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Availability of Lithium Ion Batteries from Hybrid and Electric Cars for Second Use: How to Forecast for Germany until 2030

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Abstract: Due to growing numbers of sold HEV (hybrid electric vehicles), PHEV (plug-in hybrid electric vehicles), and BEV (battery electric vehicles), new market opportunities to reuse or recycle old lithium ion batteries arise. Thus, a forecast of available batteries caused by accidents or from end-of-life vehicles was carried out using a mathematical model. Input data were obtained from an estimate of newly registered hybrid and electric vehicles in Germany from 2010 until 2030, from the accident rate of cars in Germany, and from the average cars' lifetime. The results indicate that (a) the total amount of available second use batteries in 2030 will be between 130,000 units/year and 500,000 units/year, (b) the highest amount of batteries will be obtained from end-of-life vehicles not from accident vehicles, although most batteries from accident vehicles will be suitable for 2nd use, and (c) the quantity of hybrid, plug-in hybrid, and electric car batteries available for reuse will continue to rise after 2030.

Key words: Forecast, model, lithium ion batteries, second use, recycling, HEV, PHEV, BEV.

1. Introduction

The sales of HEV (hybrid electric vehicles), PHEV (plug-in hybrid electric vehicles), and BEV (battery electric vehicles) are growing and this trend is expected to continue [1]. One important factor is the current intention to ban diesel engines from cities due to their high level of pollutant emissions [2]. An even more crucial factor for the future of hybrid and electric cars besides decreasing prices may come from politics via EU directives or German Government incentives [3].

Considering the increasing production of HEV, PHEV, and BEV worldwide and therefore in Germany too, a new business opportunity arises: the batteries' second life [4]. The second use of low and high voltage lithium ion batteries coming from car accidents or from end-of-life vehicles is becoming a reality, which is already explored on an initial stage by several companies including OEM like Daimler and BMW [5].

2. Purpose

Aware of this situation, the purpose of the present research was to create a forecast for the German market based on existing literature and a market research analysis. It aims to predict the amount of available lithium ion batteries from accidents and end-of-life vehicles until 2030.

To quantify the amount of expected batteries available for second use, a mathematical model was created and implemented using the software Matlab (The Mathworks, Inc., USA). The model received three

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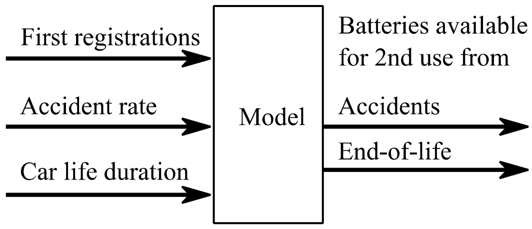

Fig. 1 Input and output parameters of the model.

different input parameters and allowed obtaining two different outputs, as can be seen in Fig. 1. The input parameters for the model were:

(1) Number of first registrations of hybrid and electric vehicles per year in Germany from 2010 until 2030;

(2) Accident rate;

(3) Vehicle life duration[1].

Due to a big uncertainty about future initial registration numbers for electric propelled cars, three fundamental scenarios (e.g. optimistic, medium and pessimistic) were considered for the input "First registrations of cars".

For the input parameters "Accident rate" and "Car life duration", it was assumed that electric vehicles behave similarly to average cars during the last years. This information will be detailed in the next chapter.

Finally, the model provides two different outputs:

(1) Number of batteries available for second use per year from accident vehicles from present until 2030;

(2) Number of batteries available for second use per year from end-of-life vehicles from present until 2030.

3. Approach

Within this chapter it will be explained how the input data for the model were obtained. Furthermore, the proposed mathematical model to calculate the number of available batteries will be presented in detail.

3.1 New Registered Hybrid and Electric Cars in Germany from 2010 until 2030

To forecast the behavior of stock in the future information about the age and size of the stock in the future is necessary. To obtain a picture of sold/registered cars containing lithium ion batteries in the next years, different literature sources like scientific papers, publications, and reports from companies and public institutions were carefully analyzed.

To further obtain information about different battery capacities, this study aimed to solicit the amount of new registered HEV, PHEV, and BEV separately per year. But, as not all found predictions specified the cars' technology as HEV, PHEV, or BEV, also EV, as a global term, has been included as a separate category in the analysis.

As the study was focused on the German market, forecasts referring to different markets (e.g. USA, China, Japan or even Europe or worldwide) were rejected. Applying a correction factor to those values to get numbers for Germany would have been imprecise and unreliable.

The starting point to build the future scope of available lithium ion batteries until 2030 was to evaluate known (not forecasted) information provided by the Kraftfahrt-Bundesamt (KBA, German Federal Motor Transport Authority). The first registration numbers sorted by technology (e.g. Diesel, Gasoline, HEV, PHEV, BEV, etc.) were available monthly from 2010 up to 2016 [6]. Based on this information, a relatively exact availability of 2nd use batteries of different technologies could be stablished for the very near future.

Additionally, different research [6-11] aiming at prospective hybrid and electric vehicles in Germany was consulted.

3.1.1 HEV, PHEV and BEV

The following sources were analyzed for the study for HEV, PHEV and BEV:

(a) Shell (2014) [7], KBA: HEV, PHEV and BEV initial registrations for the years 2013, 2020, 2030 and 2040 for Trend and Alternative scenarios, where:

(1) Trend: continue passenger car trends and consider an increasing use of biofuels.

(2) Alternative: examine the potential impacts of

[1] It was assumed that the vehicle's life period is similar to the batteries'. Thus, not more than one battery per car life was taken into account

increased electrification of propulsion systems and fuels.

(b) eMAP project (electromobility-scenario based market potential, assessment, and policy options, www.project-emap.eu):

(b1) Shell (2009) [8]: passenger vehicle registrations from 2000 until 2030 in % (forecast offered every five years). The information considered for the study was from 2010 on. To convert this information into real numbers, the passenger car new registrations offered by Shell and KBA [7] (for the years 2013, 2020, 2030 and 2040), considering the trend and the alternative scenarios, were employed. From 2010 to 2016, the information used was the one provided by the KBA, and for the rest of the years the information provided by Shell was employed. Only for the year 2025, Shell did not provide any information. Thus, the value for 2025 was obtained via interpolation between 2020 and 2030.

