Innovation Diffusion Theory – Identifying behavioural heterogeneity in the EV and V2G Markets

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Abstract

The electrification of road transport is crucial for the net-zero ambitions of decarbonising countries, by reducing energy demand through improved efficiency and the utilisation of low-carbon fuels. The UK government aims to accelerate this transition through its ban on new sales of conventional vehicles by 2030. However, this transition is inhibited by *inter alia* a lack of clear insights into consumer demand, which precludes effective public policies and disincentivises industry investments. Recognising the behavioural heterogeneity of vehicle purchasers, our work focuses on the application of the Innovation Diffusion Theory (IDT) on the vehicle market. IDT provides a bottom-up analysis to forecast the level of public readiness through the identification of swing consumer groups, enabling effective and targeted policies. With potential vehicle purchasers segmented into categories – based on their appetite for innovative technology – IDT also sheds light on the electric vehicle (EV) market landscape for auto- and policymakers. Additionally, the consumers likely to be left behind by the UK's top-down mandate – predominantly used-vehicle purchasers – are identified. Besides the 'who', the 'when' can also be determined with this methodology. Market sizes of customer groups are used to determine tipping points and phases in EV diffusion. These results could then identify windows of opportunity for vehicle-to-grid (V2G). By utilising plugged-in vehicle batteries to respond to the power grid, V2G enables the UK's twin goal of transport and power sector decarbonisation. However, typical non-V2G compatible EVs will likely inhibit V2G development, due to competing demand for consumers and technology lock-ins. To realise the benefits of V2G, IDT is used to identify industry pioneers for V2G development, enabling targeted collaboration for these projects. With the success of transport decarbonisation contingent on EV and V2G uptake, IDT can provide invaluable insights into consumer behaviours for policymakers and vehicle manufacturers.

Introduction

The UK has demonstrated its commitment to climate mitigation by legislating a 2050 net-zero target. Its government's subsequent Ten Point Plan highlighted the key areas of focus to achieve this goal, among them the shift to zero-emissions vehicles (HM Government, 2020), as the road transport sector is responsible for 23 % of the UK's greenhouse gas emissions or 113 $MtCO_2e$ in 2020 (National Grid, 2021). Despite subsidies being offered for low emissions vehicles since 2011, the market uptake has been poor, with only 0.71 % of these vehicles on UK roads in 2019 (Driver and Vehicle Licensing Agency, 2021). To achieve its net-zero ambition, the UK government has brought forward its sales ban on internal combustion engine vehicles (ICEVs) to 2030 and announced a new 2035 ban on plug-in hybrid electric vehicles (PHEVs) sales (HM Government, 2020). While vital for the UK's climate goal, these top-down mandates will require complementary policies to minimise shocks to the road transport sector. Additionally, there are at-risk groups whose access to mobility may be compromised by this transition. There is hence a need to identify the varying consumer profiles and behaviours within the vehicle-purchasing group to deliver targeted and effective incentives that fit consumers' needs while maintaining an equitable transition.

Another key area of the UK government's net-zero plan is the decarbonisation of the power sector through the large-scale deployment of offshore wind resources, up to 47 GW by 2030 (HM Government, 2020) and at a minimum, 87 GW by 2050 (National Grid, 2021). The increased share of variable and intermittent renewables in the power mix will necessitate the procurement of storage and flexibility assets to the grid (Lund *et al.*, 2015), which are crucial in maintaining stability and minimising constraints of the UK's power networks. This places a spotlight on vehicle-to-grid (V2G), an energy storage concept that utilises the batteries from EVs to provide these grid services, first conceptualised by Kempton & Letendre (1997). With battery electric vehicles (BEVs) emerging as the forerunner amongst low emissions mobility solutions, the UK is in a position to utilise V2G for its flexibility needs. With just 21 % of EVs participating in V2G, there is sufficient capacity from vehicle batteries to fully satisfy the predicted 2050 storage demands of the country (National Grid, 2021). Conversely, grid service provision offers dynamic revenue streams, which reduces the overall cost of EV ownership and accelerates the pace of the transportation transition. These forces place V2G as a unique enabler in the energy transition to promote decarbonisation in both the power and road transport sectors, while maximising resource efficiency. There are however many challenges facing V2G deployment, one of them being the additional investment needed to bring V2G to the market.

To provide insights into the consumers of the UK's EV and V2G markets, this paper utilised Innovation Diffusion Theory (IDT). IDT describes the rate of technology permeation, through profiling the consumer categories, their market sizes and respective attitudes towards novel products. Using IDT, challenges for EV and V2G uptake in the UK are highlighted and consumer-targeted policies are recommended based on the customer profiles of the UK's vehicle market. Additionally, vehicle brands primed to develop V2G are identified based on their customer base, of whom partnerships are vital to deploying V2G in the UK.

