Future Trends of the automotive Li-Ion Battery Supply Chain in Germany

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Dynamic effects on raw materials and employment

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Researchers as well as car manufacturers expect a greater market penetration of electric vehicles (EV) in Germany and worldwide for the next years and decades. The Lithium-ion battery represents the core technology of electrically driven cars, because it defines technical and economical limitations. Consequently, the knowledge about this technology and the ability to produce it are the relevant drivers for a successful EV diffusion. Due to the expected great market penetration, the battery supply chain has to grow extremely in future or otherwise the economic potential gets lost. But the prospective impacts of this fast growing demand on the supply chain and its environment can be hardly estimated. Therefore, the aim of this paper is to build up a first simulation model, which demonstrates the development of the automotive Li-ion battery supply chain in Germany over the next decades. By means of various EV diffusion scenarios we want to show expected future trends and their impacts on the battery supply chain, on raw materials, production capacities and on employment effects.

System Dynamics, Electric Vehicles, EV, Closed Loop Supply Chain, Li-ion Batteries, Diffusion

1   Introduction

Due to climate change and the global shortages of resources there has been a rethinking of individual mobility basing on combustion engines. These external drivers on the one hand and the strong technological improvements of batteries on the other hand led to the introduction of first electric vehicles (EV) during the last years (see Kley et al. 2011). But researchers as well as car manufacturers expect a greater market penetration for the next years and decades.

The most promising energy storage technology at the moment is the Lithium-ion (Li-ion) battery. This type of battery describes the core technology of electric vehicles, because it defines technical limitations, as power and range (e.g. Tate et al. 2008), and economical limitations, as the purchase price (e.g. Nemry et al. 2009; Brooker et al. 2010). Consequently, the knowledge about this technology and the ability to produce it are relevant drivers for a successful EV diffusion. Beyond the technical know-how, this technology holds high economic advantages as value and employment creation. Summing up, the battery supply chain will play a central role for the car manufacturing in future.

The automotive industry is one of the most relevant sectors in Germany. The aim of the German government is to establish Germany as lead market and provider for electric mobility (see NPE 2011). If there will be such a great market penetration as expected, this leads to a high demand of Li-ion batteries, too. Consequently, the battery supply chain has to grow extremely or otherwise the economic potential gets lost.

The effects and impacts of this fast growing demand on the supply chain and their sub-systems can be hardly estimated. Due to feedback loops, delays and the long time horizon it seems impossible to give valid information about the existing economic potential, the need of raw materials and recycling activities and the development of employment effects. Moreover, there are uncertainties of the diffusion of electric cars and of a high number of further influencing factors, such as labor productivity, recycling quotes and production capacities. Finally, there exists a high variety of future trends for the battery supply chain in Germany and its environment.

Therefore, the aim of this paper is to build up a first simulation model, which demonstrates the automotive Li-ion battery supply chain in Germany over the next decades. By means of various scenarios we want to show expected future trends and their impacts on the supply chain and its environment, as

- the need of raw materials and the potential of recycling critical materials in future and
- the development of employment in Germany and the involving need for qualified staff.

To reach this aim, the paper is structured as follows: after the introduction, chapter 2 works out the dynamic hypotheses, which describes the linkage of the electric car diffusion, the battery supply chain, raw materials and employment. Afterwards (chap. 3), the causal loop is transferred into a first stock and flow model, which is filled with data from actual studies afterwards. In chapter 4, we simulate various diffusion scenarios for

electric cars taken from actual research reports and analyze their influences on the battery supply chain and consequently, on raw materials and employment. Finally the paper closes in chapter 5 with a conclusion and an outlook for further research.