(b2) Kugler [9]: German vehicle sales per year for the period between 2010 and 2030 for HEV, PHEV, BEV differentiating between a small, medium, and large segment depending on the vehicle size for three different scenarios:

(1) BaU (Business as Usual): it models the effect of current policies and EV technologies.

(2) TeD (Technology Driven scenario): higher investments into traction battery research and development are assumed.

(3) PoD (Policy Driven scenarios): it explores EU-wide (PoD-EU) and country-specific pathways where additional policies are incorporated to enhance the reduction of CO_2 emissions and to promote electrified vehicles.

To create more scenarios, and therefore acquire more input data, the information provided from Shell and KBA [7] regarding the new car registration for the Trend and Alternative scenarios was further employed. Kugler [9] provides in total 9 combinations of 3 scenarios (BaU, TeD, and PoD) and 3 car sizes (small, medium, and large segment) for each of the 3 car types (HEV, PHEV, and BEV), which are given in a percentage based on the initial registrations in Germany. These 9 combinations were reduced by weighted summing the segments accordingly (small: 28%, medium: 59%, and large: 13%). The solicited percentages were separately multiplied with both first registration scenarios given by Shell /KBA [7], giving 6 data series per car type.

3.1.2 EV as a global term

Regarding the amount of EV, Ref. [6] was used (total amount of HEV, PHEV, and BEV) for known data of the past. The analyzed sources were:

(c) German Government plan until 2030 [11]: the goal proposed by the German Government contemplates to reach 1 million sold EV by 2020 and 6 million by 2030 (cumulative). The input data here were obtained by extrapolating the provided accumulative EV sales for 2016-2030, so that the sales for this period of time amount to 6 million in total.

(d) eMAP project: KE-CONSULT [10]: EV sales per year from 2010 until 2030 for the scenarios BaU, TeD and PoD.

The above-analyzed data provided information for initial vehicle registrations between 2010 and 2030 for new cars coming to the market in Germany sorted by HEV, PHEV, BEV, and EV (Figs. 2-5).

Using this information, three scenarios (optimistic, medium, and pessimistic) were assumed for the input data of the model. To generate the three curves, a cubic Bezier function was employed, as presented in Eq. (1):

$$B(t) = P_0 \cdot (1-t)^3 + 3P_1 \cdot t \cdot (1-t)^2 + 3P_2 \cdot t^2 \cdot (1-t) + P_3 \cdot t^3,\ t \in [0, 1] \quad (1)$$

where $B(t)$ was the number of available cars, P_0, P_1, P_2 and P_3 are the four points that define the cubic Bezier curve, and t shows how the curve increases, being $t = 0$ for all years before the rise and $t = 1$ for all years thereafter (steady state), increasing linearly in between:

$t(y) = 0$, year $< y\_start$;

$t(y) = \frac{(y - y\_start)}{(y\_end - y\_start)}$, $y\_start <$ year $< y\_end$;

$t(y) = 1$, year $> y\_end$;

The curve starts at P_0 going toward P_1 and arrives at P_3 coming from the direction of P_2. As the known rise between 2010 and 2016 is relatively small, $P_0 = P_1$ can be assumed, being renamed as C_S (cars at start of the slope), which will be always close to 0. The ending point was also fixed and it was the information provided by the different sources for the year 2030, considering three scenarios, which were manually fitted to the data points derived by the source. As a market saturation (a steady state of orders) was assumed giving $P_2 = P_3$, being renamed as C_E (cars at steady state at the end of the slope). The applied changes can be seen on Eq. (2):

$$B(t) = C_S \cdot (2 \cdot t^3 - 3 \cdot t^2 + 1) + C_E \cdot (3 \cdot t^2 - 2 \cdot t^3),\ t \in [0,1] \quad (2)$$

Figs. 2-5 represent the forecast for the registration numbers of HEV, PHEV, BEV and EV. Every colored line represents a different combination of sources. To estimate future developments, different sources and trends for the registered cars in 2010-2016 (KBA) were considered. The optimistic case is based on the assumption that all new registered cars (3.5 million/year) will be from HEV, PHEV, and EV type in saturation, which will happen in 2035. This steady state sum was distributed to the three car types according to the sources. The medium and pessimistic cases were chosen with reduced numbers fitted to the sources assuming a steady state for battery car first registrations in 2040. Finally, the three created scenarios obtained with Eq. (2) were used as input for the model. They are colored in green (optimistic case), yellow (medium case) and red (pessimistic case).

3.2 Car Accident Rates

To include damaged batteries from accidents, a car accident rate was required to serve as model input. Therefore, the EUSka (Elektronische Unfalltypen-Steckkarte) database on accident information was examined [12]. EUSka was developed by German insurance companies (Unfallforschung der Versicherer) and distributed by PTV Group. It contains information on accidents from years 2010 to 2016 with reference to the German federal states Saxony, Hessen, Hamburg, Bremen, Brandenburg, and Saxony-Anhalt.

Fig. 2 Newly registered HEV in Germany 2010-2030.

