Clean energy technology adoption – policy analysis for a cleaner future

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Introduction

This research examines the uptake of clean energy technology under a range of policy scenarios. Ireland's climate ambition has increased significantly with the recent Climate Action and Low Carbon Development (Amendment) Act (2021)[i] setting out Ireland's objective of achieving carbon neutrality by 2050 and targeting a 51% reduction of GHG emissions by 2030 (7% per annum) relative to 2018. The Climate Action Plan 2021[ii] maps out a number of targets and actions which will help to support this ambition across different sectors including electricity, built environment, transport and agriculture.

Some of the targets within the Climate Action Plan (Table 1) require the uptake of clean energy technologies such as heat pumps (hps), electric vehicles (EVs) and solar photovoltaic (PV) panels. The choice to adopt these technologies has to be made by individuals/households, unlike other targets such as electricity generation from renewables. There are a number of factors that influence the uptake of these technologies and our research explores these factors with a view to informing policies to support Ireland's decarbonisation objectives.

Sector	2030 Target
Built Environment/Retrofit	600,000 heat pumps to be installed in residential buildings (of which 400,000 are to be installed in existing buildings)
Electricity	260 MW of new micro (<50 kW) renewable generation (including Solar PV)
Transport	845,000 passenger EVs

Table 1: Key targets from CAP21 considered in this research

Background

The UCD Energy Institute has developed the Emissions and Fuel Mix, Markets and Costs, Power Flows and Networks, and End Use & Rates of Uptake (EMPowER) modelling framework. EMPowER offers integrated, comprehensive insights on achievability of a low-carbon future, from both an economic/policy perspective, as well from a technical and commercial point of view – a combination critical to formulating and executing sound energy and environmental policy. The focus of this paper is on the rates of uptake of clean energy technologies, in particular electric vehicles, solar photovoltaic panels, and domestic heat pumps.

Renewable Technology Uptake

Mukherjee and Ryan (2020) carried out a detailed literature review looking at the factors that influence renewable energy technology (RET) uptake. They found that the triggers and underlying characteristics that underpin the adoption of RETs can be classified into four broad categories, namely, costs, spatio-technical features, socio-demographics, and behaviour (Figure 1).

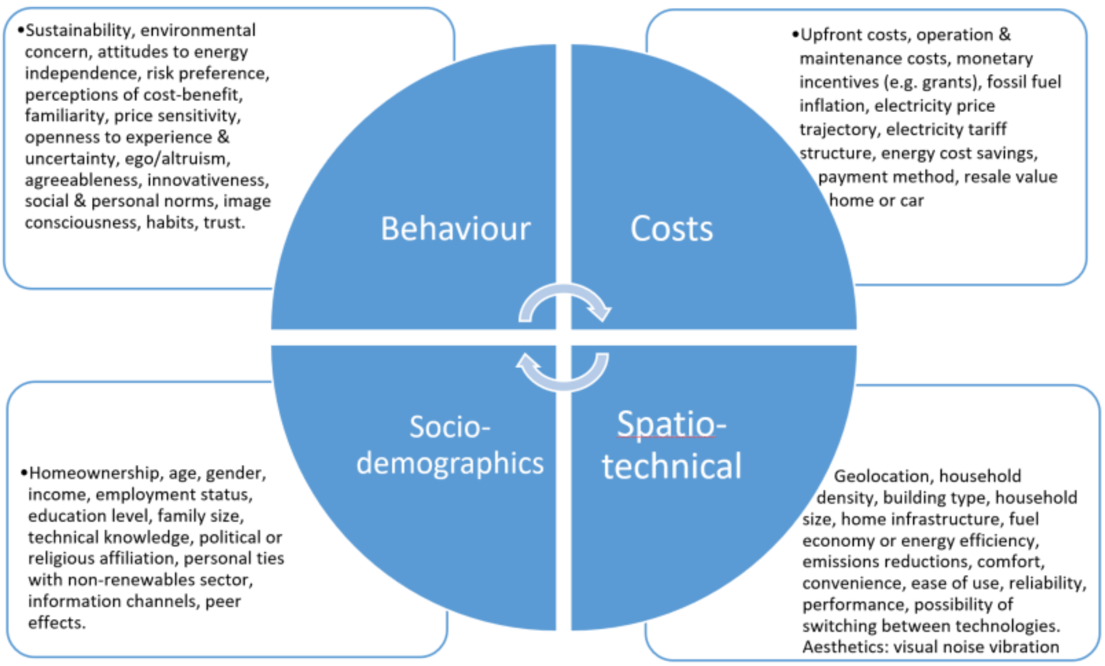

Figure 1: Determinants of RET uptake. Source: Adapted from Mukherjee and Ryan, 2020