Applying Innovation Diffusion Theory

IDT was first proposed by Everett Rogers in 1962, which grouped adopters of new technologies into five categories (Rogers, 1962). The theory posited that consumers in each category approach innovations based on varying rationales, respond differently to incentives and act as influencers for the next category (Rogers, 1962). While there are numerous studies on EV diffusion, many are focused on macroscopic factors like policy (Zimm, 2021) or technology-centric such as EV battery costs and performance (Gnann *et al.*, 2018). IDT allows a bottom-up perspective and studies how the heterogeneous vehicle market could drive effective policies, rather than policy's impact on EV markets. Other studies such as Collett *et al.* (2021) utilise S-curve fitting to model EV trends, which while compatible with IDT predictions, do not delve into the underlying forces of EV uptake. With IDT, the potential incentives behind EV adoption are identified, offering useful insights for policy- and automakers alike. IDT assumes a bell-shaped curve for technology uptake, and the market size of each category are defined based on their generalised consumer profiles and approaches to innovation. Applying IDT to the vehicle market, consumers can be grouped into the five IDT categories listed in Table 1.

According to IDT, innovation permeates into the mass market through social proofing, becoming mainstream when the technology is proven by early users. In the context of the passenger car market, we therefore assume the share of EVs in the annual vehicle sales to be dependent on the concurrent percentage of EVs on the road. EV ownership can be used as a proxy for the overall trust in EV technology and signals the consumer categories ready to transition to electric. For instance, up to 2.5 % of the annual new vehicle registration will be electric when EV technology is new, as only 'Innovators' are ready to test the technology. Once 2.5 % of vehicles on roads are EVs, up to 16 % of annual vehicle sales would be electric, as early adopters join the 'Innovators' and switch to EVs. This interpretation of IDT for annual vehicle sales is shown in Table 2. It is noted that in reality, new EV registrations are likely to be lower due to factors exogenous to "consumer interest", like the intention-action gap. This method hence needs to be calibrated with empirical data of the ratio between EV sales share and EV ownership. Furthermore, the diffusion of EVs – unlike other innovations like smartphones – will likely be strongly affected by the larger road transport ecosystem as well, such as charging infrastructure and cost of fuel.

Based on Table 2's application of IDT, the incumbency of the ICEV regime becomes an issue for EV uptake. Without external intervention, the initial high ownership and continued sales of ICEV inhibit the growth of EV market share by diluting the penetration of EVs ownership, hence delaying the entry of the subsequent IDT consumer categories, highlighting the importance of the UK's 2030 ICEV sales ban. However, targeted policies are required to complement the gaps of this top-down mandate to guarantee a smooth and equitable transition. The next section demonstrates an IDT use case, by using consumer sensitivities to different incentives to derive EV policy themes and timelines.

VEHICLE CONSUMER SEGMENTS

The 2020 Deloitte Insights report, "Electric vehicles: Setting a course for 2030" segmented the UK's EV market for stakeholders in the automotive industry to identify their consumers and market their EVs effectively (Woodward *et al.*, 2020). It is based on data collected from 1,496 participants in November 2019 who were looking to purchase a vehicle within the next three years. Nine segments were identified based on "meaningful characteristics, behaviours and needs…" (Woodward *et al.*, 2020). These segments are then fitted into buckets based on the participants' age, monthly vehicle expenditure, vehicle ownership, travel distance and patterns. The market size and likelihood of EV purchase for individual segments were provided in the report, and shown in Figure 1. The percentages represent a segment's market size and their likelihood of purchasing an EV, respectively. Columns in Figure 1 show the consumer profile, such as vehicle ownership status, age and current spend on their vehicles. Rows represent the travel patterns, where commute indicates journeys between two locations while travel means journeys with multiple locations. For example, segment *A*'s defining characteristic is their lack of vehicle, while segment *B* is largely defined by their vehicle usage for a short distance work commute.

Table 1. IDT categories, typical market sizes and brief profiles. (Adapted from: Rogers, 2003).

Category	Market Size (%)	Consumer Profile
Innovators	2.5	They are the earliest adopters and are motivated by the scarcity of technology. 'Innovators' seek to set themselves apart and are typically insensitive to price signals due to their high financial liquidity. This group are willing to take risks with unproven technology to achieve higher social status.
Early Adopters	13.5	Also termed "lighthouse customers", this group forms the subsequent adopters. They seek to convert timely technology uptake into advantages, and hence typically form a synergistic bond with the seller, by providing feedback and guiding the maturing process of a product to their needs. As such, the penetration into this customer segment is highly important for the development and maturing of an innovation.
Early Majority	34	Forming a large section of the market, these customers are guided by a different dogma from the earlier groups, focusing instead on more pragmatic concerns such as the cost and utility of a product. Hence, the policy and marketing focus must shift dramatically to entice these consumers. The successful conversion of this group marks the achievement of critical mass for the diffusion of the technology.
Late Majority	34	Along with the 'Early Majority', these conservatives make up the largest group of the technology market. The 'Late Majority' is driven by social proofing of technology by the preceding segments, which typically takes time. However, the need for rapid decarbonisation necessitates firmer policies to guide this category.
Laggards	16	This final group represents the group of sceptics actively against the transition. This could be caused by *inter alia* a general aversion to changes or behavioural lock-ins to ICEVs. Due to the low financial liquidity of the group, equitable policies will be important for this category.