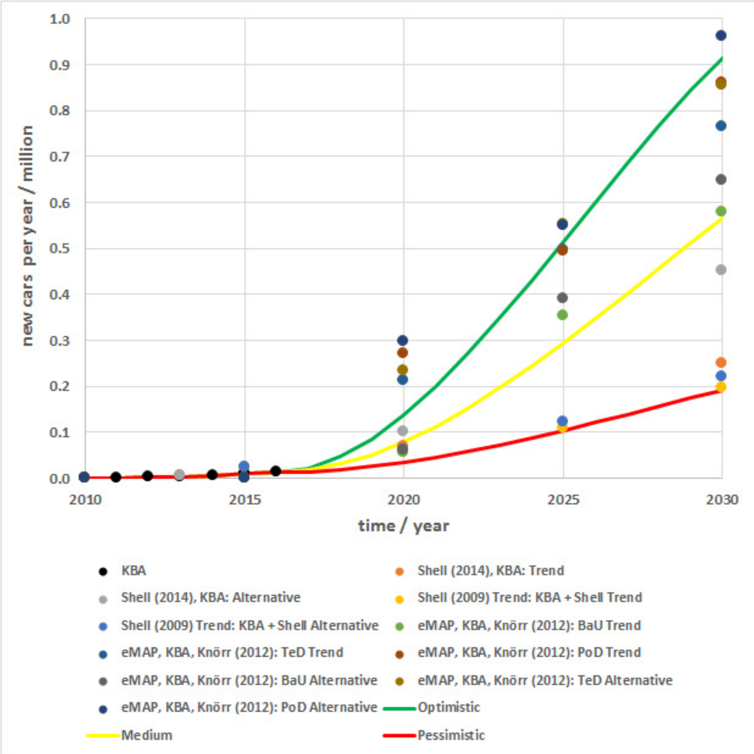

Fig. 3 Newly registered PHEV in Germany 2010-2030.

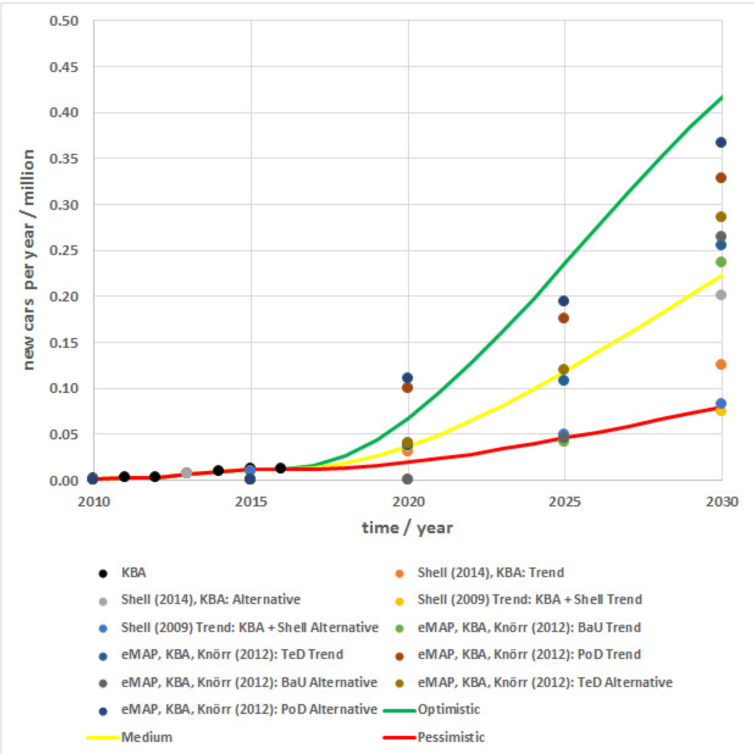

Fig. 4 Newly registered BEV in Germany 2010-2030.

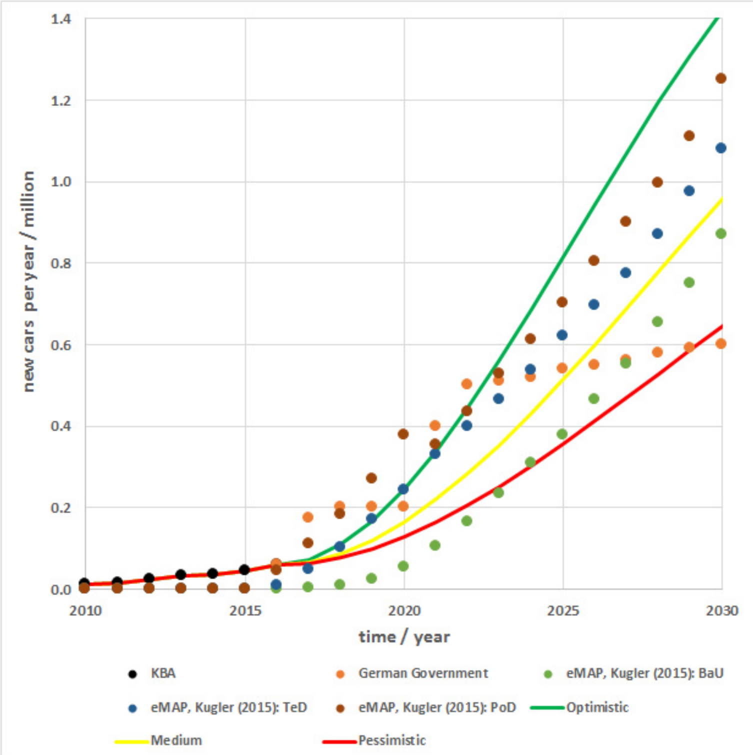

Fig. 5 Newly registered EV in Germany 2010-2030.

In terms of geographical, infrastructural, population-, and automotive-based circumstances this source can be seen as representative for Germany [13], although only data of four federal states could be used for the evaluation as no data of Hamburg and Bremen were available prior to 2014.

It was then necessary to decide, which accidents were relevant for damaged batteries. Although the EUSka database provides a wide variety of information on recorded accidents, it lacks data on the severity of deformation. It was thus necessary to analyze additional information sources for being able to split the cases according to accident severity. In addition, as the actual usage of electrical propelled cars is very low, it was necessary to extrapolate information based on all car types.

The EUSka database provides information about the injury grade of the accident participants. This information was used to estimate the influence of an accident on the battery. Car accidents with passengers, which suffered fatal (0.07% of all recorded accidents), severe (1.1%), or minor injuries (4.7%), were validated as damaged car (5.9% of all accidents). The remaining crashes (94.1%) were assumed to have only little impact on the battery—allowing its future use for second life applications. These percentages and absolute amounts of accidents showed no time-dependent trend in any of the categories in the validated time span. Thus, and because of the comparatively small effect of the rate on the final result, a constant accident rate was assumed for the forecast.