Survey on attitude of Irish Households

A comprehensive survey on the uptake of Renewable Energy Technologies (RETs) of a nationally representative sample of Irish households was carried out in order to identify the most relevant characteristics in an Irish context (Meles, Mukherjee and Ryan, 2020).

The initial phase of the research involved three focus groups and four in-depth interviews conducted in March 2018. The three groups consisted of EV owners, solar PV owners, and non-adopters of RETs. Given the very low incidence of heat pump installation, four in-depth

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interviews were conducted with those who had installed heat pumps at their property. This qualitative study provided exploratory data on the public perception of EVs, solar PVs and heat pumps in Ireland.

The focus groups formed the basis for the second phase of the research which involved an online survey of a nationally representative sample of the Irish adult population in July 2018 to collect more detailed preference data. There were 1,208 individual responses, with 203 respondents owning some type of RET (63 EV, 58 solar PV, 99 solar thermal, and 43 heat pump owners of which a few participants owned multiple technologies) whilst 1,005 owned none. A demographically representative sample was ensured in terms of age, gender, region, and social class.

The analysis led to the following conclusions in relation to the adoption of RETs in Ireland:

- Consumers are most concerned about the initial outlay which is often prohibitive.
- RET adopters tend to be younger and of higher socio-economic status, more likely to live in newer buildings with capacity for bigger families, and have higher energy use and significantly larger social networks.
- Current RET adopters tend to be innovators (Figure 2).
- Word-of-mouth recommendation plays a key role.
- A preference for environmental sustainability is not a reliable predictor of RET uptake.
- The survey revealed a preference for used cars for those considering a vehicle change and budgets under €15,000.
- Many non-adopters prefer not to change their existing systems due to the perceived complexity of energy decisions, various cognitive biases, and a genuine lack of understanding of new technologies and potential cost-benefit trade-offs.

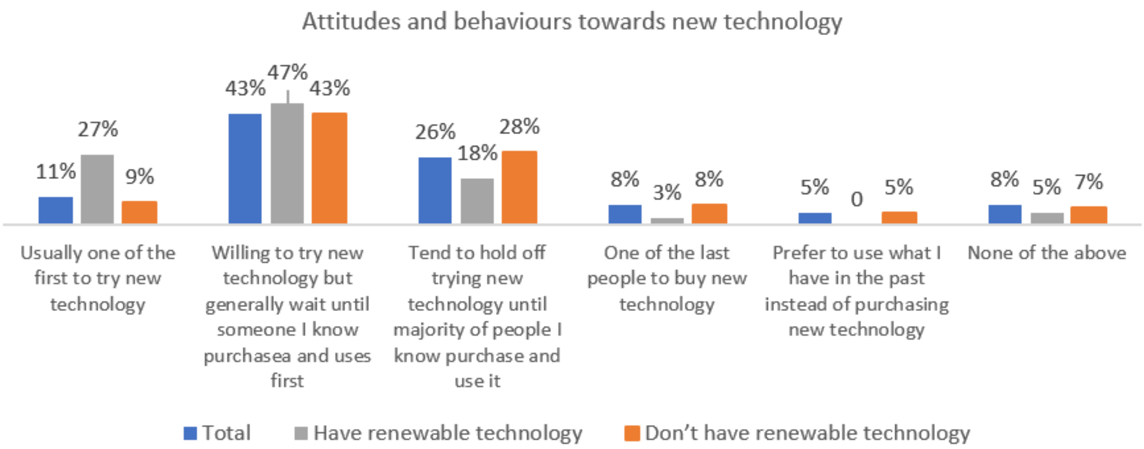

Figure 2: Current renewable energy technology (RET) adopters tend to be innovators

Modelling technology uptake – Agent-based modelling

An important area of focus for the EMPowER project is to be able to assess the effectiveness of policy interventions before they are implemented, i.e. *ex ante*. In recent years micro-simulation or agent-based modelling (ABM) has emerged as a practical tool for policy evaluation. As part of the EMPowER project an agent-based model has been developed to analyse the adoption of clean energy technologies and the underlying diffusion factors, i.e. how adoption of a technology spreads through a population.