Table 2. Application of Innovation Diffusion Theory (IDT) to EV sales. EV number on the road signals interest by consumer categories, which then determines sales shares.

EVs on Roads (%)	Categories Purchasing EVs	EV Sales Share
0 to 2.5	Innovators	Up to 2.5%
2.5 to 16	Innovators and Early Adopters	Up to 16%
16 to 50	Innovators, Early Adopters and Early Majority	Up to 50%
50 to 84	All categories sans Laggards	Up to 84%
84 to 100	All categories	Up to 100%

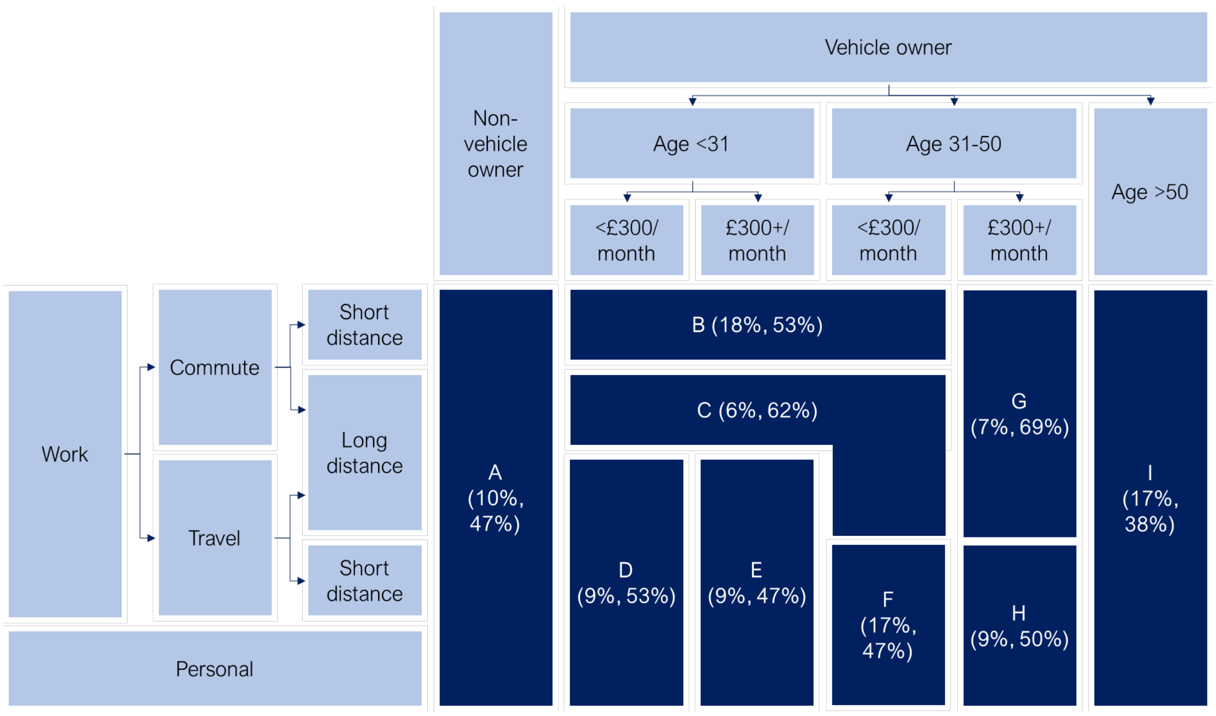

Figure 1. Vehicle buyers segmented based on consumer profile and vehicle use patterns, with each segment's market size and likelihood to purchase EVs shown as percentages respectively. (Adapted from: Woodward et al., 2020).

Figure 1 provides useful customer profile information for policymakers and market players. However, it does not inform when a policy or a marketing strategy targeting a particular segment would be most effective. This can be achieved by applying IDT to the results in Figure 1. First, we assume that the likelihood of EV purchase in each segment indicates an appetite for new technology, and hence reflect EV adoption behaviour across the segment. This is because we treat EVs as a substitute technology in the vehicle market, competing against ICEVs for customers. As a new entrant to the private transportation regime, EVs are considered as the "innovation" to be adopted, otherwise, consumers will preserve the status quo of ICEV purchase. To match the IDT adopter categories with Deloitte segments, these segments are ordered in decreasing EV interest. Once the order is determined, the segments are paired to IDT categories based on their cumulative sizes and the closest possible predefined IDT threshold. For example, segment *G* with the highest EV purchase likelihood falls under the 'Innovator' category, followed by segment *C* as the 'Early Adopters'. The subsequent segments then match to the 'Early Majority' category, as segments *G* and *C* have a cumulative market of 13 %, and the next IDT threshold being 16 %. The paired results are shown in Table 3. In this case, segments with identical EV purchase likelihood fell under the same IDT category, hence no additional process was required to further refine their order. The large number of 'Innovators' consumers may be the result of existing EV policies in the UK such as the plug-in car grant and home charging schemes, shifting consumers from the 'Early Adopter' to 'Innovator' group.

