 845k includes private passenger cars, small public service (taxis) and state-owned vehicles.

From a CO_2 perspective the situation is reversed. Table 4 shows CO_2 emissions drops from 2018 to 2030. Lower activity favours lower emissions and the shaded region indicates where a -55% or higher drop is achieved. These results include the assumption that biofuel blending is increased to B20-E10. It is also assumed that PHEV owners charge their vehicle up to twice per day ($\xi = 2$).

While PHEVs are projected to make up only $\approx$ 6% of the 2030 fleet, the charging behaviour of PHEV drivers is nearly as important for CO_2 targets as vkt reduction. If charged at most once per day, which is the type-approval assumption for PHEVs, the emissions drop is lessened from -55% to -52%.

Table 4: Emissions drop in 2030 relative to 2018.

δvkt	degrowth	lower	mid	upper
0%	-61%	-56%	-51%	-45%
-5%	-62%	-57%	-52%	-47%
-10%	-64%	-60%	**-55%**	-50%
-15%	-66%	-62%	-57%	-52%

Tables 3 and 4 show a "reverse rebound effect" for vkt reducing measures such as home-working, congestion charging etc. In the normal rebound effect, efficiency gains are partly or wholly offset by increased consumption. In the reverse case, reduced consumption lowers the uptake of a higher efficiency alternative. In this instance, a $\delta\mathrm{vkt}$ =-10% lowers emissions by only $\approx$ 4%. Discouraging private car use has the unwanted effect of reducing private investment in lower-carbon technology, offsetting some of the expected emissions gains.

Combining the results of Tables 3 and 4, we find that "mid" growth with $\delta\mathrm{vkt}$=-10% is compatible with both a -55% emissions reduction target and the EV uptake target of CAP2021. This corresponds to approximately constant activity demand ($\lesssim$ 37Gkm) because the effects of increasing $\mathrm{N_{fleet}}$ and vkt reduction cancel out. Along with the other technical and market assumptions in Section 2.2, this scenario is used in the remainder of this report, including Sections 4 and 5 where the taxation and distributional impacts of the decarbonisation transition are analysed.

The projected composition of the passenger fleet by type of purchase (new or second-hand) and powertrain in this central scenario is shown in Figure 2. Table 5 shows that second-hand diesel vehicles are still the most common category in 2030, but their numbers are declining rapidly. Table 6 shows the corresponding steep declines in ICEV Gkm activity, and Table 7 shows diesel and petrol car kilometres falls in line with CAP2021. vkt increases for BEVs as higher mileage drivers adopt them.

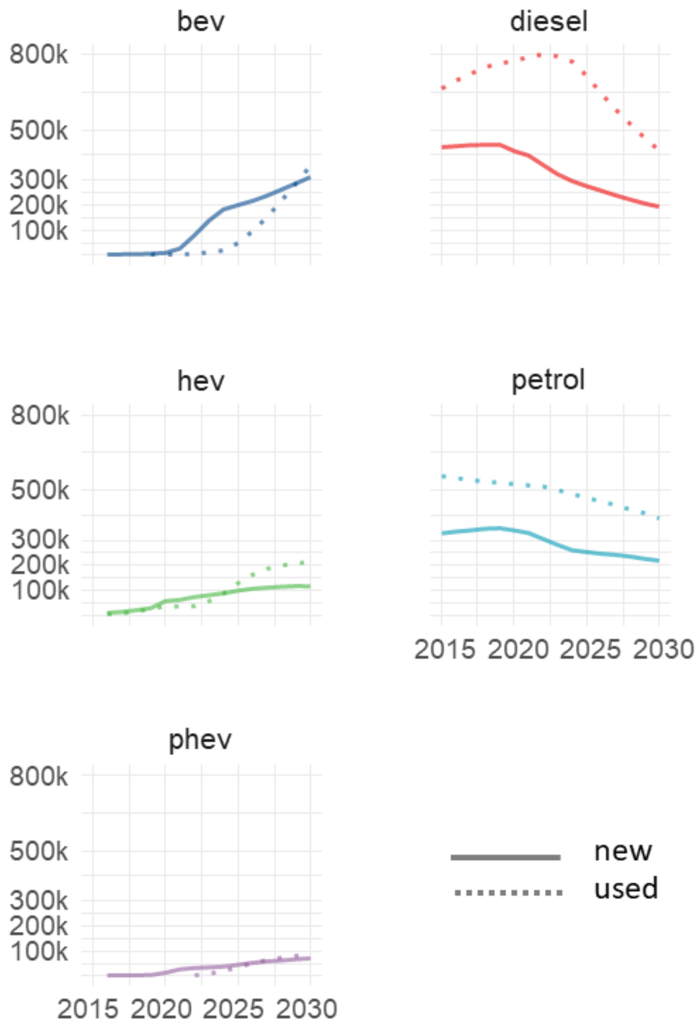

Figure 2: Passenger car fleet numbers by powertrain computed for 2015-2030. Solid and dashed lines indicate vehicles bought new and second-hand respectively.