An agent-based model is a simulation model that captures the dynamic interactions of autonomous decision-makers (called agents) with each other and with their environment to derive insights on aggregate patterns of uptake. The agent-based model provides a suitable framework to explore how various factors such as individual agent's characteristics and social networks affect the diffusion of innovation. It allows for the design for "what-if" type of questions where the impacts of alternative measures are compared. The model used in this study is innovative as the decision-making parameters for each agent in it were derived from real-world observations - the responses to the survey of household attitudes to RETs.

Heat Pump Uptake

Using this agent-based modelling approach, an analysis was carried out to investigate the adoption and diffusion of heat pumps in Ireland. The model detail is described in Meles and Ryan (2022). Researchers explore how financial aspects, psychological factors and social networks influence the adoption and diffusion of heat pump systems:

- Financial factors: The model compares the agent's annual heating bill of the existing heating system with the annualized capital cost (including available grants) and running cost of a heat pump system.
- Psychological factors: An agent's attitude, the social norm, perceived behavioural control, and intention to install a heat pump system.
- Social network factor: The influence of other agents within the agent's social interaction that have already installed a heat pump system at their home.

The benefit to a household (household utility) from installing a heat pump system is then estimated as a function of the three factors. A potential adopter decides to install a heat pump system when the household utility exceeds a certain threshold level. The parameters for the microsimulation model were derived using data from the survey referred to above.

At the end of the simulation, the simulation results are extrapolated to estimate that the corresponding numbers of Irish households that will install heat pumps over the years 2018-2030 is approximately 260,000. This is approximately 15% of the 1.76 million households in Ireland and does not meet the targets in the Climate Action Plan.

Government Grant

Meles and Ryan (2022) used the model to test the sensitivity of the results with respect to change in upfront costs, bill savings and the Irish government home grant of €3,500. Figure 3 shows the effect of increasing the Irish government grant on the uptake of heat pump technology. The current home grant of €3,500[iii] results in about 15% of the Irish households adopting heat pumps. Removal of the grant would reduce this to 12% (about 215,000 heat pumps). Grant amounts of €5,000 and €7,500 increase the number of heat pump adopters in 2030 to approximately 16% and 20% of the Irish households (around 290,000 and 355,000 heat pumps) respectively.