Additionally, it was necessary to multiply the number of accidents by the average rate of cars participating in an accident (Factor 1.2, based on EUSka), giving the final factor of 7.0% damaged cars per accident.

To extrapolate this result to the total amount of cars in Germany, a statistic of the Statistisches Bundesamt [14] was used, which states that in average 2,442,000 accidents per year happened between 2010 and 2016. The KBA [15] further provided data, that the total amount of cars in Germany was 43,969,000 in average, resulting in a total of 0.056 accidents per registered car and year in Germany. As an estimation this rate was evaluated to be similar for EVs.

Multiplying this accident rate of 0.056 accidents per registered car and year in Germany with the portion of accidents of 7.0%, which lead to deregistration, approximately 0.004 cars per registered car and year are deregistered after accidents.

This amount contains on one hand several batteries that were not deformed and thus appropriate for a second use. On the other hand, there are batteries included that are damaged and therefore not appropriate for a second use. In Ref. [16] a superposition (penetration depths and distribution of typical battery installation positions) was realized to estimate the number of deformed batteries from accident cars. With an extrapolation, it was possible to estimate the number of deformed batteries within the amount of accident EV. This portion of damaged batteries (0.8% of all accident batteries) was so small, that all batteries from accidents were seen as applicable for second use.

3.3 Ageing Function for the Car Lifetime

The third input parameter of the model was the ageing function of the car. To describe the probability of a car of still being registered along the years from its first registration [18], the Weibull reliability function was used as suggested by Ref. [17], represented in Eq. (3), and seen in Fig. 6.

$$relf_{\text{Weibull}}(t, \alpha, \beta, \theta) = e^{-(\frac{t-\theta}{\beta})^{\alpha}} \qquad (3)$$

where:

θ is the location, being a minimum value of t that the end of life can occur, which will be the age at which scrappage starts; in unit time.

α is the shape, being the failure steepness for a generic car. It is always > 0 and determines the Weibull distribution slope (in that case > 1 as the failure rate increases with age); no dimensional parameter.

β is the scale, a parameter indicating the characteristic service life for a generic car; in unit time.

t is the time, the actual age of a car in units of time, being the only variable of the equation.

To identify a scenario for the generic car lifetime in Germany, information about the Weibull parameters for a car's lifetime in Germany in 1995 [19] was chosen as the starting point:

θ = -5 years; α = 5; β = 15.7 years;

In Ref. [19], the authors found as a general rule that choosing θ in years similar to -α fits well to real data for most of the countries in their research.

To update that relatively old information for the forecast, calculations were made for determining the Weibull parameters for a car's lifetime in Germany based on information from "Vehicle registrations (FZ15): Stock of motor vehicles and trailers by vehicle age (KBA)" [20, pp. 6-7].

Stock data were given depending on the time of first registration of individual cars, allowing recalculating this information based on the age of the cars. In year 2008 the statistics changed in categorizing ambulances and caravans, so data from earlier years had to be fitted (by a factor reducing the step) to the number of cars in 2008. The stock of the first year was used as absolute number (100%) for calculating the percentage of still registered cars depending on their age, because directly using the first registration numbers would have caused a 9% loss in the first year. One reason for this difference is short-term registrations of cars, which are exported to other countries shortly after registration, thus causing a registration but no stock at the first of January, when the statistic is recorded. The solicited results are marked in Fig. 6 using different colored dots depending on the first registration years.

The Weibull parameters were fitted manually to this graph to minimize the error relative to the average of the available values at each age, to meet the requirement to have θ (in years) similar to -α, and third that the integral of the reliability function should be nearby 13.45, which was the ratio of the 2016 stock (45,071,000 cars) by 2016 new registrations (3,350,000 cars). In this way, the calculated number of existing cars in steady state will fit to the actual reality.

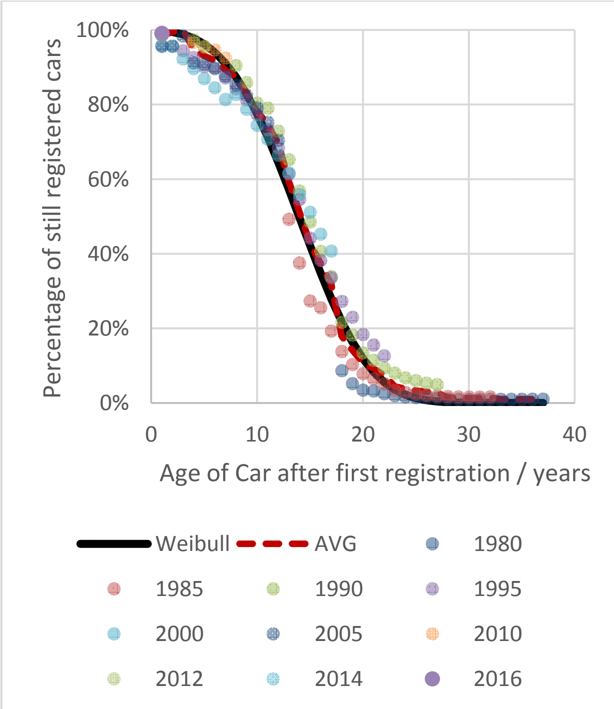

Fig. 6 Registration rate depending on age of the cars (depending on year of first registration) and fitted Weibull reliability function for the car's probable lifetime.

Although the past trend showed an increasing reliability of cars, no base to forecast this trend to the future was found.

The following results were obtained and used for the forecast:

θ = -3.0 years; α = 3.5; β = 17.7 years;

The according function is shown as black line in Fig. 6.

