Electric vehicles policy impact quantification tool

Technical documentation

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1 Model description

The "EV policy impact assessment tool" estimates the future share of Electric Vehicles (EV) in the Light Duty Vehicle (LDV) fleet in a given country based on an assessment on the status of policy implementation. The assessment tool is comprised of two components: policy package rating and its translation into future projections.

The policy impact quantification assumes that the market penetration of EVs – measured as share of newly registered vehicles – will roughly follow a logistic growth/ diffusion scenario ("S-curve") in the coming decades. An "S-curve" approach was chosen as it reflects a pattern of growth previously observed in the car industry, in particular for diesel vehicles (Cames and Helmers, 2013; Roedenbeck and Strobel, 2014; ACEA, 2015) and for the diffusion of other new technologies in the car industry (i.e. automatic transmission, power steering, air conditioning, disk brakes, etc) (Jutila and Jutila, 1986 as cited in Gruebler, 1990). This market penetration growth pattern is not particular to the car industry, it describes diffusion of different new technologies and has been the focus of multiple technology innovation studies and studies on technological forecasting (Rogers, 1971; Gruebler, 1990; Packey, 1993; Kucharavy and De Guio, 2011).

1.1 Mathematical framework

A typical symmetric S-curve describing market share penetration over time can be represented with the following equation:

$$S(t) = A\left[exp^{\left(-\frac{x(t)-\mu}{\beta}\right)} + 1\right]^{-1} - \left[exp^{\left(\frac{\mu}{\beta}\right)} + 1\right]^{-1} + K$$

Where A is the curve's "saturation level" given by the maximum market share, K is the market share of EVs in new vehicles on the first year of market introduction (t_0) or $S(t_0) = K$, t is given in years, and parameters μ and β define the curve's symmetry when $A = 1$. These parameters are equal to $\mu = 1/2$ and $\beta = \frac{\mu-1}{\ln\,(S_c^{-1}-1)}$, where S_c is the market share at saturation or $S_c = 1 - K$.

1.2 EV policy impact using an S-curve approach

The estimation of the policy impact for each country is done in two steps. First, we define a "good practice" logistic growth curve as an upper boundary for each country. It represents an extrapolation of the fastest currently observed expanding market for EVs. For this, Norway's EV growth is applied to a country's historical market share. Second, we define a "no policy" curve representing the lower boundary of future growth in a country. This curve assumes that the global policy support observed today will be continued but not enhanced further. Under the no policy scenario, the EV market expansion takes longer to reach saturation and the saturation level is lower than the "good practice" curve. Each of these curves are adapted to the historical market share of a country, making them country specific. These curves are defined as follows:

- The ***"good practice" curve*** is based on the currently observed growth of the Norwegian EV market, which went from 0.7% to 54.3% of the incremental market share within 10 years (IEA, 2021b). We first construct a curve based on historical growth of EV market share in Norway between 2010 and 2020. Based on Norway's historical growth, we estimated a saturation period for the "good practice" s-curve of 19 years. For each country, the curve is adapted to fit its historical EV market share. As a consequence, we can reflect the difference in EV development in different countries.

- The ***"no policy" curve*** is based on the global electric vehicle market development projections from recent studies (Sussams and Leaton, 2017; BNEF, 2018). These studies both project that the share of EVs in new car sales will exceed 55% by 2040 under currently existing policies or under NDCs combined with recent battery cost developments. Based on these findings, we assume that without any support policies the EV share in LDV sales in a country will gradually increase over time but remain below 50% by 2050 – this means that the conventional internal combustion engine (ICE) vehicles would still maintain a large market share in the long-term future. Based on this assumption, we have estimated a saturation period of 39 years for the "no policy" curve (starting at year with earliest historical data, no later than 2012). It should be noted that the no policy trajectory defined here could differ significantly across countries.

We assume that the development of the EV market in any country would fall somewhere in between these two extremes. This is indicated in Figure 1.

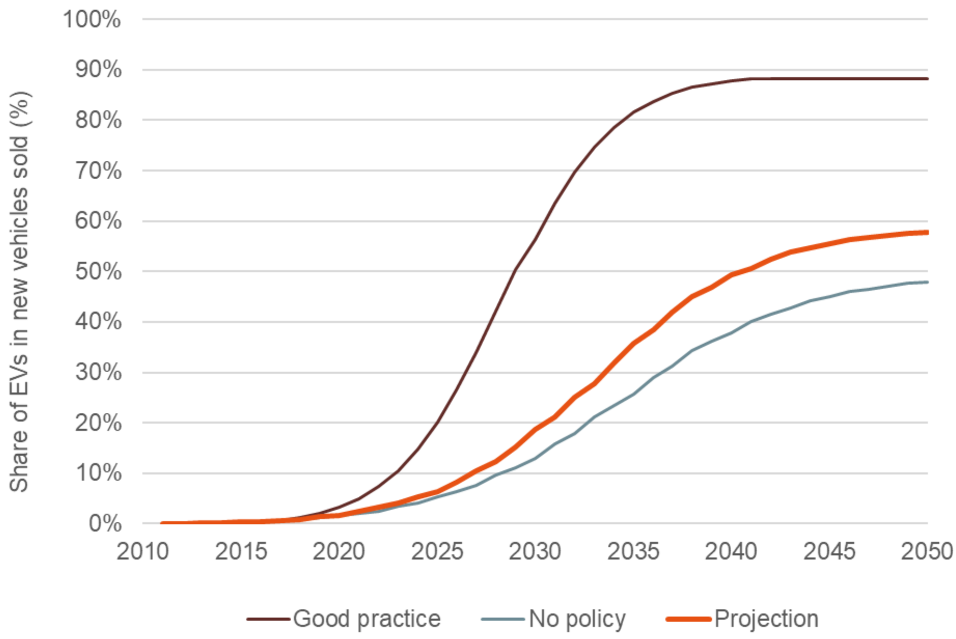

Figure 1: The assumed development of the incremental EV market in any given country lies in between the "good practice" and "no policy" logistic growth curves in our study. The "projection" curve in this case does not represent an actual country but is only shown for illustrative purposes.