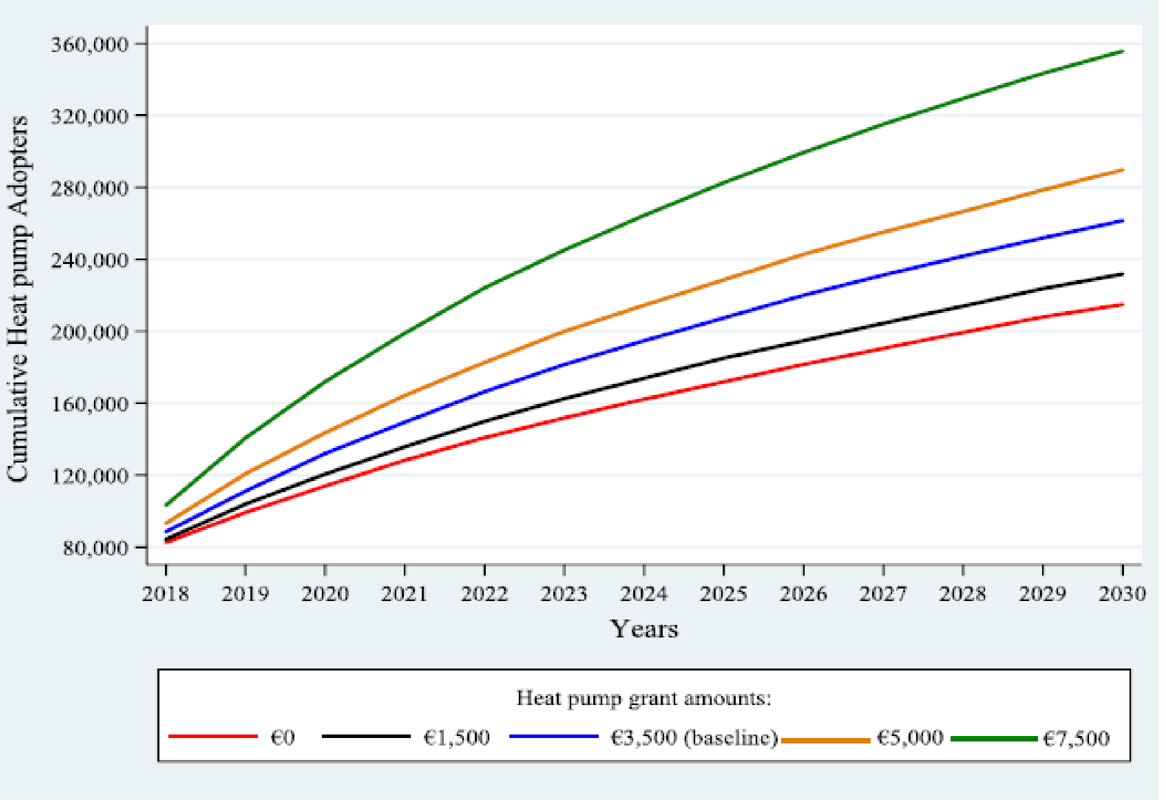

Figure 3: Uptake of heat pumps based on different grant amounts. Target of 400,000 heat pumps is not achieved. Source: Meles and Ryan (2022)

Upfront costs and bill savings

The impact of changes in the upfront costs and bill savings was also examined. Figure 4 shows the different combinations examined, corresponding to different sizes and types of heat pumps. The simulation results show that, depending on the type and size of the heat pump considered, about 6% to 31% of the 1.76 million Irish households will install a heat pump at home in 2030. In the case of air source heat pumps, which have lower upfront costs and billing savings, results show that about 31% of the 1.76 million Irish households will install an air source heat pump at home in 2030. This is equivalent to approximately 550,000 air source heat pumps by the end of 2030, and is sufficient to reach the target of 400,000 heat pump installations. On the other hand, ground source heat pumps, which have higher upfront costs and bill savings, have much lower adoption rates with about 106,000 ground source heat pumps predicted to be installed in Ireland until 2030. The result supports the argument that a high upfront cost of a heat pump system is the main barrier for the adoption of a heat pump system.