3.4 Mathematical Model to Calculate the 2nd Use Battery Emission to the Market

The parameters typical life (ageing) and accident rate will likely fit to battery cars as well. Nevertheless the result strongly depends on the not well-known registration rate of cars in future. Therefore, it was decided not to differentiate between car types, suppliers and so on. Thus, a generic car life could be represented by a typical curve of the probability of being still in use/registered (abovementioned reliability function).

In the proposed time discrete forecast, all vectors are indexed with the parameter *m*, a representative of time.

To find the curve for registered cars in all years, the reliability vector has to be convoluted (* in Eqs. (4)-(6)) with the registration of new cars to the market as seen in Eq. (4):

$$car_{\text{registered}}(m) = car_{\text{new registered}}(m) * car_{\text{typ life}}(m) \quad (4)$$

The emission of aged batteries could be calculated by a convolution with a (still unknown) vector describing the probability of deregistration as of ageing according to Eq. (5):

$$bat_{\text{aged}}(m) = car_{\text{new registered}}(m) * car_{\text{typ ageing}}(m) \quad (5)$$

The amount of defect batteries caused by accidents could be calculated using this convolution shown in Eq. (6):

$$bat_{\text{accident}}(m) = car_{\text{new registered}}(m) * car_{\text{typ accident}}(m) \quad (6)$$

The described model assumes the following parameters as known to start the forecast:

(1) Simulation time step: time format of all input and output data, time distance between time points *m* and *m*+1;

(2) Accident rate $p_{\text{accident while step}}$ of a car, in unit 1/time step;

(3) The emission of new cars to the market $car_{\text{registered}}(m)$ as a vector, in nr. of cars in the certain time step;

(4) A statistic representing the typical life of a generic car.

The time step was selected to be one year, which is accurate enough, considering the weak assumptions for initial car registrations. In the present model a car's life was calculated based on the Weibull distribution from Eqs. (7) [21] and (8) [22]:

$$pdf_{\text{Weibull}}(t,\alpha,\beta,\theta) = \frac{\alpha}{\beta}\cdot\left(\frac{t-\theta}{\beta}\right)^{\alpha-1}\cdot e^{-\left(\frac{t-\theta}{\beta}\right)^{\alpha}} \quad (7)$$

$$cdf_{\text{Weibull}}(t,\alpha,\beta,\theta) = 1-e^{-\left(\frac{t-\theta}{\beta}\right)^{\alpha}} \quad (8)$$

The PDF (probability density function) describes the probability that a car will be deregistered at a specific date in its life. After calculating the time discrete PDF, the vector was normalized to 1, to avoid calculation errors as of the limit not to calculate in infinite future (error < 0.5%). This vector was recalculated to the probability, that a still registered car will be deregistered in a certain time step:

$$p_{\text{deregister while step}}(m) = \frac{pdf_{\text{Weibull}}(m,\alpha,\beta,\theta)}{1-\sum_{t=0}^{t=m-1} pdf_{\text{Weibull}}(t,\alpha,\beta,\theta)} \quad (9)$$

$\sum_{t=0}^{t=m-1} pdf_{\text{Weibull}}(t,\alpha,\beta,\theta)$ is a term for the probability of a car deregistration before the certain time step m. Here, a time discrete representation of the CDF (cumulative distribution function) of the Weibull distribution based on the PDF was used to settle rounding differences. Due to calculation errors with float values, the results need to be limited to 1.

The Weibull CDF represents the probability for a deregistered status of a generic car as of both reasons (age, accident) in a certain time step.

To calculate $car_{\text{typ life}}(m)$, which represents the probability for a car still being registered starting from its registration, a time discrete version (Eq. (10)) of the Weibull reliably function (Eq. (3)) deduced from the Weibull PDF results was used to achieve consistent time-discrete data:

$$car_{\text{typ life}}(0) = 1 \quad (10)$$

$$car_{\text{typ life}}(m) = \prod_{T=1}^{T=m} 1 - p_{\text{deregister while time step}}(T-1)$$

Eq. (11) now allows to separate both reasons for deregistration (accident, age):

$$p_{\text{deregister while step}}(m) = p_{\text{ageing while step}}(m) + p_{\text{accident while step}} - p_{\text{ageing while step}}(m)\cdot p_{\text{accident while step}} \quad (11)$$

To calculate the probability of ageing in a certain time step, Eq. (11) was transformed to Eq. (12):

$$p_{\text{ageing while step}}(m) = \frac{p_{\text{deregister while step}}(m) - p_{\text{accident while step}}}{1-p_{\text{accident while step}}} \quad (12)$$

Due to float rounding errors, the results should be limited to values below 1. Additionally, if the accident rate was above the probability of deregistration based on the Weibull statistics (negative result) in the first months, these values must be set to zero. Using the actual input values, the error in additionally generated batteries was below 0.5 % and was removed completely by linear reducing the output vectors $car_{\text{typ ageing}}(m)$ and $car_{\text{typ accident}}(m)$.

As there was a probability of aging and accident in the same time step, this amount was considered (subtracted) accordingly in the above-mentioned Eq. (11). To generate the output for aged and accident batteries separately, it was necessary to decide where to put this amount. Even when years are used as time step, this error was very low (< 0.2% of absolute cars) compared to the error of the input estimations. Thus, the authors chose to distribute this error equally employing Eqs. (13) and (14):

$$car_{\text{typ ageing}}(m) = car_{\text{typ life}}(m)\cdot p_{\text{ageing while step}}(m)\cdot\left(1-\frac{1}{2}p_{\text{accident while step}}\right) \quad (13)$$

$$car_{\text{typ accident}}(m) = car_{\text{typ life}}(m)\cdot p_{\text{accident while step}}\left(1-\frac{1}{2}p_{\text{ageing while step}}(m)\right) \quad (14)$$

4. Results and discussion

The above described model and data allow to predict the number of available batteries per year from present until 2030 coming from accidents on one side, and the number of available batteries per year coming from end-of-life electric vehicles (HEV, PHEV, BEV, and EV) on the other side. Figs. 7-14 summarize the results for all the studied technologies. As not all references specified the different vehicles technologies uniformly, HEV, PHEV, and BEV were treated as separate sources from EV for the model.