Table 5: Car numbers in 2030.

type	new	used
bev	314k	355k
diesel	193k	419k
hev	119k	215k
petrol	217k	387k
phev	70k	85k

Table 6: Activity (Gkm) by powertain.

type	2021[a]	2030
bev	0.2	9.1
diesel	23.5	10.5
hev	2.0	5.5
petrol	11.6	6.4
phev	0.7	5.0
Total	38	36.5

[a] The impact of 2021 pandemic restrictions is not taken into account.

Table 7: Car km by powertrain.

type	2021	2030
bev	6.6k	13.6k
diesel	19.8k	17.2k
hev	20.4k	16.3k
petrol	13.8k	10.6k
phev	23.3k	32.5k

A striking feature of Figure 2 is the sharp uptake of second-hand BEVs from mid-decade, reflecting increased availability, improved range of available second-hand BEVs and favourable total cost of ownership (the financial advantage of second-hand BEVs is described in Appendix B). In 2030, the projected demand for new BEVs is 82k, compared to 124k for second-hand BEVs. Supply from trade-ins, (57k) is not adequate to meet this demand, and there is an import requirement of 67k second-hand BEVs (Table 15 in Appendix C).

The central role of second-hand demand in meeting emissions targets is sometimes overlooked. While demand for used BEVs exceeds domestic supply from trade-ins, supply and demand are approximately in balance for ICEVs in 2030. This suggests that costly large-scale scrappage schemes may not be required.

3.2 Contribution to carbon budgets

Simulated cumulative emissions from private cars corresponding to the -55% scenario of Figure 2 are 22.7 $MtCO_2$ for the years 2021-2025 and 16.0 $MtCO_2$ for 2026-2030. These numbers assume a linear increase in biofuel blending to B20-E10 in 2030. However, real-world emissions are estimated to be $\approx$ 14% higher [13] than implied by type-approval values used in the simulation model. Applying this correction, the projected contribution of private passenger cars (25.9 $MtCO_2$ and 18.2 $MtCO_2$) represents 9% of each of the first two approved Carbon Budgets 295 $MtCO_2$-eq and 200 $MtCO_2$-eq.

4 Implications for revenue

The Department of Public Expenditure and Reform (DPER) [4], the Tax Strategy Group [14], and the Parliamentary Budget Office [15, 16], have drawn attention to the potential impact of road transport decarbonisation on public finances. According to the DPER, *“the widespread diffusion of EVs will necessitate considerations of the sustainability of the current vehicle taxation model and the sustainability of public finances.”*

Here, transactional data generated by the ABM are used to project future tax revenues from passenger cars in the deep decarbonisation scenario described in Section 3. These data correspond to the -55% emissions reduction scenario underlying Figure 2. Cumulative private investment in passenger cars from 2021 to 2030 in this scenario is $\approx$ €100Bn, with EVs projected to account for 40% of this investment (Table 8). Therefore it is not surprising that tax changes designed to decarbonise road transport can have a potentially large effect on public finances.

Table 8: Investment 2021-2030.

type	Bn€[a]
bev	30.4
diesel	26.5
hev	14.1
petrol	19.7
phev	9.8
TOTAL	100

[a] After taxes and subsidies.

4.1 Revenue per car

The projected average annual tax revenue per car by source is shown in Figure 3 and Table 10. Incentives (VRT rebates and SEAI purchase grants) correspond to negative revenue. As anticipated [4], there is a downward trend in average tax revenue per car.

Some revenue streams in Table 10 decline steeply. In particular, there are significant falls in average annual motor tax paid per car (-34%), average VRT (-24%) and average mineral oil tax per car (-21%) between 2021 and 2030. However, despite lower ICEV activity, the average VAT paid on fuels is nearly flat. This is a consequence of the high 2030 fuel price assumption (∼ €2.30, Section 2.2). The average carbon tax paid is approximately flat after 2025. VAT collected on new and imported cars is a significant component of tax. This revenue stream is supported by the price premium of BEVs over ICEVs (price parity is not reached until the end of the decade, Appendix B).