Table 3 shows the nine Deloitte consumer segments in the order of likeliest to purchase EVs to the least likely (Woodward *et al.*, 2020). The following section offers a brief explanation for the results, referencing consumer profile insights drawn from Woodward *et al.* (2020). Segment *G* emerges as the forerunner for EV adoption, which aligns with their stable financial status which minimises the impact of higher EV cost, and increases the likelihood of possessing private parking. Meanwhile, segment *C* customers are driven by the cost savings from EV usage as they typically travel long distances. Segments *B*, *D* and *H* fall under the 'Early Majority'. While these segments are generally environmentally conscious, they are pragmatic and weigh their purchase choice on concerns such as EV range, driving needs and vehicle prices, consistent with the IDT characteristics of the 'Early Majority' group. The 'Late Majority' consists of segments *A*, *E* and *F*. This is likely due to consumers in segment *A* preferring to purchase EVs from start-ups or brands not currently in the automotive market. On the other hand, while segment *E* is willing to pay more for EVs, their interest in EVs is lacklustre, likely due to their high brand loyalty. Their demand will hence be driven by EV model offerings from ICEV brands. Segments *F* and *I* have the least interest in EVs and are the unlikeliest groups to spend more on them, but due to different rationales. Segment *F* is likely constrained by socioeconomic factors, while segment *I* is resistant to change.

EV POLICY RECOMMENDATIONS

Based on the above profiles, as well as behavioural drivers derived from the IDT, general policy themes are constructed to target the segments. For segments using vehicles for long-distance travel for work, cost-saving from EVs may be inhibited by high upfront costs. Hence, policies targeting workplaces, such as purchase subsidies, charger installation and tax exemptions may encourage EV diffusion to these consumers. Segments willing to pay higher for vehicles are likelier to be in higher-income groups with off-street parking, hence more responsive towards home charging schemes, while the other segments will respond better to street charger installations as well financial incentives. As for IDT categories, 'Innovators' will likely respond to EV privileges such as access to bus lanes and restricted zones, which was implemented in Norway with positive results (Figenbaum, 2017). Meanwhile, financial incentives like direct purchase subsidies and tax incentives will spur uptake for 'Early Adopters' but are expected to have a larger efficacy on categories in later stages of change such as the 'Early Majority' and 'Late Majority' (Langbroek *et al.*, 2016). The 'Early Majority' and 'Late Majority' categories will also benefit from favourable policies for the used-vehicle market. The 'Laggards' will require stronger mandates such as the ICEV sales and tailpipe emissions ban. These policies are shown in Table 4, which lists the consumer segments along with their paired IDT category, in the order of EV adoption. It is hence advisable for the UK government to implement category-specific policies in this sequence. This will raise the level of EV ownership organically before the sales ban in 2030, to realise road decarbonisation through a path of least resistance and minimal cost.

Table 3. Consumer segments ordered by decreasing EV interest, matched to IDT categories based on market sizes. (Adapted from: Rogers, 2003; Woodward et al., 2020).

Consumer Segment	EV Purchase Likelihood (%)	Segment Size (%)	IDT Category and Size
G	69	7	Innovator (2.5%)
C	62	6	Early Adopter (13.5%)
B	53	18	Early Majority (34%)
D	53	9	
H	50	9 (Sum: 36)	
A	47	10	Late Majority (34%)
E	47	9	
F	47	17 (Sum: 36)	
I	38	17	Laggards (16%)

Table 4. Policy recommendations for consumer segments and categories, listed according to the order of EV adoption.

Consumer Segment	IDT Category	Policies	
		Segment-Specific	Category-Specific
G	Innovator	Company plug-in car grant Workplace charger installation grant Home charging scheme	Road access
C	Early Adopter	Company plug-in car grant Workplace charger installation grant Street charger installation Purchase subsidy	Financial incentives
B	Early Majority	Street charger installation Purchase subsidy	Financial incentives Used market regulation
D		Company plug-in car grant Workplace charger installation grant Street charger installation Purchase subsidy	
H		Home charging scheme	
A	Late Majority	Company plug-in car grant Workplace charger installation grant	Financial incentives Used market regulation
E		Company plug-in car grant Workplace charger installation grant Home charging scheme	
F		Street charger installation Purchase subsidy	
I	Laggards	Company plug-in car grant Workplace charger installation grant	ICEV sales and tailpipe emissions ban