The results show that the number of available batteries is rising with the biggest slope between 2020 and 2025. This finding results from an assumed steady state of initial registrations in 2035 and from a typical lifetime for cars of 15 years (Fig. 6). In 2030, the total amount of available second use batteries will be between 135,000 units/year and 500,000 units/year. The amount of batteries coming from end-of-life vehicles (between 120,000 and 430,000 per year in 2030) will be much bigger than the number of batteries coming from accidents (between 15,000 and 70,000 per year in 2030). Among end-of-life vehicles the biggest share of batteries will be obtained from hybrid electric vehicles (between 70,000 and 240,000 per year in 2030, Fig. 8), followed by plug-in hybrid electric vehicles (between 30,000 and 130,000 per year, Fig. 10). The smallest amount will arise from accident battery electric vehicles (between 2,000 and 10,000 per year, Fig. 11), of which the amount of batteries, which are not available for 2nd use after accidents, will be relatively low.

The quality of this prediction about the availability of batteries for second life strongly depends on the quality of the input data. Analysis of different literature sources during this study to obtain input data showed a complex situation concerning the stated technologies (HEV, PHEV, and BEV versus EV). In addition, the quality of the listed figures like future new EV sales strongly depends on several influencing factors like policy directives from the EU or German Government incentives, as well as on electric vehicle prices. Updating

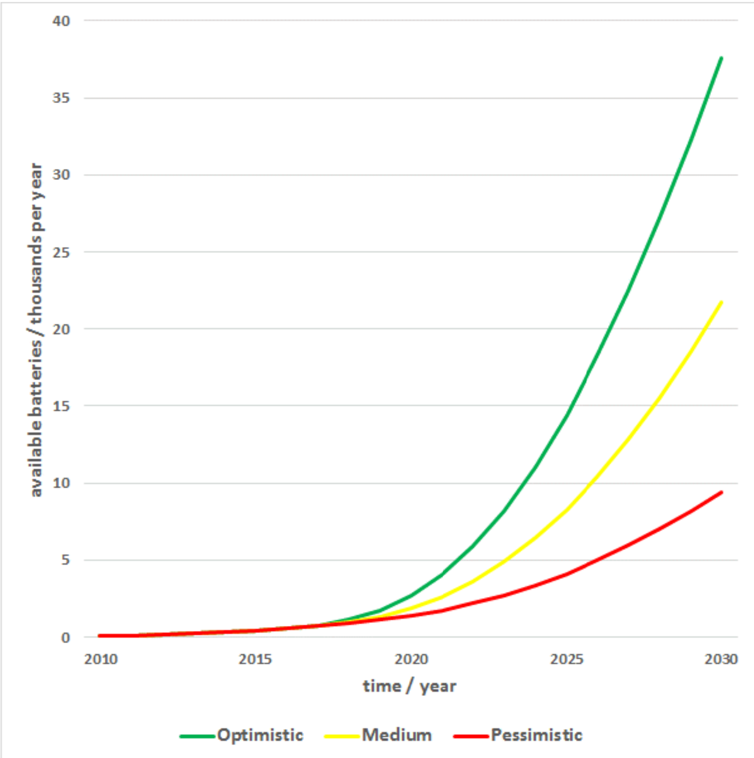

Fig. 7 Available batteries from accidents for HEV 2010-2030.

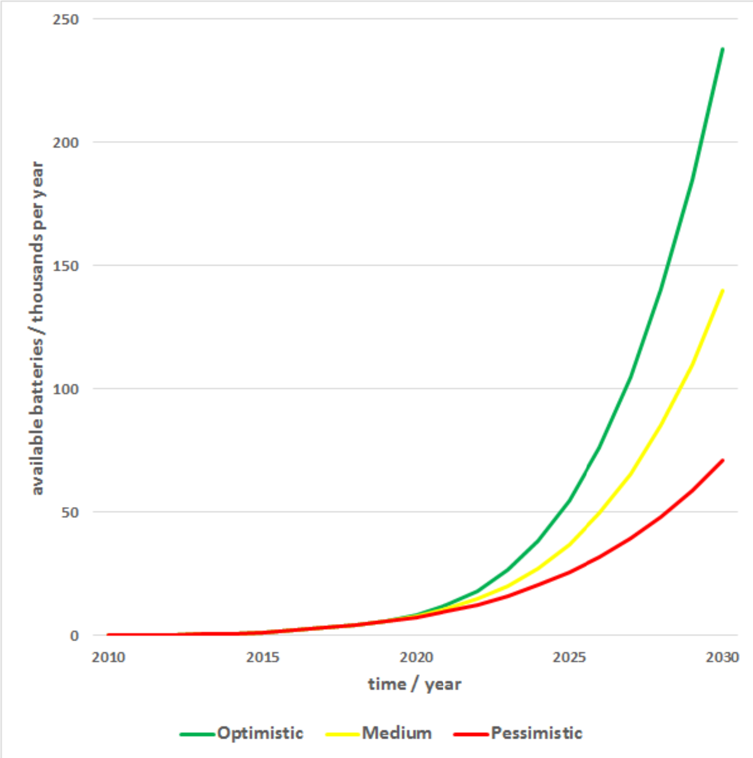

Fig. 8 Available batteries from end-of-life for HEV 2010-2030.