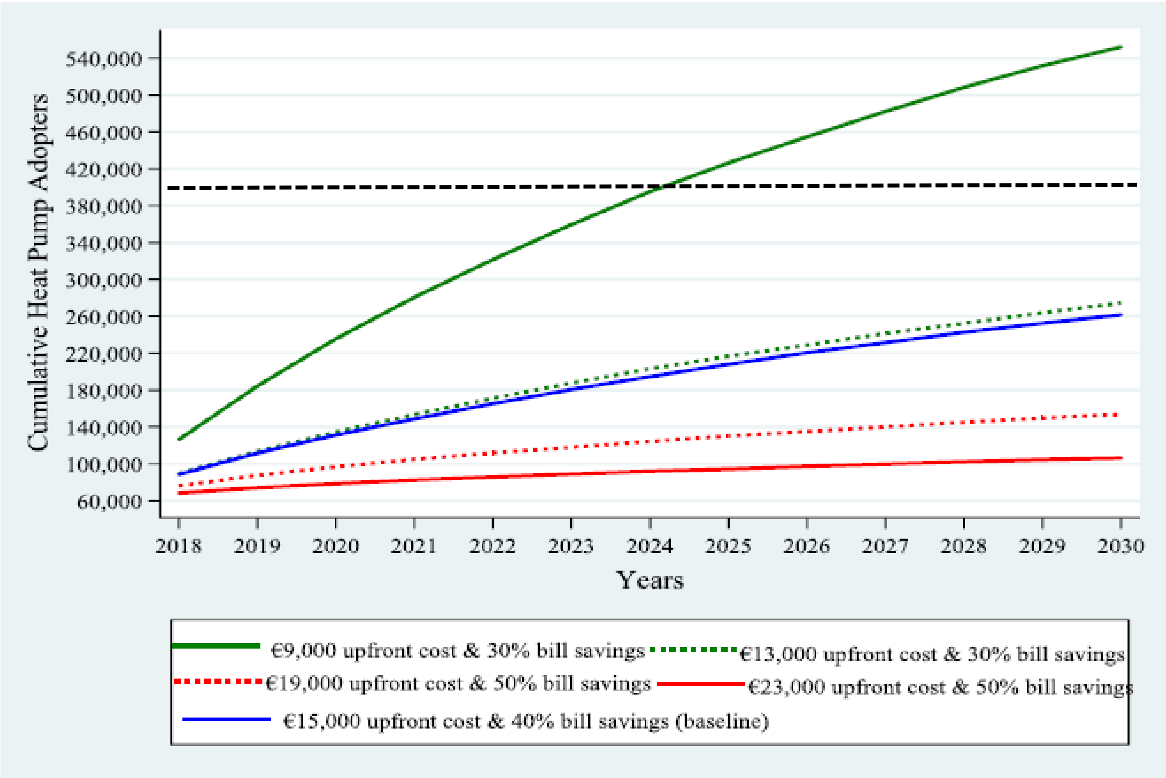

Figure 4: Uptake of heat pumps based on different combinations of upfront costs and bill savings. 400,000 heat pump adoption target shown by black dashed line. Source: Adapted from Meles and Ryan (2022)

Electric Vehicle Uptake

The Agent-Based Modelling framework was also applied to consider policy measures that incentivise rapid consumer uptake of electric vehicles (EVs) up to 2030 (EMPowER Report, 2022). In this model, agents represent households who could potentially purchase a Battery Electric Vehicle (BEV). Demand-side policy measures promoting EV adoption are investigated by allowing autonomous agents to exercise choices on a realistic passenger car fleet.

The inputs to the model include assumptions for taxes, incentives, fuel prices, battery pack prices and fleet growth. The fleet comprises a wide range of battery electric vehicle (BEV), plugin hybrid vehicle (PHEV) and internal combustion engine (ICEV) powertrains. This enables rich detail on the heterogeneity of both consumers and the passenger car market to be assimilated, expanding the range of policy measures that can be investigated. The microsimulation model was calibrated using data from the survey described above. The output of the microsimulation consists of monthly transactional data, from which summary information can be extracted to give fleet composition, emissions per vehicle etc. Simple scaling is used to generalise from the survey to the national fleet.

The microsimulations were used to demonstrate the role of complex policy interactions. For example, higher overall vehicle activity favours higher EV numbers. Measures to reduce activity, such as the target within CAP21 to reduce vehicle kilometres travelled, result in lower uptake of EVs due to the reduced benefits of ownership. This demonstrates the importance of modelling tools that allow interacting policies to be tested *ex ante* using a simulation approach.

A scenario for 2030 was identified which satisfied the targets for uptake of EVs (821,000 EVs adopted in households), 55% emissions reductions relative to 2018, a 10% reduction in vehicle kilometres travelled, while still allowing growth of the vehicle fleet in line with population growth projections. This scenario assumes the current vehicle taxation system is maintained until 2030, phase-out of grants, and high fuel prices of €2.30/l diesel in 2030. This scenario was then used to assess the expected demand for second-hand vehicles as well as the exchequer revenue associated with meeting EV adoption targets.

Second hand EV Market

Using the Agent-Based Model, a quantitative assessment of potential demand imbalances in the second-hand car market was carried out. Figure 5 shows the composition of the fleet in a scenario where tailpipe emissions are halved by 2030. The fleet composition is further divided into cars that were bought new or used. 821,000 EVs are present by 2030 with a slight majority of these bought second-hand.[iv] BEV uptake from new car buyers grows strongly in the first half of the decade as is currently being observed. Growth moderates somewhat after incentives are removed around mid-decade. This is compensated for by strong growth in second-hand BEV uptake in the latter half of the decade. The share of Internal Combustion Engine Vehicles (ICEVs) declines in line with BEV and PHEV uptake.