A country with as ambitious policies as Norway would see a development very close to the good practice curve, whereas a country with no policies in place to stimulate EV penetration would see its market develop close to the no policy curve.

1.3 Rating currently implemented policies and translating it to future projections

The policy tool allows to model the impact of policies and drivers in different countries by shifting the logistic growth curve between the "no policy" and "good practice" options using an *incentive factor*, which is defined as a number between 0% and 100%. For an incentive factor of 0% the country-specific curve is equal to the "no policy" case, whereas for an incentive factor of 100% the curve is equal to the "good practice" case. This scaling thus happens in a linear manner.

Drivers of EV market penetration

We have identified five drivers that are theorised to be important drivers behind EV uptake (Sierzchula *et al.*, 2014; Nijland *et al.*, 2016; Yong and Park, 2017) in a given country. These are:

1. **Charging infrastructure density** – represented as number of publicly available chargers per million capita;
2. **Purchase subsidies**;
3. **(Number of other financial incentives** – Registration Tax Benefits, Ownership Tax Benefits, Company Tax Benefits, VAT Benefits and Other Financial Benefits – as per the categorisation of the European Commission (2012);
4. **Personal wealth** – represented by GDP per capita;
5. **Presence of behavioural incentives** – which include free parking benefits, toll benefits, access to bus lanes with EVs (IEA, 2016). Behavioural incentives also include exemptions to driving restrictions in cities such as Germany's "Diesel ban" in some cities (Bundesverwaltungsgericht, 2018), or the "Hoy No Circula" (day without a car) program in Mexico (Secretaria de Medio Ambiente y Recursos Naturales, 2016).

The incentive factor is a number that represents an aggregate quantification of these five drivers.

The drivers are quantified in a specific metric M, and compared to a lower bound M_l and upper bound M_u of this metric, after which a ratio R is calculated using the formula

$$R = \frac{M - M_l}{M_u - M_l}.$$

In cases where $M \leq M_l$ or $M \geq M_u$, the value of R remains 0% and 100%, respectively.

To aggregate all drivers, the R_n value of each driver is given a certain weight w_n, and the weighted average of R_n is then taken as the incentive factor, denoted F_{inc}:

$$F_{inc} = \frac{\sum_{n=1}^{N} R_n \cdot w_n}{\sum_{n=1}^{N} w_n}$$

where $N = 5$ is the number of drivers aggregated into the incentive factor.

For the estimation of the "good practice" and "no policy" curves, the reference values for the aforementioned drivers are given in Table 1. Additionally, metrics for all five drivers need to be specified for each assessed country in the same units. Detailed explanation of weighting factors given for each driver can be found in Appendix.

1.4 EV shares in total fleet

The share of EVs in total light duty vehicle (LDV) fleet is estimated based on a simple stock turnover model developed for Kriegler et al. (2018). This model uses LDV projected activity data from the ICCT Roadmap (ICCT, 2017) and the share of EV in new cars sold assuming a 15 year lifetime for vehicles.

Table 1: An overview of the default reference values for the metrics M and their weights w, and their lower and upper bounds for comparison M_l and M_u, respectively.

Driver	Metric M	Unit	Default Weighting factor w	Lower bound M_l		Upper bound M_u	
				Value	Representation	Value	Representation
Charging infrastructure; strong, smart and financed grids	Number of public charging units per capita	units / million cap	30%	0	No charging infrastructure	3,174	Norway (IEA, 2021b)
Purchase subsidies	Amount of monetary subsidy for EV purchase[1]	€	30%	0	Threshold of price difference	9,440	Norway (tax reductions) (Norsk elbilforening, 2021)
Other financial incentives	Number of financial scheme types in place	-	30%	0	No schemes	5	All five types of schemes
Personal wealth	GDP per capita	Current US$ / cap	5%	3,119	Least developed countries: UN classification (World Bank, 2021)	44,823	OECD members (World Bank, 2021)
Behavioural incentives	No (0), local (1) or nationwide (2) presence of such incentives	-	5%	0	No behavioural incentives	2	Behavioural incentives implemented nationwide

[1] This can depend per country on the exact type of vehicle. Where available, we use numbers that refer to full battery electric vehicle (BEV) purchase. If dependent on vehicle weight class, we use numbers referring to personal cars (category M1), not minibuses or vans or freight vehicles.

2 Tool setup

The EV policy impact assessment tool is a spreadsheet-based tool. The current version of the tool consists of roughly four different sections with one or more sheets each. These sections are:

1. Introduction & Instructions
2. Dashboard,
3. Default country results,
4. Background calculations, LDV calculations and Default input.

Each of these sections is explained below.

2.1 Introduction & Instructions

The introduction sheet provides an overview of the tool, description of sheet content and navigation to other sheets. The instructions sheet provides a detailed explanation on how to use the dashboard and the data inputs required in the model.

2.2 Dashboard

The dashboard is an interactive sheet, where data for country analysis needs to be entered and results are displayed dynamically based on that data. The tool's dynamic set up allows users to immediately see the results of a projection both graphically and as a time series, when changing any of the input variables (this includes country specific and reference values).