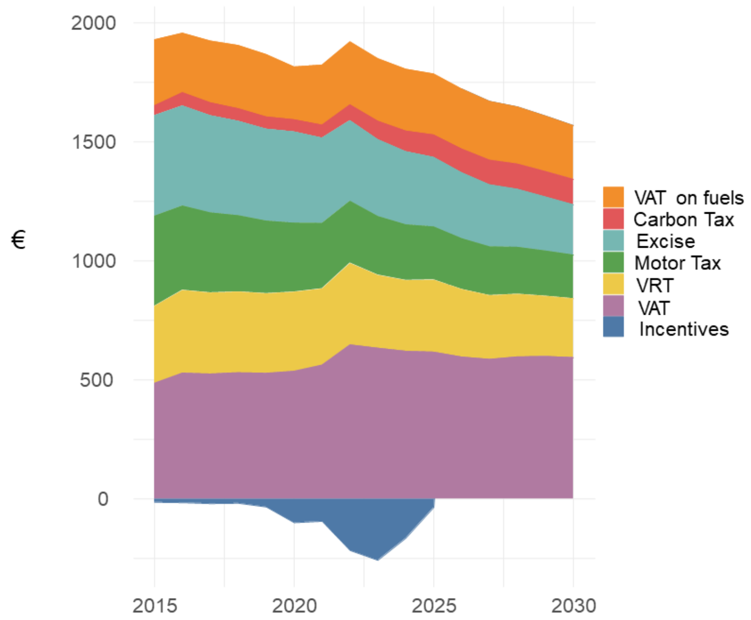

Figure 3: Mean tax revenue per vehicle by source (€).

Table 9: Average tax revenue per car 2030.

powertrain	€
bev	1562
diesel	1552
hev	1791
petrol	1402
phev	1947

It might be expected that their generous tax treatment relative to ICEVs implies that the average tax revenue from BEV owners is much lower. In fact, this expectation is not corroborated as can be seen in Table 9 that shows the average tax revenue by powertrain in 2030. BEV owners pay comparable tax because new car buyers make up a far larger share of BEV ownership, with higher value taxes, in 2030 (see Appendix C). This offsets the much lower tax paid on fuels.

Table 10: Simulated revenue per vehicle 2018-2030 (€).

year	VRT	VAT_{car} [a]	Motor	Excise [b]	Carbon [c]	VAT_{fuels} [d]	Incentives	TOTAL
2018	333	523	322	398	53	269	-18	1880
2019	335	530	305	388	51	266	-30	1846
2020	328	530	290	387	51	226	-95	1718
2021	322	559	275	364	55	257	-95	1738
2022	342	641	261	345	67	272	-212	1716
2023	306	630	247	330	79	271	-256	1608
2024	305	632	234	315	89	268	-164	1678
2025	298	606	223	301	97	266	-36	1754
2026	287	607	213	286	103	261	0	1757
2027	268	598	204	269	107	256	0	1702
2028	256	604	195	252	110	249	0	1666
2029	245	597	188	235	111	242	0	1619
2030	244	605	182	218	111	234	0	1594

[a] VAT paid on car purchases
[b] Assumes linear petrol/diesel equalisation at €0.54/l
[c] Linear increase to €100/tCO_2
[d] $\approx$ €2.30 pump price and €0.25/kWh electricity price in 2030

4.2 Total revenue

The projected total tax revenue is shown in Table 11. Despite the assumed growth in N_{fleet} (“mid” scenario Section 2.2.1), total revenue peaks in 2025 after incentives are removed before starting to decline as a result of reductions in fossil fuel excise duty, motor tax and VRT. VAT on vehicles and carbon tax increase over the period on the other hand. The projected incentive costs are significant. Note that the excise, carbon tax and VAT_{fuels} figures are calculated based on type-approval emissions and therefore each is likely to underestimate the true value by $\sim$14% [17].

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Table 11: Simulated total exchequer revenue from passenger cars (M€).

year	VRT	VAT_{car}	Motor	Excise	Carbon	VAT_{fuels}	Incentives[a]	TOTAL
2018	714	1119	673	836	111	565	-38	3981
2019	717	1135	654	830	110	568	-72	3943
2020	720	1165	626	832	111	487	-216	3724
2021	700	1232	600	786	120	556	-205	3789
2022	758	1431	572	749	146	591	-478	3770
2023	684	1414	547	721	173	591	-575	3555
2024	669	1397	524	693	195	589	-371	3696
2025	688	1402	504	665	214	586	-82	3978
2026	649	1368	488	636	229	581	-0	3952
2027	617	1358	472	605	241	573	-0	3866
2028	612	1394	459	571	249	562	-0	3847
2029	593	1411	446	537	253	550	-0	3791
2030	584	1412	435	504	256	537	-0	3728

[a] No allowance has been made for the effect of the pandemic or the present supply-chain constraints.

The revenue and incentive values in Table 11 can be benchmarked against reported values in 2018 and 2019 [4, 16]. Comparisons with 2020 and 2021 are less meaningful here because the pandemic effect has not been modelled. Motor Tax receipts from passenger cars in 2018 and 2019 were €772M and €753M, compared to the simulated values €673M and €654M. Reported excise receipts were €2.1Bn in 2017 and 2018, which include contributions from goods vehicles, marked diesel and fuel tourism in addition to passenger cars. With a 14% WLTP correction, the simulated excise from passenger cars is ≈1Bn in 2018 and 2019. The reported VRT receipts include a contribution from light commercial vehicles, and were €885M in 2018 and €941M in 2019, compared to simulated passenger car values of €714M and €717M of Table 11. In summary, the tax receipts in 2018 and 2019 are compatible with the observed values, but there is a hint that car buyers have a preference for higher specification trims (engine size, etc.). This could result in a somewhat higher tax take than the simulated values.