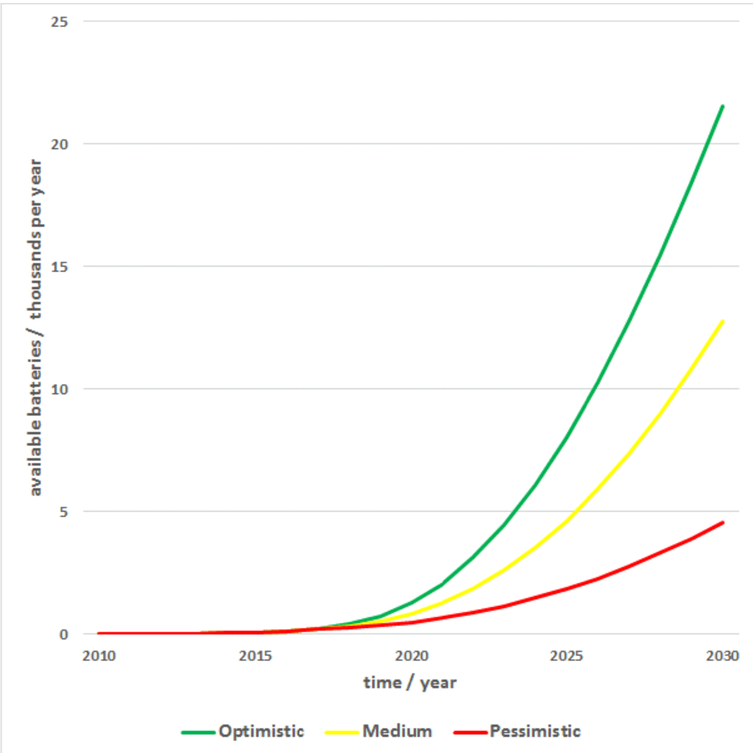

Fig. 9 Available batteries from accidents for PHEV 2010-2030.

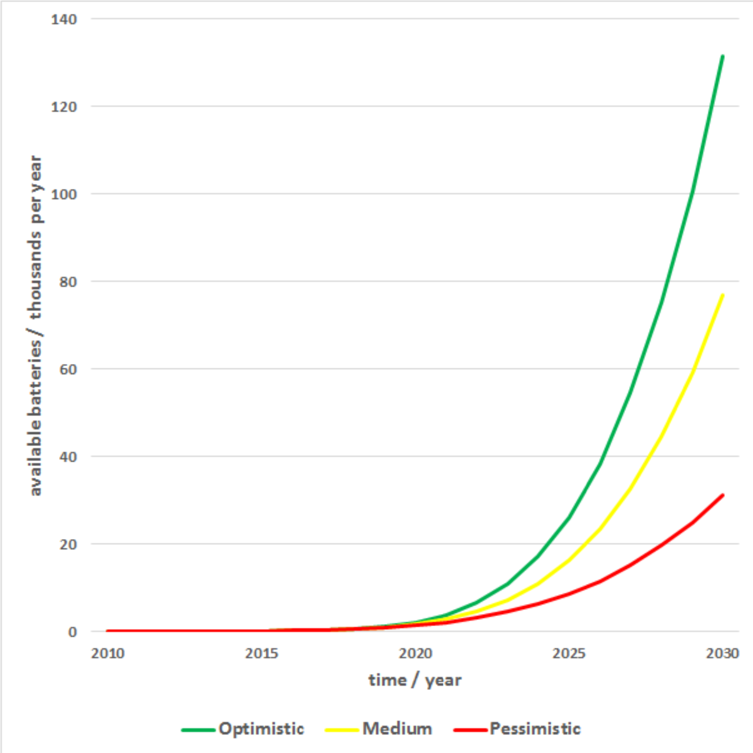

Fig. 10 Available batteries from end-of-life for PHEV 2010-2030.

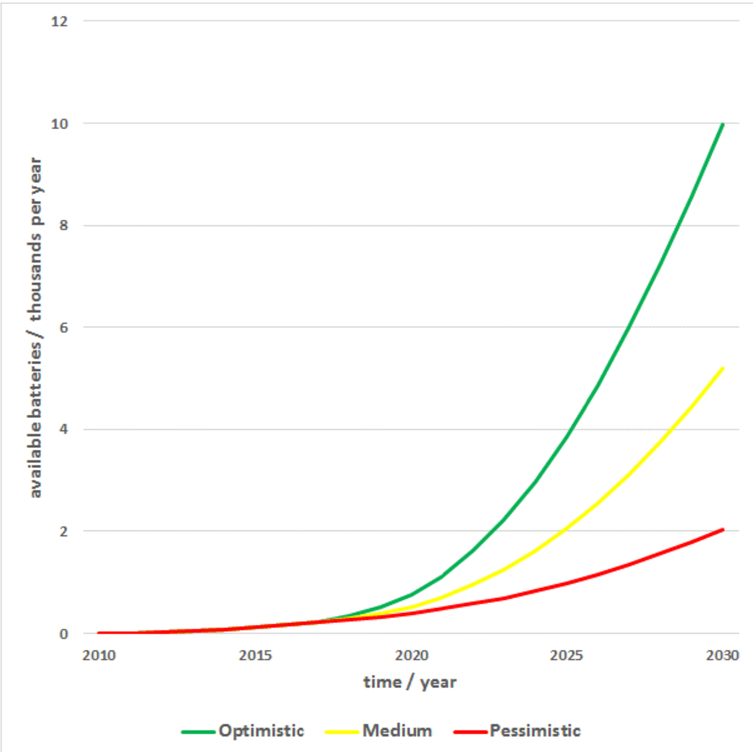

Fig. 11 Available batteries from accidents for BEV 2010-2030.