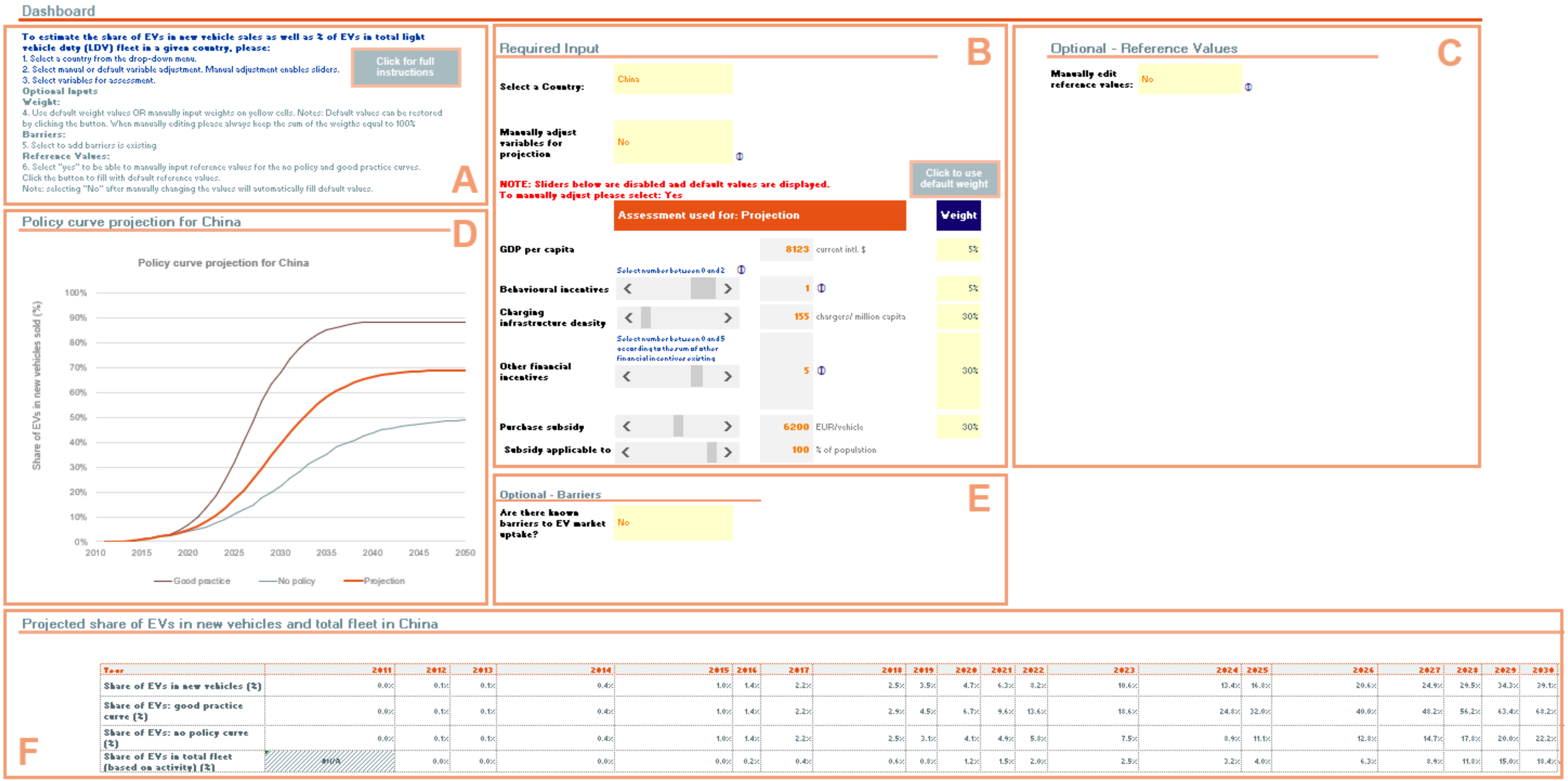

Figure 2: EV policy modelling tool’s dashboard divided in five panels (A-E). Panel A: Brief instructions. Panel B: Country selection and country policy inputs. Panel C: Input of reference values used for the “good practice” and “no policy” curves. Panels D and E: Results on EV market share projection and EV share in total fleet.

The dashboard is divided into six main sections as shown in Figure 2. Below, each section is described:

- **Panel A - Brief instructions.** This section provides brief instructions on how to use the dashboard and a link to navigate to the instructions sheet, where more detailed instructions are available.
- **Panel B – Minimal required input: Selection of country and input of EV policies** (see Figure 3 below)**.** Here is where the user chooses the country to be assessed and inputs the data on EV policies for that country. The user may choose to use default values for available countries (i.e. Norway, G20, EU27 countries and other CAT countries[2]) or manually input EV policy values. Selecting "yes" for manually adjusting variables for projection enables the sliders, while choosing "no" feeds default values. In this section, the user may also change the weighting factors for each of the indicators. A button on top of the weighting factors gives the option to restore the values if needed. The cells with an ⓘ contain additional information on the input required.