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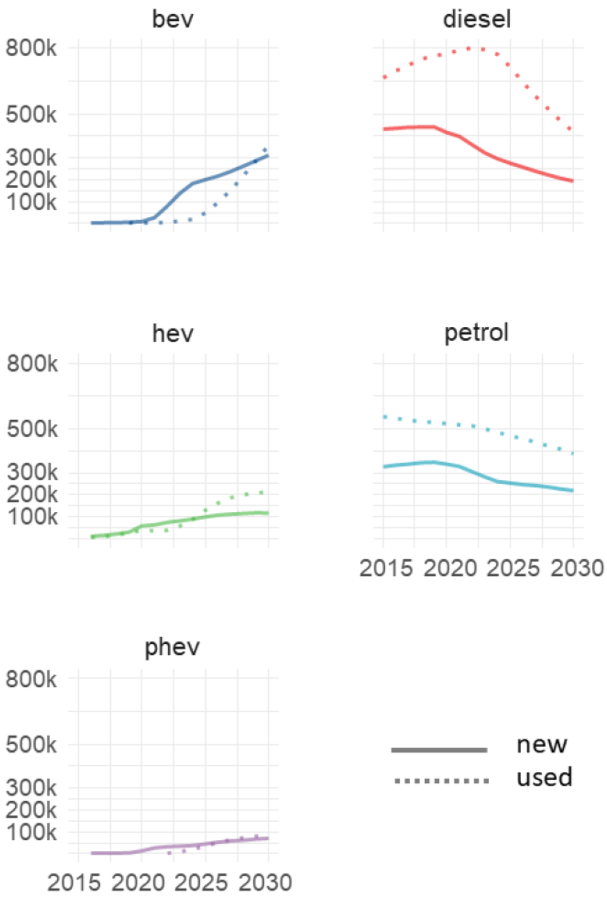

Figure 5: Passenger car fleet numbers by powertrain computed for 2015-2030. Solid and dashed lines indicate vehicles bought new and second-hand respectively. Source: EMPowER Report 2022.

Exchequer Implications

Attention has been drawn to the potential impact of road transport decarbonisation on public finances. Transactional data generated by the ABM are used to project future tax revenues from passenger cars. These data correspond to a -55% emissions reduction scenario. Cumulative private investment in passenger cars from 2021 to 2030 in this scenario is €100Bn, with EVs projected to account for 40% of this investment. Projected total tax revenue is shown in Table 2. These numbers include passenger car revenue only.

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

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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

Table 2: Simulated total exchequer revenue from passenger cars in M€ by source in the "mid" fleet growth scenario. Source: EMPowER Report 2022.

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

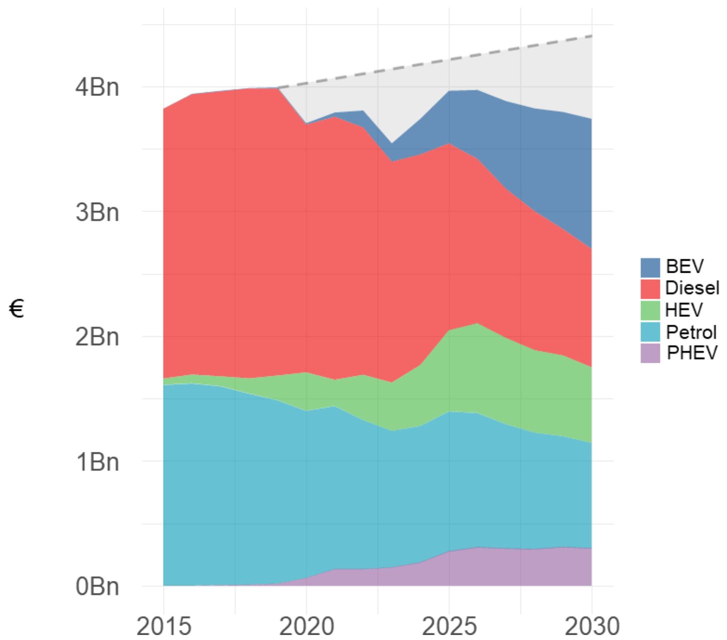

Figure 6: Projected total revenue from passenger cars by powertrain. The dotted line is "business as usual"' using a 2019 baseline. Source: EMPowER Report 2022.