Projected incentive costs (SEAI purchase grants plus VRT rebates) can also be benchmarked against reported costs [16]. In 2018, the reported total incentive cost was €37M compared to €38M in Table 11. Incentive costs for 2019 were €68M compared to a simulated value of €72M. This is a very good agreement.

The projected revenue in Table 11 can be compared to "business-as-usual" using a 2019 revenue-per-car as a baseline, for example. This suggests a cumulative decarbonisation revenue loss during 2021-2030 of €4.1Bn (or €4.7Bn for 2020-2030). The cumulative incentive cost for the period 2021-2030 in Table 11 is €1.7Bn. This number depends on the assumption that the VRT rebate and purchase grant supports for BEVs are removed at the beginning of 2024 and 2025 respectively. Of course, the realised cumulative cost of incentives will depend on the timing of incentive removal and the ability of the market to meet the projected demand for BEVs. From Section 4.3 below, a further €0.5Bn revenue loss is associated with vkt reduction. The remaining €1.9Bn cost comes from the loss in excise duty and losses from the bonus-malus system for new cars.

The cumulative emissions savings for 2020-2030 are 15.4 $MtCO_2$ relative to a 2019 baseline emissions per vehicle. Therefore the cumulative revenue loss of €4.7Bn indicates an abatement cost to the exchequer of €305/tCO_2. If the home charger grant cost is included, and this is assumed to be maintained until 2030, then the abatement cost increases to €335tCO_2. However, as already noted, the CO_2 emission calculations use type-approval gCO_2/km that underestimates real-world emissions. This lowers the true cost to the exchequer of $\approx$ €295/tCO_2. This estimate ignores any additional direct expenditure that might be required and therefore it is certainly the case that €/tCO_2 abatement costs to the exchequer are high compared to the carbon tax or ETS prices over the 2030 time horizon.

The simulated total revenue by powertrain type is shown in Figure 4. BEVs account for 28% of total tax revenue in 2030, in line with their share of the fleet. The grey area represents revenue lost relative to a 2019 baseline projection.

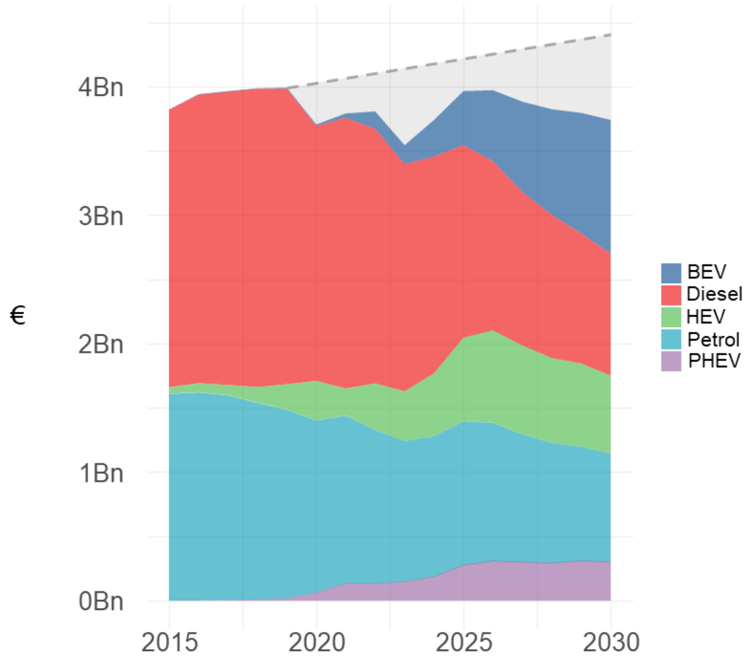

Figure 4: Projected total revenue from passenger cars by powertrain. The dotted line is "business as usual"' using a 2019 baseline.

4.3 Cost-effectiveness of vkt reduction

Measures to lower CO_2 emissions by reducing car usage also lower tax revenue to the exchequer. An implied €/tCO_2 abatement cost can be calculated by comparing model output with and without a 10% reduction in vkt. Revenue loss for 2021-2030 is estimated at €0.46Bn. This cost reflects reduced Gkm activity and lower investment in EVs, as seen in Table 3. Cumulative 2021-2030 CO_2 emissions are 1.8 MtCO_2 higher when $\delta\mathrm{vkt} = 0$, implying an abatement cost of €253/tCO_2. Of course, this estimate neglects any additional direct costs associated with the $\delta\mathrm{vkt}$ measures.