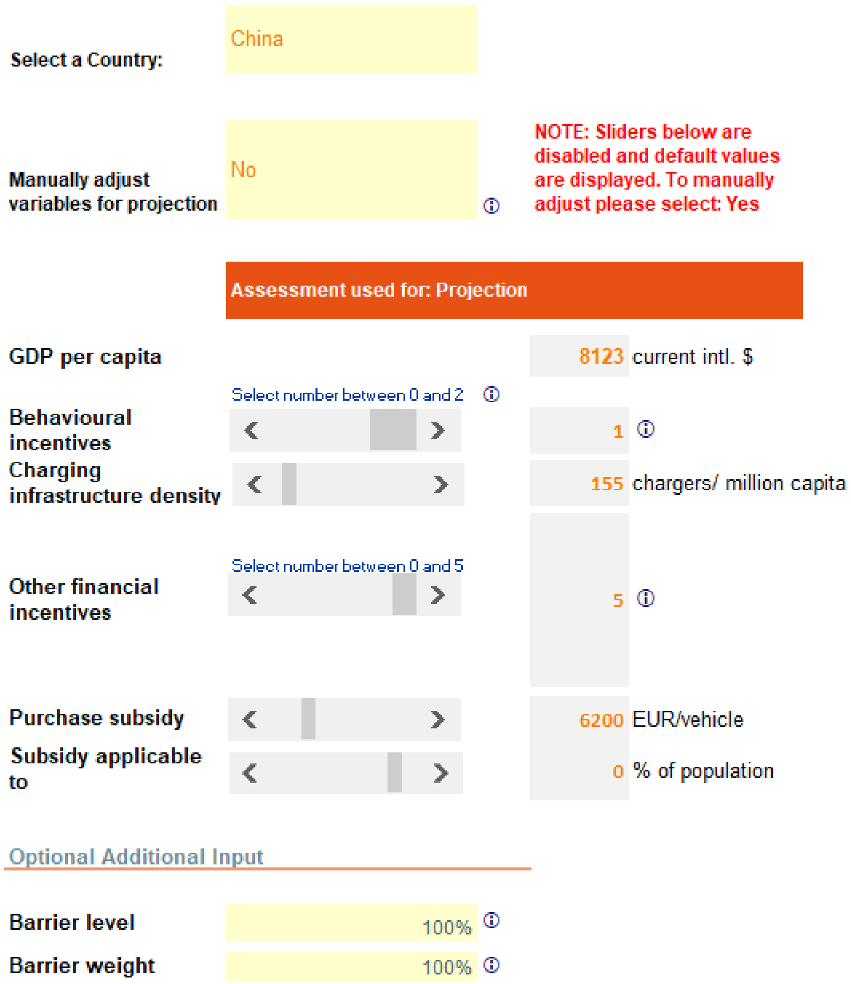

Figure 3: Dashboard's panel B - Selection of country and input of EV policies. In this example, China is selected with default values. These values are fed automatically, and the sliders are disabled.

[2] Countries with specific country assessments at the Climate Action Tracker (CAT), see https://climateactiontracker.org/

- **Panel C - Input of reference values** (see Figure 4 below)**.** The reference values are used for the "good practice" and "no policy" curves, as explained in Section **Error! Reference source not found.**. Here, the user may choose to use default values (enabled by a button) or may manually input reference values by typing them directly to the yellow cells. Clicking the button to use default values will overwrite any manual input. Default reference values are specified in Table 1.

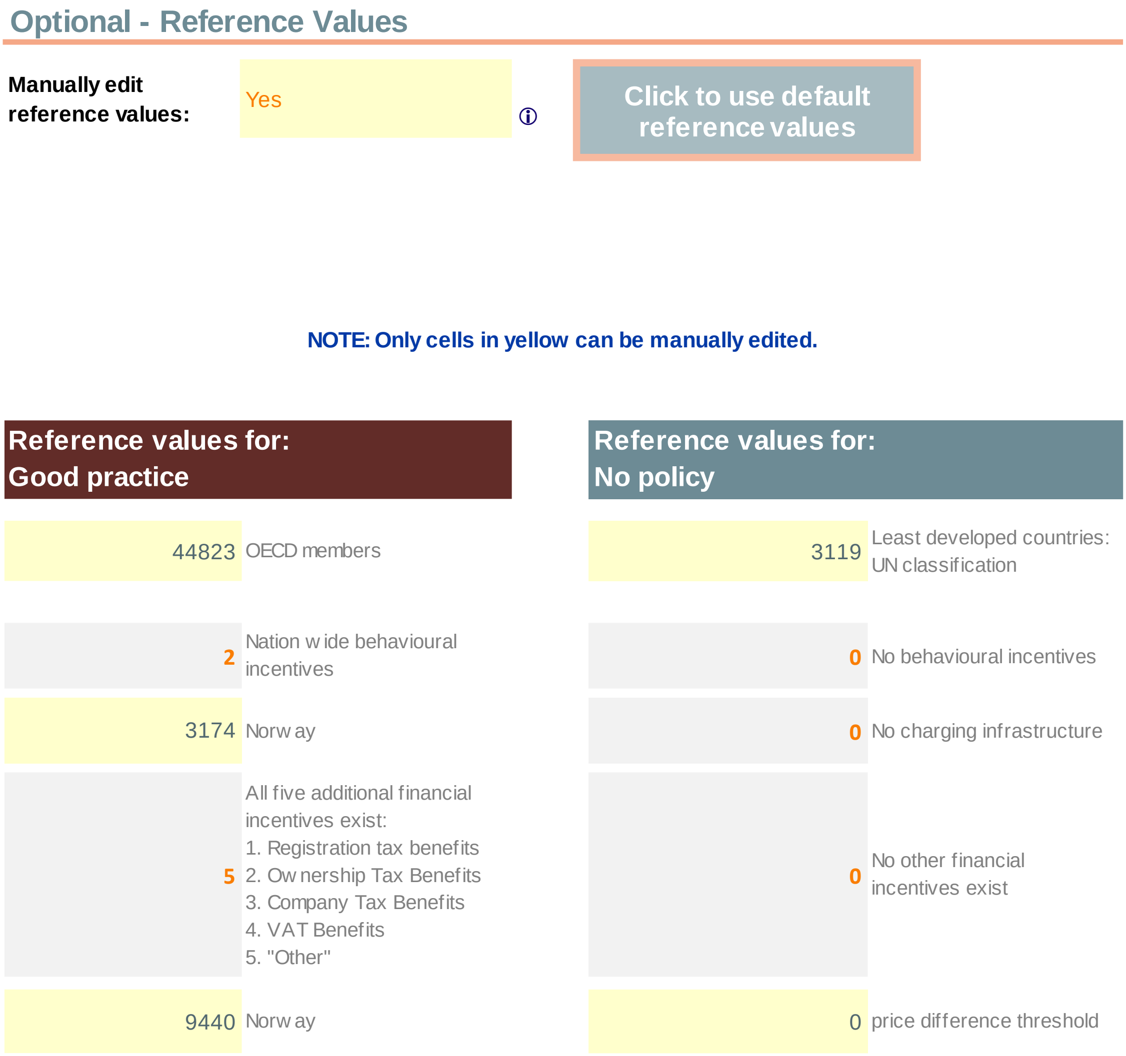

Figure 4: Dashboard's panel C - Input of reference values. In this example the default reference values are used. These values are the same as the ones in Table 1.