2   Linking electric car diffusion and the Li-ion battery supply chain

As literature shows, System Dynamics is a practical tool for analyzing future trends of closed loop supply chains or to demonstrate the market diffusion of innovative technologies. Moreover, system dynamics is already used for analyzing the dynamics of electric car diffusion. The basic ideas of those topics can be described by the following:

Closed loop supply chains are modeled and simulated in lots of system dynamics contributions and publications. A high variety of topics is regarded under different points of views, as e.g. replacement part management (e.g. Spengler/Schröter 2003; Lehr/Milling 2009), remanufacturing processes (e.g. Rodrigues et al. 2012) or stock management (Mutallip/Yasarcan 2012). A basic structure for recycling processes, as e.g. for replacement parts, is delivered by Fleischmann 2001. The author describes the generic idea of a dynamic recycling management: A new product generation is introduced to the market and after a specific time horizon the first products of this generation become obsolete. Consequently, these products may be recycled and delivered back to the market again. Those material feedbacks exist all over the whole life cycle of new product generations and continue a long time after the last product was introduced to the market. Accordingly, the recycling rates or rather the material feedbacks depend on the market stock and may be used to decrease the need of raw materials. Following this basic idea, the simulation of closed loop supply chains is an adequate instrument for analyzing the material feedback during the battery production life cycle.

Also the diffusion of new technologies is a relevant topic in system dynamics research. Generic structures are shown for example in Sterman 2000, Morecroft 2007 or Warren 2008. Other authors transferred the famous diffusion model of Bass (1969) into a system dynamics structure and are then able to analyze the influences of single factors on the diffusion progress (see Maier 1998; Milling, Maier 1996). Moreover, those models give recommendations for the innovation management of companies aiming at a faster or greater diffusion of new products under competition (e.g. Milling 2002). As a consequence of this system dynamics diffusion research, there exist some simulation models, which deal explicitly with the diffusion of electric vehicles, but under various points of views (e.g. Keith et al. 2012; Wachter/Spengler 2012).

But up to now, there seems to be a gap considering the diffusion of electric vehicles and their impacts on the supply chain of batteries and its environment. Because of the high relevance of this topic for policy makers and manufacturing companies in Germany, we will combine existing approaches and present a first automotive Li-ion battery supply chain model for Germany.

As a first step, this paper works out the linkage between electric car diffusion, the demand and production of batteries and the involving dynamic effects on raw materials

and employment. Therefore, Figure 2-1 shows a causal loop diagram describing the dynamic hypotheses of the battery supply chain model with sub-sectors.

At first it gets obvious, that the model uses four sub-systems: the sales market, for defining the diffusion of electric cars, the production and supply chain and the supply markets, for analyzing the dynamic effects on raw and recycled materials as well as on employment.
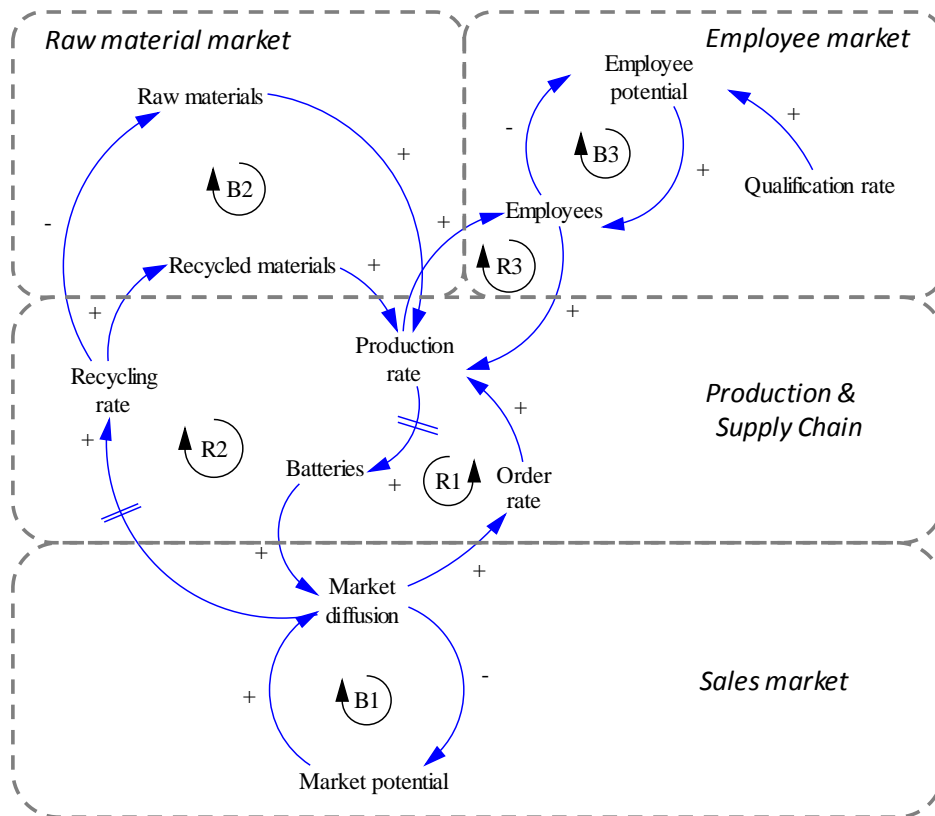