5 Distributional impacts of decarbonisation

A sustainable climate policy must be socially acceptable. Studies have shown that the "fairness" or perceived distributional impact of a carbon tax is more important for acceptability than economic efficiency [18, 19]. The complex policy measures designed to decarbonise the passenger car fleet are likely to impact the relative welfare of different social groups. This is examined here using the same micro-simulation output as Section 4.

5.1 New versus second-hand car buyers

New car buyers pay significant taxes (VRT and VAT) when replacing their cars. There is a large difference ∼€1k between the direct tax revenue from new versus second-hand car buyers. A difference in the direct tax burden between social groups can often be explained by a relative preference for new versus second-hand cars. Figure 5 shows that the generous financial incentives for BEVs lead to a deep reduction in the net tax from new cars in the first half of the decade, falling to a minimum of €2k per vehicle. However, this rebounds to €2.5k after incentives have been removed. In contrast, the revenue from second-hand car buyers falls continuously after mid-decade, approaching ≈ €1k by 2030, as many second-hand buyers switch to BEVs (Figure 2). The average tax revenue from new cars has not yet fallen below that of second-hand car buyers when incentives are removed around mid-decade. The low tax burden projected for second-hand BEV ownership seen in Figure 5 is mirrored in the low total cost of ownership (TCO) for these vehicles (Appendix B).

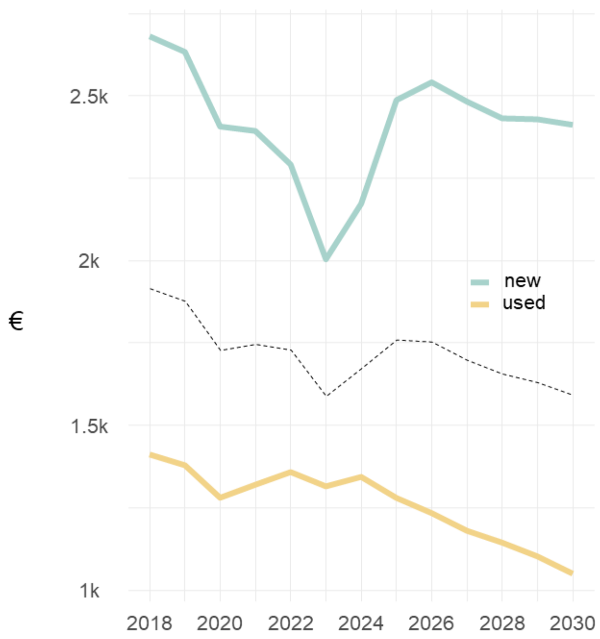

Figure 5: Simulated mean annual tax per car for new versus second-hand buyers. The dashed line is the fleet mean.

5.2 Income

Figure 6 shows the projected average annual tax revenue per car by income tercile. “Low” represents household incomes less than €30k and “High” represents incomes over €60k. As a consumer good, taxation on passenger cars is progressive and remains so throughout the transition. All income groups have a declining average tax burden on passenger cars, but with the steepest declines for middle and low-income groups (Table 12). Thus, there is no evidence in the simulation output that the tax system designed to decarbonise passenger cars is regressive over the longer term. Figure 6 also suggests that middle-income earners tend to benefit most from BEV incentives before they are phased out.

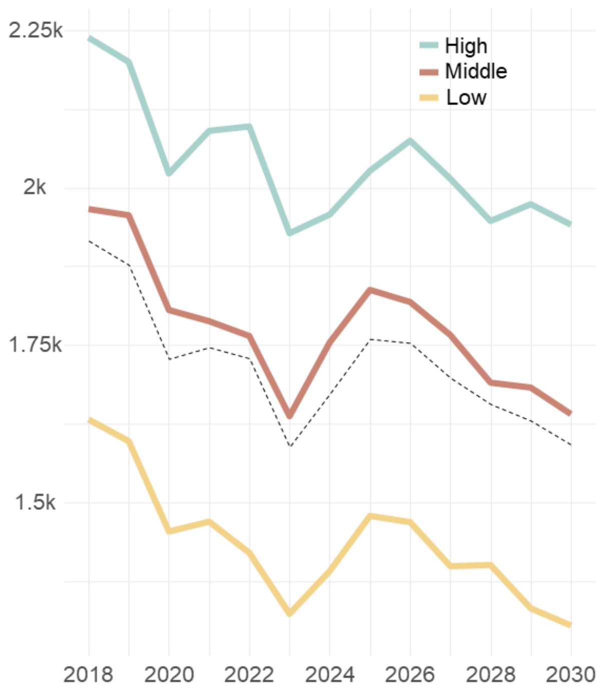

Figure 6: Simulated mean annual tax revenue per vehicle by income tercile.