Simulated total revenue by powertrain type is shown in Figure 6. BEVs account for 28% of total tax revenue in 2030. The grey area represents revenue lost using the 2019 baseline. The projected revenue can be compared to "business- as-usual" using a 2019 baseline. This gives a cumulative decarbonisation revenue loss during 2021-2030 of €4.1Bn (or €4.7Bn for 2020-

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2030). The cumulative incentive cost for the period 2021-2030 in Table 2 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.

The final cumulative cost of incentives will depend on the timing of incentive removal and the ability of the market to meet projected demand for BEVs. Using the 2019 baseline, cumulative emissions savings are 15.4 $MtCO_2$ and therefore the cumulative revenue loss of €4.7Bn suggests an abatement cost to the exchequer of €305/tCO_2. However, the CO_2 emissions calculations use type-approval gCO_2/km that underestimate real-world emissions by ≈14%, suggesting a lower true cost to the exchequer of ≈€270/tCO_2. This estimate ignores any additional expenditure required on public transport, charging infrastructure etc.

Distributional Impacts

The model was also used to look at the distributional impact of the policy measures designed to decarbonise the car fleet. Figure 7 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 tax burden on passenger cars, but with the steepest declines for middle and low-income groups. 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 7 also suggests that middle-income earners tend to benefit most from BEV incentives before they are phased out

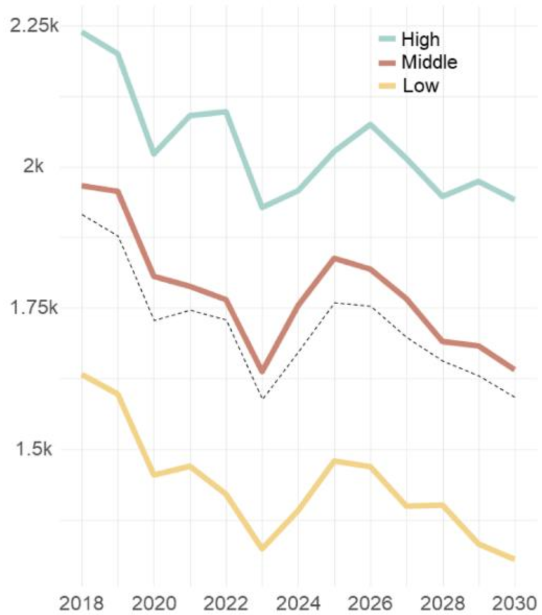

Figure 7: Simulated mean annual tax revenue per vehicle by income tercile. Source: EMPowER Report 2022.

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Policy Implications

The examples provided in this paper demonstrate the ability of the agent-based modelling approach to assess the effectiveness of different policy levers on technology uptake at a household level before the policies are introduced. The corresponding impact on emissions reductions targets and exchequer revenues can also be assessed (as demonstrated in the analysis of EV uptake).

Some of the key policy implications from this research include:

- Upfront capital costs of Renewable Energy Technologies are a barrier to adoption. Government grants are likely to be required until there is cost reduction in the technology and the timing of removal of grants will require careful consideration and monitoring of progress towards targets.
- In the case of heat pumps, there is a low level of awareness of the technology and the benefits it can bring in terms of bill savings. There is a need for reliable information and education of contractors/installers as well as a simplification of the installation process.
- There will be a need for a strong second-hand market for BEVs to support the growth in demand in the second half of the decade.
- There are implications for the Exchequer arising from the transition to decarbonised transport and heating. These implications need to be well understood.
- There is no evidence in the simulation output that the tax system designed to decarbonise passenger cars is regressive over the longer term.

Research is still ongoing into the development and application of these models in support of government policy development. Future research will focus on the adoption of Solar PV by households.

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[i] https://www.irishstatutebook.ie/eli/2021/act/32/section/15/enacted/en/html
[ii] https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/
[iii] Correct at the time of the analysis
[iv] 355k out of 669k BEVs on the road at the end of 2030 are bought second-hand.

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