Figure 2-1: Dynamic hypotheses for the battery supply chain model

The sales market describes the diffusion of electric cars. Therefore, this sub-system holds the market potential, defining the saturation limit of the new technology. The market diffusion represents the number of sold EV. The higher the market potential or rather the saturation limit, the higher the number of sold electric cars over time and the smaller the remaining potential of customers. Consequently, this balancing loop (B1) describes the market diffusion by means of an S-shaped growth.

Depending on the progress of the market diffusion, the order rate as well as the production rate increase over time (Sector "Production & Supply Chain"). The manufacturing of batteries is a time-consuming process, but a few weeks or months later they ran through the whole supply chain and are delivered to the market. This reinforcing loop (R1) demonstrates the interconnection between the demand of batteries and the production rate. Afterwards the battery is in usage and after a longer time of maybe a few years

the obsolete battery gets recycled. Consequently, the growth of the market diffusion leads to a few year time-delayed increase of the recycling rate.

The supply market of materials is separated into two sectors: the raw materials and the recycled materials. This leads to the opposing trend that a higher recycling rate leads on the one hand to a higher availability of recycled materials and on the other hand to a decreasing demand of raw materials. Consequently, these connections close two loops (R2 & B2). While recycled materials are pushed by an increasing production rate (R2), the need for raw materials is slowed down by a higher recycling rate.

Finally, there exists a linkage to the employee market. This supply market is directly linked with the production rate. A higher production rate leads to a higher demand of employees. This demand gets slowed down by the employee potential, which describes the number of available persons with an adequate qualification. The growth of the production rate leads to an increase of the demand of employees and hence, to an exhaustion of the employee potential. The only possibility to raise the pool of qualified persons is to modify the external driven qualification rate. Accordingly, the pool gets exhausted by a greater production rate and gets raised by a higher qualification rate. The linkage between battery supply chain, employees and qualification is shown by the loops R3 and B3.

3 Stock and flow structure and interaction of the sub-systems

The simulation model has a simple system structure and consists, as already mentioned above, of four sub-systems. The sub-systems and their interaction are illustrated in Figure 3-1.
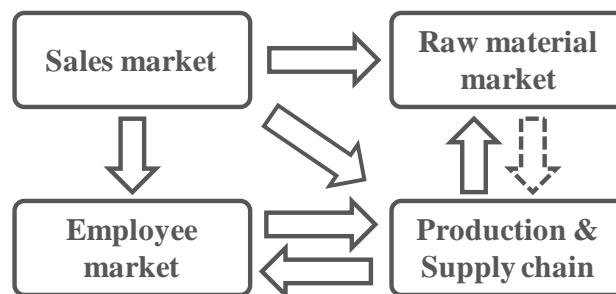