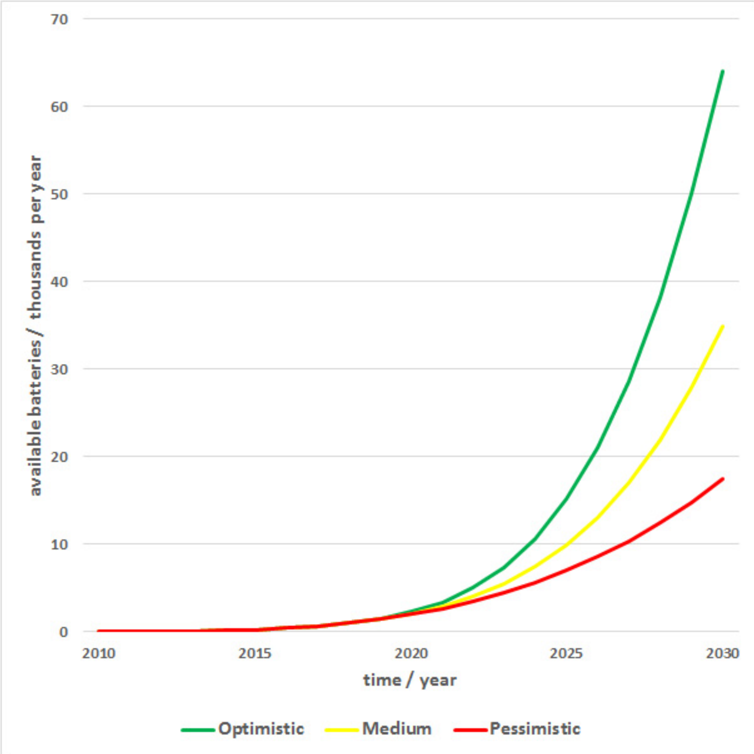

Fig. 12 Available batteries from end-of-life for BEV 2010-2030.

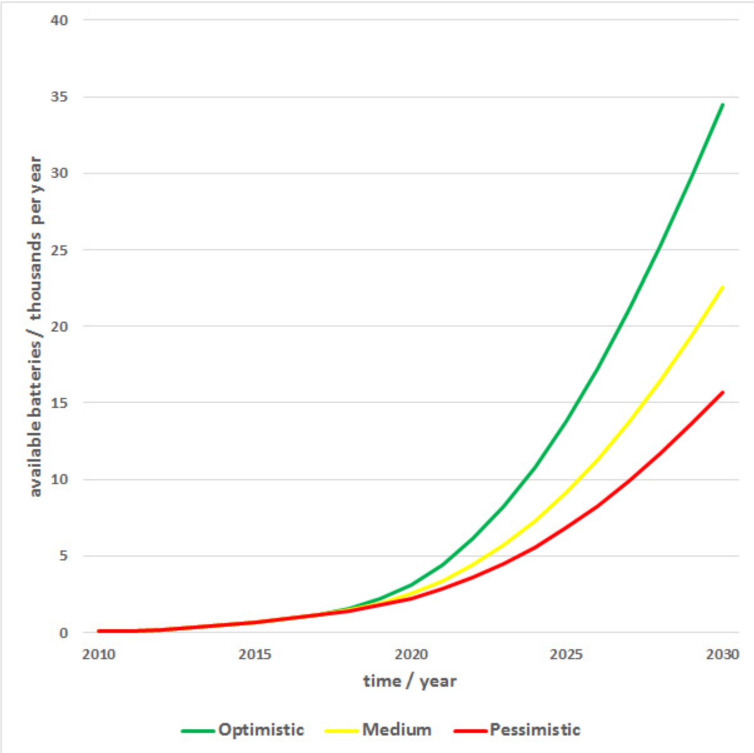

Fig. 13 Available batteries from accidents for EV 2010-2030.

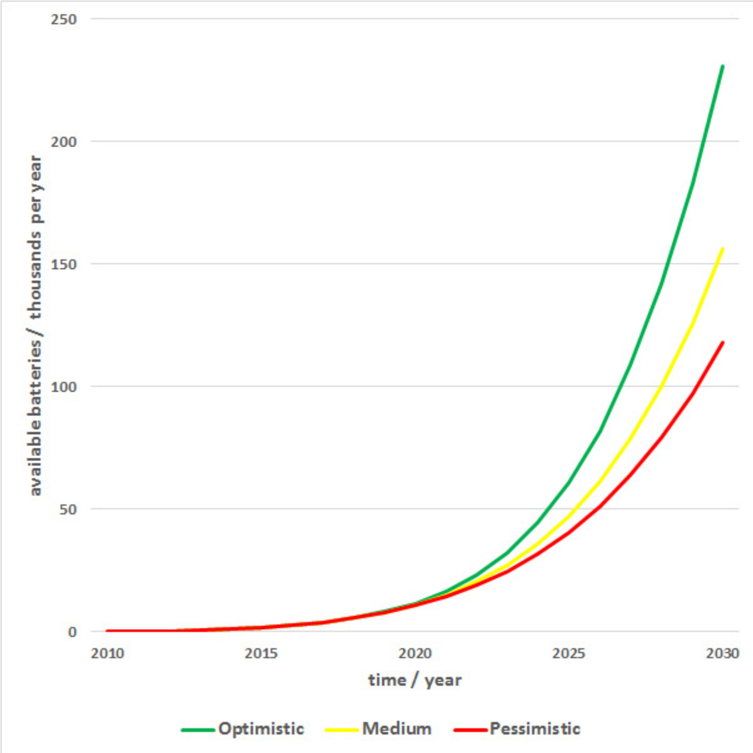

Fig. 14 Available batteries from end-of-life for EV 2010-2030.

the model with newly available data will allow a more reliable picture about the number of batteries from accidents and end-of-life vehicles after 2030.

While German automotive companies like Daimler or BMW already explore the 2nd use lithium ion battery market [23], form consortiums and establish cooperations aiming at innovating projects to give a second life to batteries coming from electric vehicles, several challenges to this very specific market should not be disregarded [24].

In today's vehicles, a plethora of different battery types concerning chemistry or formats is applied [25]. It can be expected that this complexity will increase as new technologies enter the market and the obtained values of available batteries for second use will be split into small portions of similar battery types. In the same time, the efficiency of stationary storage systems strongly depends on a most homogenous distribution of battery types. Also, different aging behavior of cells in 2nd use systems is a challenge when combining these sub-systems into bigger units. Potential providers will have to collect the cells from the user, identify the cells' status correctly, organize safe transportation, and ensure assembly of similar cells in a most economical way to succeed in this new market—a challenge that will surely need a significant amount of batteries available to be profitable, but that will gain importance in the future.

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