- **Panel D - Policy curve projection for the selected country** (see Figure 5 below)**.** This section includes a graphic representation of the results of the tool. Here the selected country's EV market penetration projection curve is displayed together with the "good practice" and "no policy" curves.

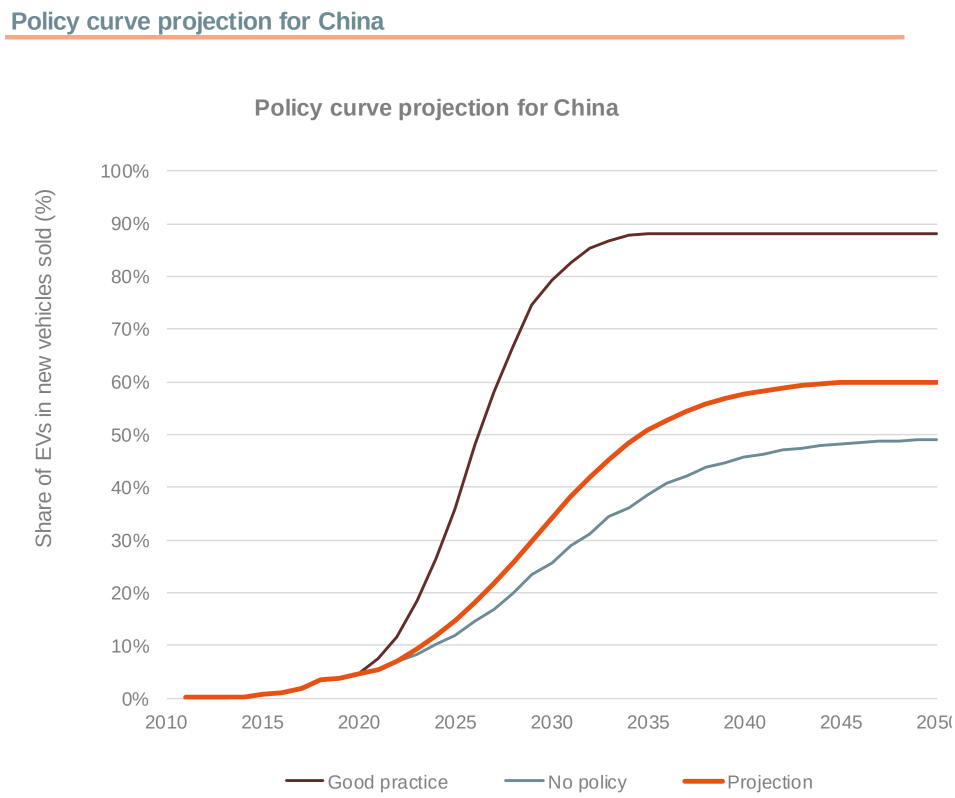

Figure 5: Dashboard's panel D: Policy curve projection for the selected country. In this example, the policy projection curve is for China and uses default values. The "good practice" and "no policy" curves are estimated using reference values.

- **Panel E – Optional: barriers hindering EV market penetration** (see Figure 6 below)**.** Here, the user has the option to account for barriers hindering EV market penetration. To enable this function, the user needs to select "yes" if there are any known barriers to EV market uptake. If "yes is selected, additional input will be required, the barrier level, a percentage between 0% and 100% and the desired weight for this barrier level (also a number between 0 and 100%).

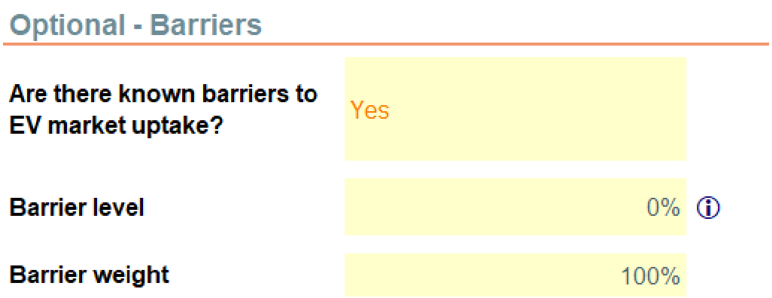

Figure 6: Dashboard's panel E: Optional input to add known barriers to EV market penetration.

- **Panel F – Results as time series.** This section provides projections of EV market share and EV share in total fleet as a time series. The EV market share projections include the assessed country and the "good practice" and "no policy" curves from 2011 until 2050. These data are shown graphically in Section D. The EV share of total fleet includes only projections for the assessed country from 2011 until 2030. The latter is calculated based on a model by Kriegler et al. (2018) using LDV activity from the ICCT Roadmap (ICCT, 2017), which only includes data until 2030.

2.3 Default country results

This sheet provides an overview of input variables and results on EV market penetration and EV share of total fleet projections for G20 countries, 27 Member States of the European Union and all CAT countries[3]. In this sheet, available default data as well as results for default countries is available for comparison. The user can choose a country at the top and immediately see the input data and results for that country, which are automatically highlighted in the available graphs. For more details on default countries input data and results see Section 0 (Country Examples) below.

2.4 Background calculations, LDV stock turnover, Default input

These sheets contain the calculations needed to estimate EV projections based on the s-curve model described in Section 1. The default sheets contain the data collected for default countries and default reference values. The default section also contains historical EV market penetration shares (2010 – 2020) from IEA's EV Outlook 2021 (IEA, 2021b) and values on projected shares for 2030 for selected countries as published in literature[4].

3 Country examples

To test the model used in the EV policy modelling tool, data for G20 countries, of the Member States of the European Union and all CAT countries[3] were collected. The data were used to estimate projections on share of EVs in new cars (market penetration) and share of EVs in total fleet for a total of 60 countries. Due to the large number of federal-level policies in the United States, the US data was gathered on a state level and averaged according to population. The projections of future market share of EVs were compared to other projections available in literature for selected countries[4].