Table 12: % change in average tax burden vs 2018 by income bracket.

year	Low	Middle	High
2030	-20%	-17%	-13%

5.3 Urban, rural and commuter belt

Households with high car kilometres stand to benefit most from the low TCO of BEVs (Figure 10 in Appendix B). The distributive impact of decarbonisation on rural and urban households during the transition is compared in Figure 7.

Average tax revenue per vehicle falls in both cases but the urban-rural disparity is notably smaller than the income disparity (Figure 12). It appears that decarbonisation modestly improves the position tax position of rural households compared to urban households (≈€50).

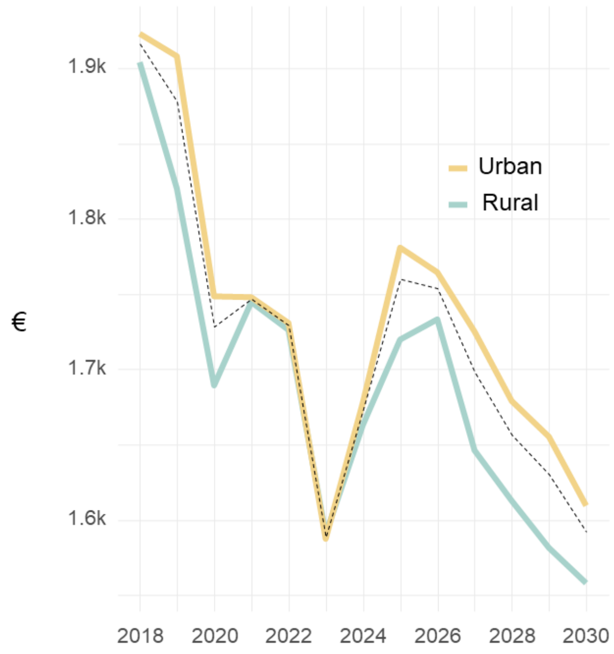

Figure 7: Simulated annual tax take per vehicle for rural and urban dwellers.

This can be further explored by looking at the regional dependence of the urban-rural disparity in tax revenue, Figure 8. There is little distinction between the urban areas of Dublin, Leinster and Munster. However, the impact in rural areas is more diverse. The biggest distributive beneficiaries of the transition are Connulster and rural Munster.

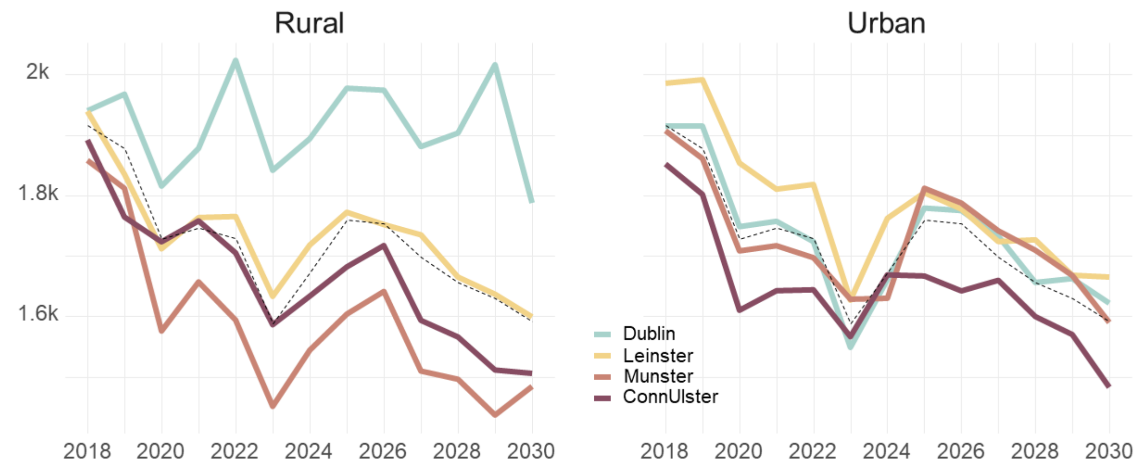

Figure 8: Simulated annual tax take per vehicle for rural (left) and urban (right) areas within Dublin, Leinster, Munster and Connulster.

A similar conclusion is reached when Dublin is compared with surrounding counties. Figure 9 suggests that the transition reverses the distributive position of the commuter counties, paying more tax per vehicle than Dublin before the transition and less tax after the transition.