After this policy grouping, a timeline was developed for the rapid decarbonisation scenario published by the UK's National Grid's Future Energy Scenarios (FES) 2021 (National Grid, 2021). Using the yearly EV ownership numbers from FES 2021, phases of the transition are defined by the most advanced IDT consumer category buying EVs in a specific year, shown in Figure 2. For example, in this scenario, the 'Early Majority' phase lasts from 2028 to 2033 and comprises purchasers from the 'Innovator', 'Early Adopter' and 'Early Majority' groups. To reach this target level of ownership, policies focusing on 'Innovators' and 'Early Adopters' are needed from 2020 and 2026 respectively; while 'Early Majority-'targeted schemes are required from 2028 to sustain EV growth within the scenario. This provides crucial information for policy planning, for example, estimating the level of spending needed for a home charging scheme. The policy themes from Table 4 are broadly fitted into Figure 2, matching their target audiences. This method of applying IDT to EV diffusion goals allows policymakers to implement appropriate policies with precise timelines to maximise their efficacies and cost-effectiveness.

The V2G Market

V2G is a storage and flexibility service that utilises EV batteries to provide ancillary grid services such as frequency and voltage control, as well as to participate in the balancing market and energy arbitrage. The concept is theoretically attractive, capitalising on EV batteries when not in use – 95 % of the time (Morris, 2016) – to defer and replace network development, thereby maximising resource and cost-efficiency. There have been examples of successful V2G research projects, such as the Parker Project in Denmark and Project Sciurus in the UK. However, practical concerns such as battery degradation costs, lack of supporting infrastructure and V2G-capable vehicle models, as well as unfavourable markets, have prevented commercial-scale V2G in the UK thus far. Nonetheless, these factors are predicted to change with falling battery costs (Curry, 2017) and increasing demand for storage and flexibility assets to complement the energy transition to intermittent renewable generation (National Grid, 2021). The transportation sector transition provides an opportunity for V2G development, with vehicle original equipment manufacturers (OEMs) pivoting to electrified models and the mass installation of charging infrastructure. This window of opportunity is narrow, however, as the road transport regime, once settled into a non-V2G configuration, will self-reinforce and lock out the UK's V2G pathway. According to the FES 2021's rapid decarbonisation scenario, achieving net-zero in the UK by 2050 necessitates 230 GW of flexibility assets, with 39.1 GW of V2G capacity (National Grid, 2021). Assuming a capacity of 7 kW per connected vehicle, this represents 5.6 million participants or only 21 % of all EVs, over which V2G may experience market cannibalisation (where V2G supply outstrips demand resulting in reduced overall revenue). This highlights the need for a precise and orderly deployment for V2G in the UK. To this end, we analysed the potential for V2G in the UK, by repeating our above methodology on the V2G market.

V2G CONSUMER PROFILE

Deloitte's consumer segmentation is applied to identify potential V2G adopters based on income and vehicle usage patterns. It is assumed they are rational and will engage with the technology based on their suitability and needs. First, as an optional technology with higher upfront price, consumers who spend more on vehicles are likely to have higher V2G interest (Sovacool *et al.*, 2019). Next, driving distance is assumed to correlate negatively to V2G uptake, since an EV battery's state of health is vital for long-range travel, likely dissuading its owners from V2G participation (Geske & Schumann, 2018). Long-distance travel also places a tighter constraint on the battery state of charge requirement, limiting the flexibility of an EV to provide V2G services (Geske & Schumann, 2018). Finally, V2G is assumed to be more appealing to participants with regular vehicle usage patterns, as it increases the confidence of drivers in the charging availability along their route (Sovacool *et al.*, 2018). Segments that fulfil these income or vehicle usage characterisation are defined as the potential V2G market. As some Deloitte segments span both positive and negative V2G characteristics in Figure 1's grid, it is assumed that each grid unit has an equal market size due to the lack of more granular data. The result (Figure 3) shows the Deloitte segments that are suitable for V2G uptake – denoted with subscript "V2G" – along with their potential V2G market size. For instance, customers from segment A_{V2G} make up 1.88 % of the total vehicle purchasing cohort.

For our analysis, we assumed that consumers maintain the same appetite for innovation, such that high interest in EVs indicates an elevated likelihood of V2G adoption. While segments B_{V2G} and I_{V2G} have the largest group suitable to engage with V2G, segment G_{V2G} as the 'Innovators' are needed to social proof V2G technology before subsequent groups opt-in. Initial V2G policies could target segments G_{V2G} and B_{V2G} simultaneously through workplace V2G charger installation, as they use their vehicles for short-distance commutes to work. Similar to EVs, increasing company procurement of V2G-capable cars helps with providing experience while minimising risks to the driver. These workplace schemes may also accelerate technology diffusion to segments A_{V2G} and I_{V2G}, which also rely on vehicles to commute to work. Additionally, fleet purchases may also serve to offset the increased V2G price for installation and vehicles through scale economics, while acting as stable service off-takers for V2G aggregators. Bi-directional electric school buses, for instance, are used in many V2G projects such as the