3.1 Input: Drivers

As described in Section 1.3, the model requires country information on five drivers of EVs market penetration. Figure 7 provides an overview of the collected data for the five drivers in G20 countries, EU27 Member States and other CAT countries. Norway's values, which are used to estimate the "good practice" policy curve, are also included and are highlighted (in orange).

[3] Countries with specific country assessments at the Climate Action Tracker (CAT), see https://climateaction-tracker.org/

[4] The projection shares have not been updated in the 2021 tool update

Figure 7: Driver overview for Norway, G20 countries, 27 EU Member States and other CAT countries. Data on charging infrastructure are taken from (Chargemap, 2021; electromaps, 2021; IEA, 2021b); data on purchase subsidies, behavioural incentives and other financial incentives are taken from (EAFO, 2021a; IEA, 2021b) and various country specific sources; GDP per capita and population data are taken from (World Bank, 2021)

The collected input data for these 60 countries are available in the tool as “default values”. However, the user can choose to use other values and overwrite these values if necessary, when assessing a country in the dashboard.

3.2 Results: Incentive factor, share of EVs in new vehicles and share of EVs in total fleet

Incentive factor

Based on the model described in Section 1,the five drivers are used to estimate an incentive factor for each assessed country. The incentive factor is then used to estimate the projections on EV share in new vehicles (market penetration) and share of EVs in total fleet. The estimated incentive factors for all 60 countries as well as the resulting share of EVs in new vehicles and total fleet for 2030 can be observed in Figure 8.

Figure 8: Incentive factor resulting from drivers, as well as share of EVs in new vehicles in 2030 and share of EVs in total fleet resulting from the model.

Projected market share of EVs and share of EVs in total fleet for selected countries

The market share projections from the EV policy modelling tool include time series data. Figure 9**Error! Reference source not found.** depicts our projections for selected countries (here China, Unites States of America, European Union, Japan and India) as well as minimum and maximum projected values of future market share of EVs as reported in other literature (Note: values from literature are from 2018 and have not been updated in 2021). As can be observed below, most our model's projections lie within other publicly available projections but are not completely in line for Japan. A reason may be that the projections are several years older than the inputs of our analysis.

The projection of EV market share was used as an input in the LDV stock overtake model by Kriegler et al. (2018) to estimate the share of EVs in total LDV fleet. This was estimated using activity data from the ICCT Roadmap model (ICCT, 2017) assuming an LDV lifetime of 15 years. In Figure 10, projected EV share in total fleet for the same countries are presented. As a reference, projections for Norway and the Gambia (maximum and minimum respectively, out of the 60 assessed countries) are also shown.

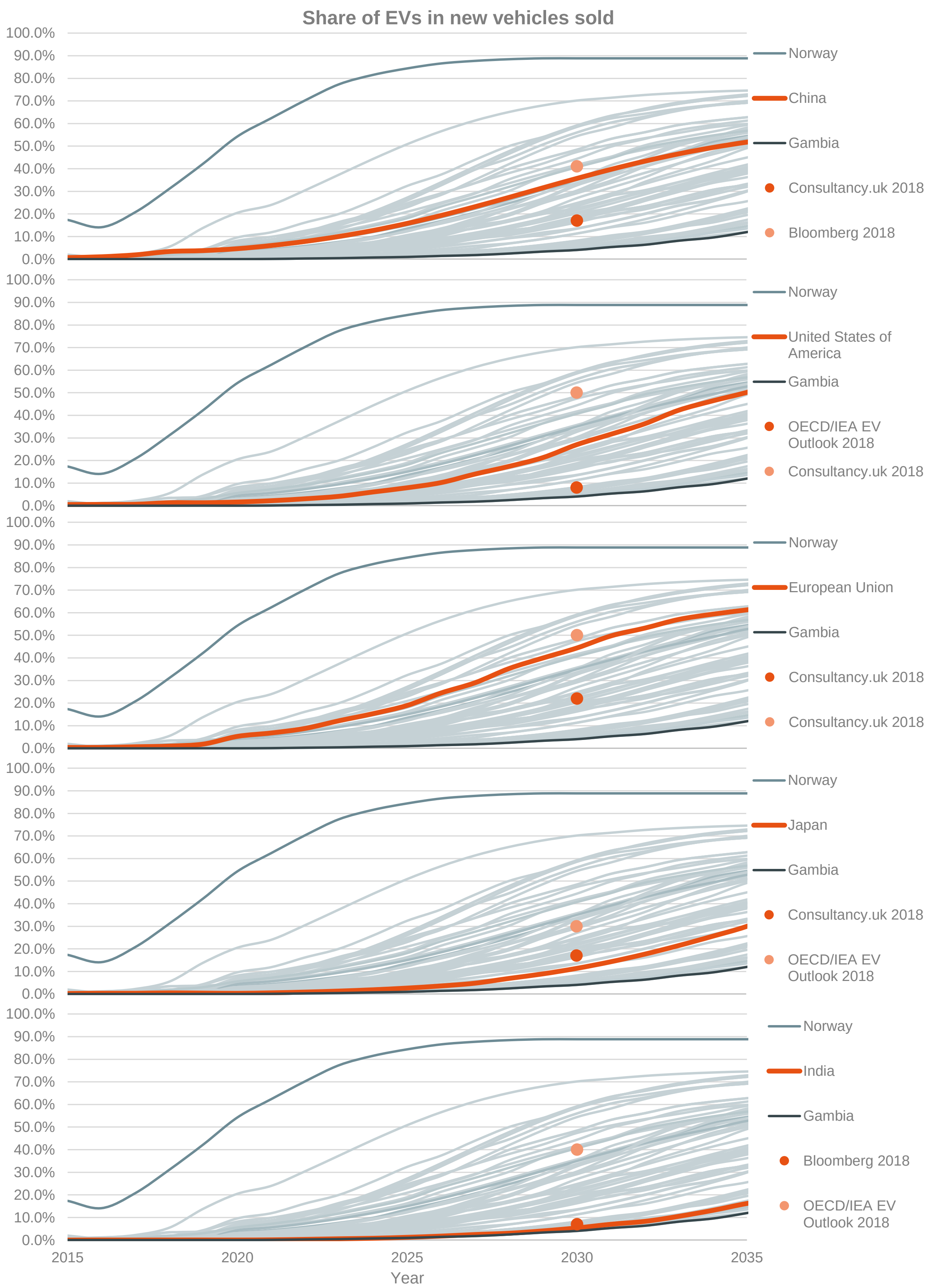

Figure 9: Projections on future market share of EVs in selected countries, as well as minimum and maximum data points from literature for EV market share in 2030 for those countries. Data from literature include the OECD/IEA EV Outlook 2018 (IEA, 2018), Bloomberg 2018 (Gupta, 2018) and (Consultancy.uk, 2018).