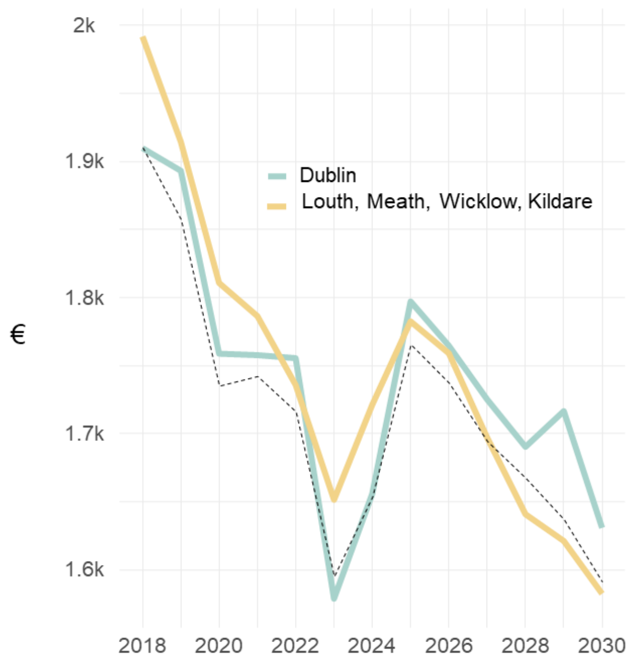

Figure 9: Mean annual tax for Dublin compared to surrounding counties.

6 Conclusions

This report used an agent-based model calibrated to describe the future powertrain choices of Irish car buyers. Analysis of rich transactional data generated by this model shows rapid decarbonisation of the passenger car fleet as electric vehicles are purchased in response to technical improvements, high fuel prices, incentives, and favourable tax policies. Decarbonisation policy measures are projected to come at a cumulative cost to the exchequer of €4-5Bn relative to historic baselines. The projected revenue loss may not be as sharp as feared because revenue is supported by value taxes on the purchase of EVs. Nevertheless, the cost to the exchequer, equivalent to $\approx$€300/tCO_2, is high relative to other sectors. An encouraging quantitative finding is that the distributional impact of policy is progressive, with lower-income groups, rural areas and commuters faring best by 2030.

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Appendices

A Parameters

Table 13: Main parameters and assumptions used in this report.

category	parameter	name	value
policy	BEV grant ends	-	2025.5
policy	PHEV grant ends	-	2022
policy	VRT rebate ends	-	2024
policy	2030 Carbon Tax	-	100€/tCO_2
policy	diesel excise 2030	-	54¢/l
policy	petrol excise 2030	-	54¢/l
policy	VAT on cars	-	23%
policy	VAT on fuels	-	23%
policy	VAT on electricity	-	13.5%
policy	new ICEV ban	-	2035
policy	ICEV import ban	-	2040
policy	biodiesel blend 2030	-	20%
policy	petrol blend 2030	-	10%
policy	travel demand reduction 2030	δvkt	0,0.05, 0.1,0.15
market	2030 oil price	-	100€/bbl
market	refining margin	-	10¢
market	*2030 pump prices*	-	*≈ 2.30€*
market	long-term battery pack cost	-	60€/kWh
market	battery cost learning (decay) rate	-	0.4[a]
market	effective electricity price 2030	-	25¢/kWh
market	annual vehicle depreciation rate	-	16%
market	mean age of used cars at purchase	-	4€[b]
technology	ICEV gCO_2/km reduction rate	-	-1.20%[c]
technology	ICEV gCO_2/km reduction ends	-	2024
technology	BEV conversion efficiency gain	-	2%
technology	annual reduction in AER due to battery degradation	-	3%[d]
agent	monthly transaction rate	p.	1.6%[e]
agent	horizon for TCO evaluation (years)	-	3
agent	new car buyer percentage	-	38%[f]
agent	new car brand loyalty	-	0.8
agent	used car brand loyalty	-	0.3
agent	segment loyalty	-	1
agent	PHEV daily charging willingness (homogeneous)	ξ	0.5,1,1.5,2
agent	daily kms gamma distribution shape parameter	-	2.5 [g]
agent	initial range anxiety	-	2[h]
agent	range anxiety begins to fall	-	2018
agent	range anxiety reaches 1 (rational value)	-	2026
agent	short run fuel price elasticity with respect to car kilometres (homogeneous)	ϵ	-0.19 [i]
agent	# of vehicles evaluated by agents before transaction	-	2-15
agent	PHEV barrier relative to BEV	-	0.5
agent	mean barrier from survey before hypothetical bias correction	θ	0.152
social	social network homophily exponent	ν	-4.5[j]

[a] Consistent with BNEF price projections.
[b] Fleet mean vehicle age is ≈ 8.5 years with this assumption.
[c] T&E
[d] Most studies place this number in the range 2-4%
[e] Inferred from distribution of vehicle ages on Irish roads (Cartell, 2014)
[f] Values of 31%-45% are compatible with the survey data.
[g] Inferred from National Travel Survey, 2019
[h] Range anxiety is related to the subjective probability that a daily trip exceeds the AER of the vehicle.
[i] Graham and Glaister, 2004
[j] Inferred from UCD survey.