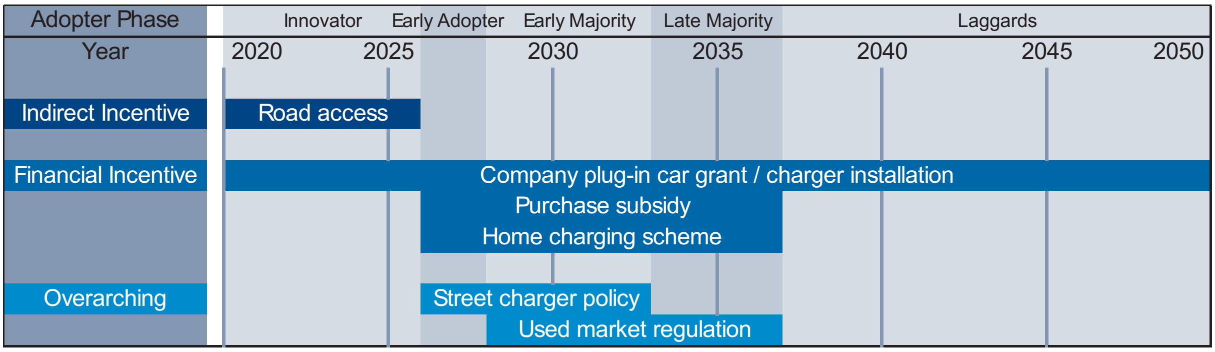

Figure 2. Adopter phases and policy timelines based on IDT categories (2020-2050). Initial policies focus on advantages afforded by scarcity of EVs and are replaced by strategic policy targeting mass market concerns such as charger availability and the used market.

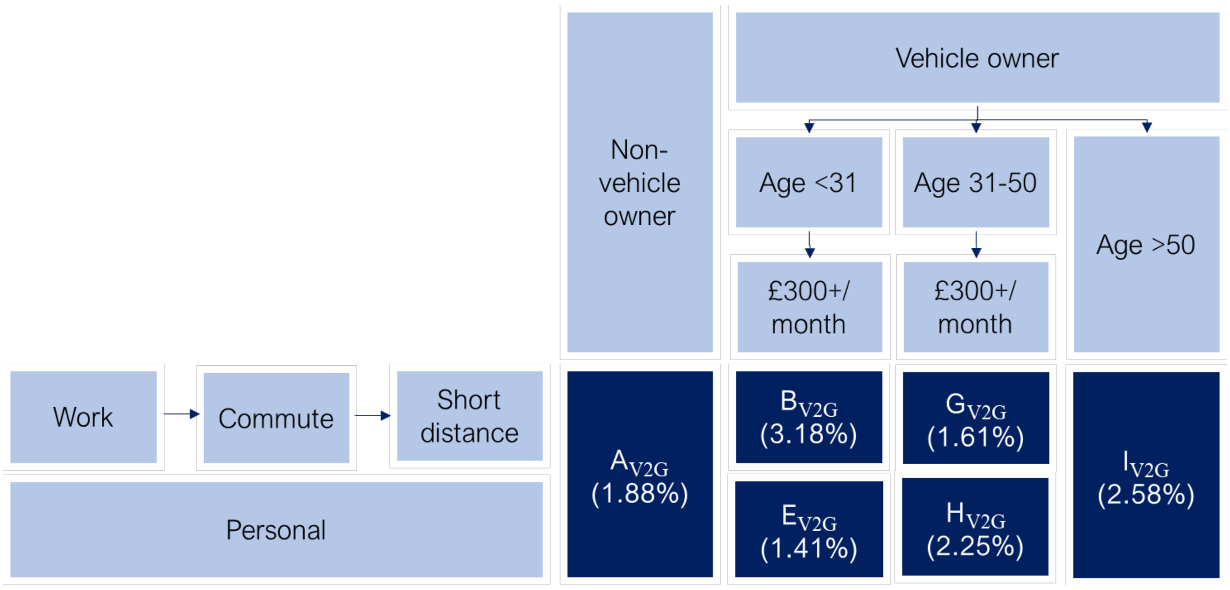

Figure 3. V2G-suitable consumer segments with market sizes, labelled as a percentage of the entire cohort of annual vehicle purchasers.

BlueBird School Bus V2G and the Clinton Global Initiative School Bus Demo in the US.

As stated above, early V2G deployment is important to avoid being locked out. As such, EV policies could be expanded to promote V2G along with EVs. In the UK for instance, the Workplace Charging Scheme – offering a 75 % reduction of charge point purchase and installation costs (Office for Zero Emission Vehicles, 2020) – could be extended to support V2G-capable charger installations. The UK government also charges 0 % benefit-in-kind tax for company EVs, with minor increments planned over the coming years (Office for Low Emission Vehicles, 2018). This tax can be maintained at 0 % for V2G to differentiate the technology from EVs to further promote V2G. By leveraging on using existing government machinery for EV promotion, V2G-specific policies could be implemented while minimising cost. Apart from policies, Figure 3 findings can be used to support commercial guidance to OEMs interested in developing V2G technology.