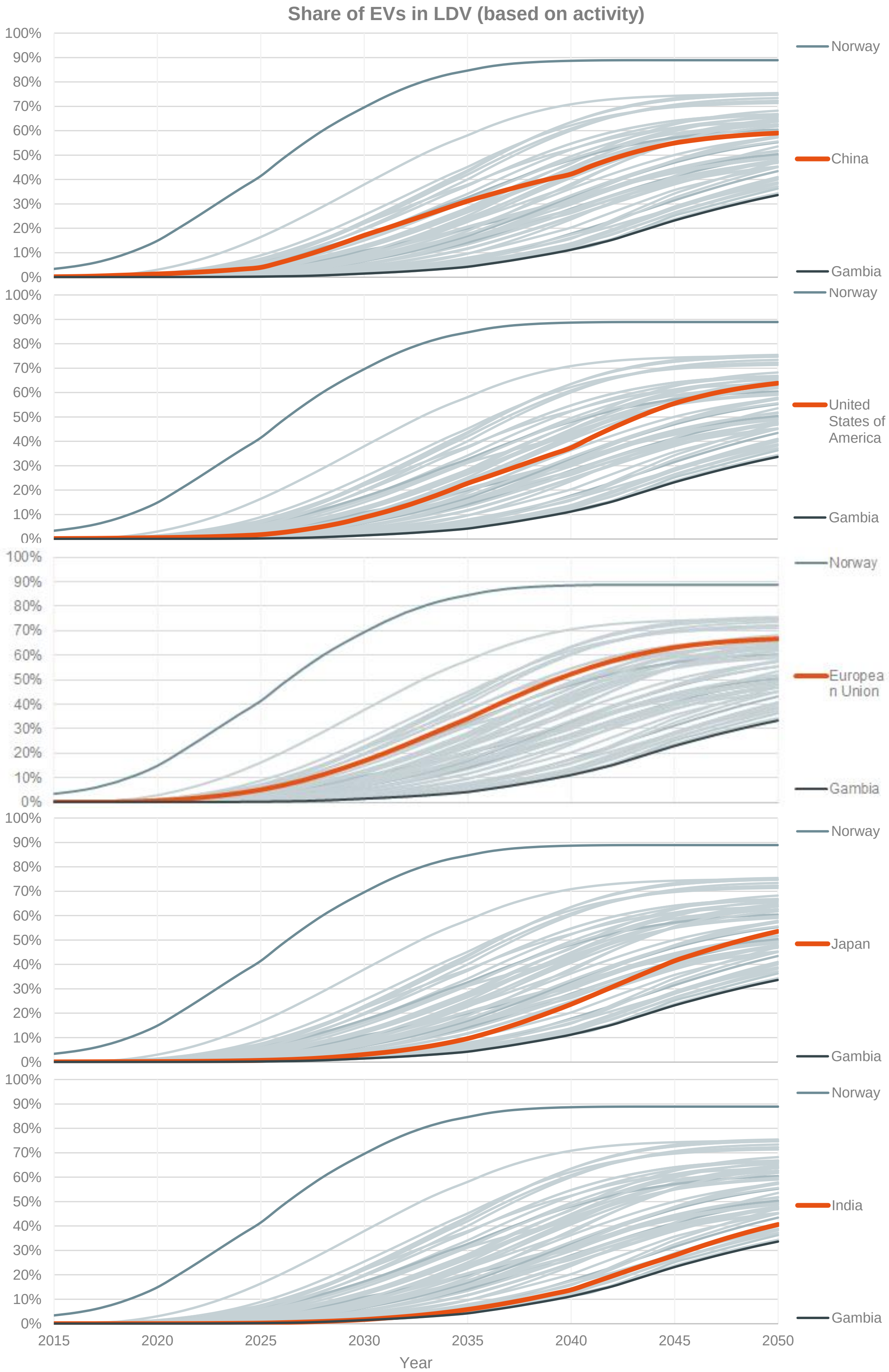

Figure 10: Projection of EVs share in total fleet based on activity for selected countries.

4 Limitations and factors not accounted in the EV policy modelling tool

- Our model considers only private passenger vehicles (including taxis). Other vehicles, such as scooters, low-speed EVs or busses are not included in the EV policy modelling tool. According to other studies on future EV projections (Gupta, 2018; IEA, 2018), some of these vehicles are expected to have significant market shares in the future in most countries.
- Our model does not consider other drivers than the five mentioned in Section 1 (Model Description). Other potential drivers influencing EV market penetration could include:
  - **Rare metal availability and consumption** have the potential to hinder future EV market penetration (West, 2017). A higher amount of rare metals is needed for EVs than for conventional vehicles as these are used for batteries. Scarcity in the supply of such metals could potentially hinder EV market penetration, particularly in countries where a larger price gap between conventional and EVs exist.
  - **Car manufacturers** have the capacity to drive or hinder EV market penetration (McKinsey & Company, 2017). Example of countries where this development has already been observed are Japan and Germany or China (even when the latter does not have big in-country car industries). Car manufacturers from these countries have however been turning around and some are even planning a full phase-out of combustion engines.
  - Other factors out of the direct control of manufacturers such as **fuel prices and consumer characteristics** (Yong and Park, 2017).
  - **EV's limited driving range & long charging time** have been identified as obstacles for EV adoption and diffusion in some studies (Yong and Park, 2017). We do not consider those factors separately but consider that they overlap with of technology driver: charging infrastructure.
  - A report by McKinsey & Company (McKinsey & Company, 2017) has identified **increased urbanization** as a factor that could create more pull for green mobility solutions. This due to stringer air pollution control measures in cities and need for shorter distances resulting in the need for shorter ranges.
- Our model does not consider countries' EV market share targets as a driver, as targets do not drive EV implementation.
- To our knowledge, there are no barriers hindering EV implementation. Nonetheless, barriers – represented by a *barrier factor* can be added as an input if necessary. The barrier factor is a number between 0% and 100% that is applied to the incentive factor to reduce its value. A barrier factor of 100% means no barriers exist – no reduction of the incentive factor, whereas a barrier factor of 0% means total hindering of EV uptake. If a barrier factor of 0% is chosen for a country, its policy curve projection will equal the "no policy" curve.