B Total Cost of Ownership

Agents assess the total cost of ownership (TCO) of a vehicle given its price, fuel efficiency and motor tax band. Discounting (depreciation and credit) and service assumptions are also required. TCO appears as a financial contribution $-TCO/B$ to an agent's (dimensionless) choice utility, where B is the agent's budget for their next car. At present, the running cost of BEVs is lower than ICEVs but the depreciation cost is higher. However, the 2022 fleet data and technology cost assumptions used in this report suggest that price-parity between BEVs and ICEVs is achieved by 2030, at least in some market segments (Table 14). Price-parity implies that the TCO of BEVs is well below ICEVs in our high pump price scenario, particularly for high mileage drivers.

Table 14: Projected median passenger car prices in 2030 by powertrain and market segment.

type	B	B_{SUV}	C	C_{SUV}	D	D_{SUV}
bev	27k	29k	28k	34k	40k	54k
diesel	24k	36k	32k	49k	47k	67k
hev	26k	32k	32k	40k	37k	-
petrol	20k	28k	29k	35k	49k	41k
phev	-	47k	37k	44k	51k	79k

Figure 10 shows mean TCOs calculated for all C and C_{SUV} segment car models. Incentives and the expected fall in battery pack cost lower the TCO of new BEVs below new ICEVs. BEVs are especially competitive for high mileage drivers on a TCO basis before range anxiety is considered. In fact, by 2030 used BEVs have by far the lowest cost of ownership. For example, for mileage of 17,000 km, TCO for second-hand BEV owners is €3100 compared to €4720 for second-hand diesel owners.

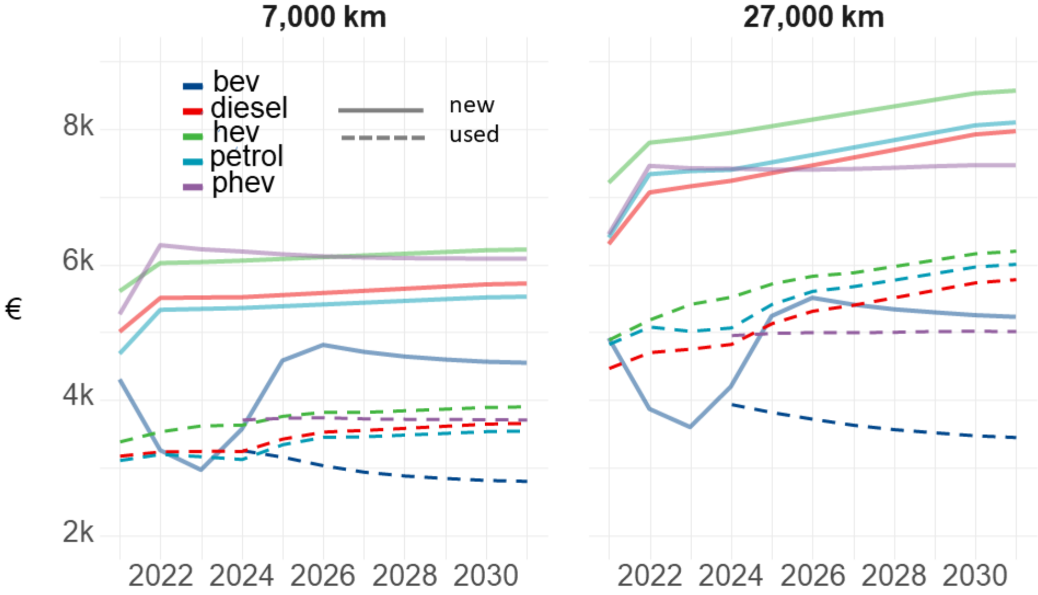

Figure 10: Mean annual total cost of ownership for C-segment cars by powertrain, projected for low (7,000 km) and high (27,000 km) mileage drivers.

C Supply and demand imbalances in 2030

Table 15 shows the projected demand for new and used cars in 2030 by powertrain. Historically, the supply of used vehicles from trade-ins is insufficient to meet the demand for second-hand vehicles. This situation is projected to continue requiring the import of $\sim$ 67k second-hand BEVs in 2030. Conversely, the import requirement for used petrol and HEVs falls to 33k, while there is a small glut in the net supply of second-hand diesel cars ($\approx$ 5k) that must be either exported or scrapped.

Table 15: Projected demand and supply of used cars in 2030

type	new demand	used supply[a]	used demand	used import demand	total demand
bev	82k	57k	125k	67k	206k
diesel	24k	41k	37k	-5k	60k
hev	24k	23k	43k	19k	67k
petrol	33k	43k	57k	14k	90k
phev	14k	12k	22k	11k	37k

[a] From the sale of cars bought new (trade-ins)