VEHICLE MANUFACTURERS

While Kester *et al.* (2018) viewed V2G proliferation as simply a matter of time, close competing technologies, specific requirements to market, and close collaboration between multiple sectors and stakeholders may require an organised and guided V2G development. For example, the lack of interoperable V2G standards may constrain revenues for vehicle owners, discouraging V2G participation and hampering its growth. It is hence vital to encourage cross-enterprise collaboration amongst OEMs, such as the Parker Project which brought together Mitsubishi, Nissan and PSA Groupe (Parker Project, 2021). However, the historical lack of a commercially successful large-scale V2G project may have contributed to the lack of V2G commitment from OEMs. There is therefore a need to identify OEM pioneers to lead the way and demonstrate the viability of the technology. In this context, IDT could be used to categorise vehicle OEMs, which describes their risk appetite for innovation investment. In 2021, the Centre of Automotive Management in Germany published an innovation ranking of EV manufacturers and categorised them based on nearly 300 parameters (Centre of Automotive Management, 2021). This ranking is shown in Table 5, with brands without UK brand presence omitted.

While this ranking is not specific to V2G, it is nonetheless useful as it can be used to infer the attitude towards innovation for each vehicle brand's respective customer base. We hypothsised that a brand's IDT category is the result of its customers' demand for innovation, and hence mirrors the consumers' IDT category. For instance, Tesla's ranking may be due to a high number of 'Innovators' and 'Early Adopters' within its buyers, which calls for continuous innovation from the company to sustain their interest. This pressure, therefore, implies that a V2G breakthrough may be contingent on customer demand, rather than from the private sector or government. It is noted that Nissan, a V2G pioneer, is categorised in the 'Laggards' group. Following the argument that Nissan's ranking reflects on its customers, this may also explain the lack of V2G uptake from Nissan Leaf consumers, due to their more conservative approach towards technology. The ideal partnerships to develop V2G are therefore with the top-ranking OEMs in Table 5 that have a significant local customer base, in order to justify investment into the technology. The following analysis below used the UK as the focus region. Figure 4 shows UK vehicle brands with annual EV sales above 4,000 from 2018 to 2020, based on sales data published by the UK's Driver and Vehicle Licensing Agency, (2021).

Cross-referencing Table 5 and Figure 4 identifies Tesla, Volkswagen and Hyundai-Kia as the ideal partners for V2G projects. It is hence vital for the UK government to engage these OEMs to develop V2G technology, especially VW which owns Scania, one of the largest brands for commercial fleet products. Partnerships between OEMs should also be encouraged to minimise their risk exposure and promote interoperable charging standards. While Tesla is known to not favour the V2G concept – presumably due to battery warranty concerns (Walton, 2020) – the other two OEMs are more open to vehicles as mobile storage solutions. VW announced in March 2021 that all their EV offerings – including sister brands such as Audi and Skoda – will be V2G-capable from 2022 (McKerracher, 2021), while Hyundai-Kia has migrated to a new chassis that supports bidirectional charging including V2G and vehicle-to-building functionalities in their newest models (Hyundai, 2021). These observations strengthen our earlier hypothesis – that a brand's innovation is dependent on its buyers, and hence will direct investment into research to satisfy their consumer base. It is therefore also important to sow V2G interest in consumers from the top OEM innovators, as these trendsetting consumers are likelier to demand V2G capability from their vehicle manufacturer. V2G participation from the innovators will further aid V2G diffusion via social proofing of the technology. Once subsequent consumer categories are interested in V2G, their respective vehicle OEMs would then be incentivised to invest in V2G-capable vehicles.

Table 5. Centre of Automotive Management's innovation ranking for vehicle OEMs with UK brand presence. (Adapted from: Centre of Automotive Management, 2021).

Rank	Company	Category
1	Tesla	Top Innovator
2	Volkswagen Group	Fast Follower
4	Hyundai Group	Fast Follower
5	Renault	Follower
7	Geely	Follower
11	Daimler	Follower
13	BMW	Follower
16	Nissan	Laggard
17	Ford	Laggard