5 Tool update 2021

In the first half of 2021 the tool was updated. This update included the addition of 15 default countries, the update of raw data as well as update of policy data of all default countries.

5.1 Additional Countries

The country list was updated by 15 additional CAT countries (bold below) and now consists of this country list (60 countries in total, including the EU27):

- Reference country: Norway
- EU27 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
- G20 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korean, Mexico, Russian Federation, Saudi Arabia, South Africa, Turkey, United Kingdom, United States of America, European Union
- Additional CAT countries[5]: **Bhutan, Chile, Costa Rica, Ethiopia, Gambia, Kazakhstan, Morocco, Nepal, New Zealand, Peru, Philippines, Singapore, Switzerland, Ukraine, United Arab Emirates**

5.2 Data update

The following data was updated to cover latest values that were available in 2021:

- Raw data for all countries
  - Population (World Bank, 2021)
  - GDP per capita (World Bank, 2021)
- Raw data for selected countries
  - Number of Chargers (60 countries: G20, EU27, and CAT) (Chargemap, 2021; electromaps, 2021; IEA, 2021a)
  - Vehicles in use / motorisation rate (Europe) (acea, 2021)
  - Historic market share (Europe and selected countries with IEA data) (EAFO, 2021b; IEA, 2021a)
- Policy data for 60 default countries (G20, EU27, CAT countries) and 23 US federal states (accounting for 80% of the US population) based on research of various (country specific) sources
  - Purchase subsidy
  - Other financial incentives
  - Behavioural incentives
- Admin data
  - Currency exchange rates
  - Country lists

[5] Countries with specific country assessments at the Climate Action Tracker (CAT), see https://climateactiontracker.org/

5.3 Methodological fixes/changes

In addition, certain methodological practices were adapted based on issues with previous working principles or more available information.

- In the previous version the incentive factor of the **European Union** was calculated through weighted averages of all (then) 28 member States. Now the data for motorisation rate, GDP/capita, population, historic market share, number of chargers and behavioural incentives are taken from direct EU27 data and only the purchase subsidy and other financial incentives are weighted and averaged.
- As a large proportion of EV policies in the **United States** are organised on state level, the results for the US were not representative of the entire country in the previous version. Now the US default data regarding purchase subsidies, other financial incentives and behavioural incentives were collected on a state level (for the 23 most populous states accounting for over 80% of the country's population) and their weighted average was used to project market shares.
- Historical market share data is now available for more countries, going beyond the data available from IEA. Now all European countries have historical data, this goes beyond the European countries with populated policy data. On the other hand, historic market share data is still not available for all pre-populated countries. Instead of using a generic value for all other countries (average from world or 'other'), countries with no data now use data from a country from the region (e.g. historical market shares of data from Chile is now applied to all South America), 'world' data is only used in a few cases where a better assessment was not possible.
- Yearly stock turnover calculations were added to correct the EV share in total fleet, which was overestimated in the previous version of the tool.

Appendix: Setting weighting factors for each driver

The weighting factors are informed by the regression analysis presented by Sierzchula *et al.* (2014), but are adapted based on expert judgement.

We judge the presence of **charging infrastructure** to be of paramount importance, as due to the limited driving range of EVs, users need the confidence that they can charge their vehicles as per need. In a country such as the Netherlands, with a high population density and generally short distances between cities, this will have different implications than in Norway, with low population densities and large distances – for instance, in Norway, many EVs are used as “second car” to be used for driving short distances (Nijland *et al.*, 2016; Volkskrant, 2016). Nevertheless, the absence or limited availability of charging infrastructure is likely to limit EV uptake.

We also consider the **presence of purchase subsidies** to be of similar importance, since as long as price parity with conventional cars cannot be reached, it is not to be expected that the latter can be easily pushed out of their current market position. We assign this indicator the same weight as the one measuring charging infrastructure density.

The effect of **other financial subsidies** is expected to play a strong role too. It would be best to quantify the aggregate effect of all such subsidies on the lifetime savings of having an EV as compared to another type of car, but in the absence of a robust method for this within the scope of this study, we quantify it by counting the amount of such types of subsidies implemented. We assign it the same weight as purchase subsidies: as the example of the Netherlands, which currently have the highest shares of (B)EVs on the road in the EU but did not use to provide purchase subsidies, shows, other financial benefits can play a significant role, although they reach the company market more than the individual consumer market (Nijland *et al.*, 2016).

The proxy for **personal wealth**, measured in GDP per capita, is also a proxy for the propensity to own more than one vehicle. In many cases this may have an impact on the uptake of EVs, given that they have a limited driving range and thus are more suitable to replace short-distance trips, as mentioned above. This indicator can furthermore enhance the sales of EVs when price parity is not reached. We assign it a weight of 5%.

Lastly, the presence of **behavioural incentives**, such as access to free public parking with an EV, exemption on city driving restrictions or the privilege to drive on bus lanes, is likely to play a limited role as well. We assign it a weight of 5%.

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