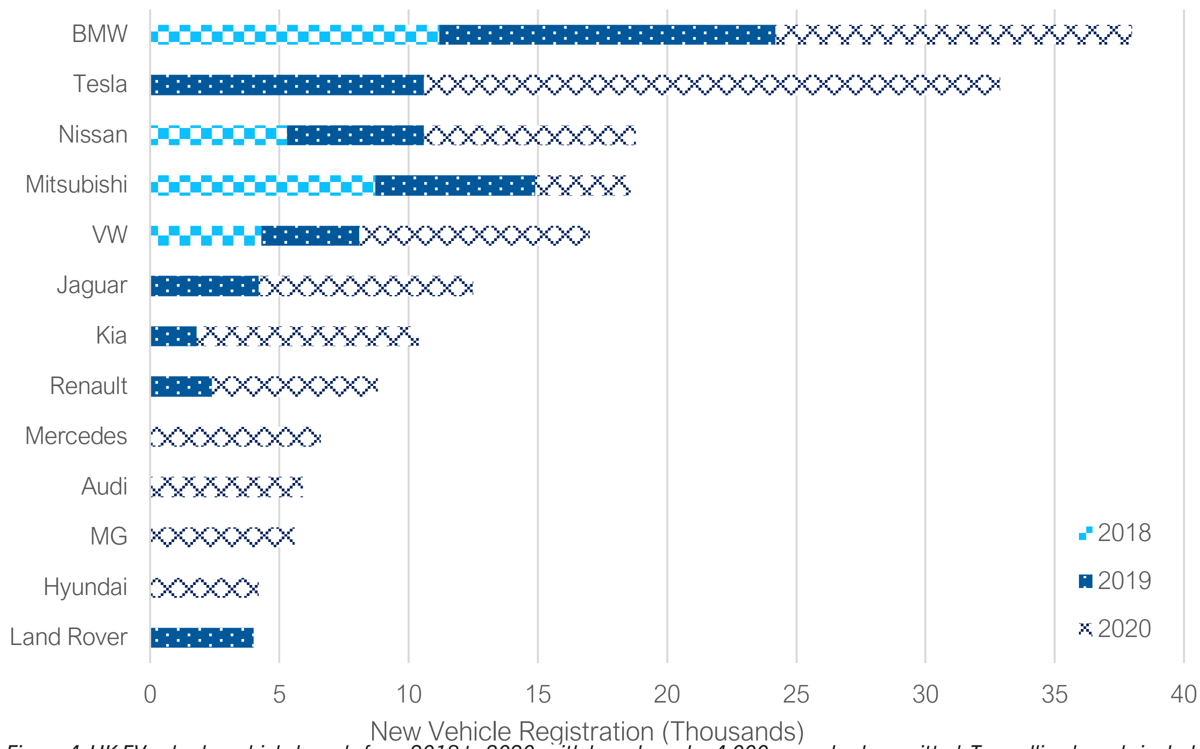

Figure 4. UK EV sales by vehicle brands from 2018 to 2020, with brands under 4,000 annual sales omitted. Top-selling brands include BMW, Tesla, Nissan, Mitsubishi and Volkswagen. (Adapted from: Driver and Vehicle Licensing Agency, 2021).

Conclusion

The transition of the road transport sector can be seen as a cornerstone for net-zero aspiring countries. However, there are challenges to ensure a rapid, cost-effective and equitable transition. Consequently, there is significant research interest in both academia and the industry exploring the vehicle market. However, many studies focus on the macroscopic narrative such as policy impacts (Zimm, 2021), or top-down modelling methods such as S-curve fitting (Collett *et al.*, 2021) to forecast EV uptake. A consumer-centric study could identify the heterogenous drivers behind vehicle purchase and afford policymakers key insights to the incentives required to encourage consumers to switch to EVs. This paper applied IDT to the vehicle market, showing a bottom-up perspective on the profiles and motivations of different consumer categories. A further analysis for the UK is performed, by pairing IDT categories with Deloitte's consumer segments for vehicle purchasers in the UK, revealing more in-depth buyer characteristics based on demography and vehicle usage pattern. Using the results of the analysis, consumer-targeted policies are suggested to assist the EV transition. By using EV penetration numbers from the FES 2021's rapid decarbonisation scenario, a general policy timeline is defined. This exercise affords a view of policy implementations needed to materialise the UK's rapid decarbonisation scenario. For V2G, we again used Deloitte's consumer profiles to determine consumer segments likely to adopt V2G and their respective market size. We conclude that concurrent EV policies could be extended to include V2G, as both markets target the same consumer categories. As vehicle manufacturers' participation is vital in bringing V2G technology to market, IDT is also applied to OEMs, recognising that each OEM and their respective consumers may have distinct appetites for innovation. By cross-referencing the top innovators against their UK EV sales, the OEMs suitable for V2G collaboration in the UK are shown to be Volkwagen and Hyundai-Kia. This paper demonstrated our method of integrating IDT with results from other studies, allowing it to be a versatile tool for many stakeholders. For OEMs, IDT can shed light on the consumer market, allowing investments based on their respective customer's EV appetite, as well as time the market entrance of their EV offerings based on phases of the vehicle transition. For policymakers, by integrating IDT to specific decarbonisation scenarios, our method provides a key link between ambitious climate targets and effective, actionable policies. Finally, as this study is focused on the UK, further studies could be conducted to apply IDT to other regional EV markets, as well as exploring individual IDT categories in more detail.

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