Figure 3-1: Overview of the sub-systems and their interaction

The "Sales market" represents the superior sub-system, which triggers the development in the other three sub-systems by the customers demand for electric vehicles (see Figure 3-2). The model distinguishes between three types of electrically driven cars: The hybrid electric vehicle (HEV), the plug-in hybrid electric vehicles (PHEV) and the battery electric vehicles (BEV). All types of cars influence the Li-ion battery supply chain. For this purpose, Bass's diffusion model for demand development was used as initial point for model and modified to take repeat purchases into consideration (adopted from Sterman 2000; Bass 1969). A certain customer potential exists at product introduction,

which is exhausted over time by the demand. "Customers" describes the client stock. "Obsolescence", the period in which an electric vehicle ages and must be repurchased when the client becomes a potential customer again (see Sterman 2000; Stumpfe 2003). Alpha and beta are factors for describing the diffusion process (see Bass 1969) for initial purchases. Furthermore, the model shows two specifics compared to the origin models of Sterman 2000 and Stumpfe 2003. The "Obsolence" does not only lead to the repurchase of an electric vehicle´s battery, it also represents the input for the battery recycling of aged batteries. Another special character of the sub-system is the decline of the HEV life-cycle ("Potential customers"). This is based on the assumption, that HEV are only seen as an interim solution.
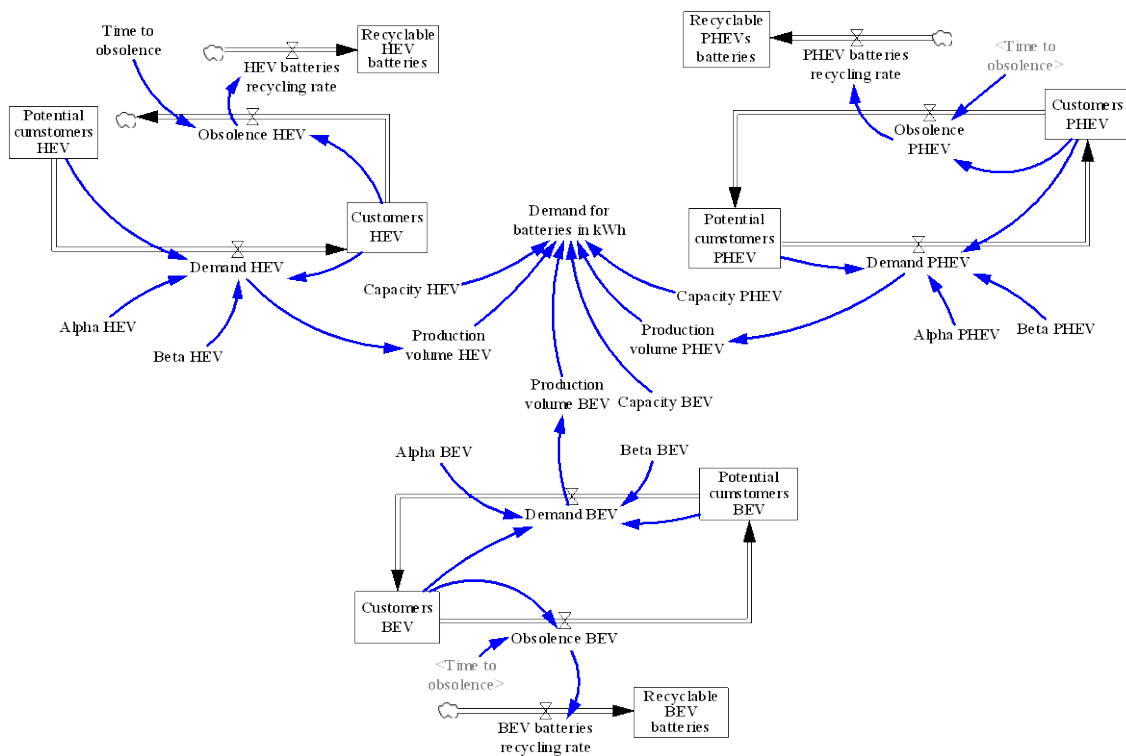

Figure 3-2: Development of the demand for electric vehicles and the required battery capacity

The demand for each kind of electric vehicle, together with their specific battery capacity (in kWh) results in the total demand for produced battery capacity. This value also determines the required working force in the "Employee market" sub-system as well as the required production capacity in the "Production & supply chain". Currently there are different approaches to construct an electric vehicle battery. Besides the design, they differ in the materials used for the cathode, which constitutes the core element of all cells. In the model it is assumed that so called NMC-cathodes are used for the batteries. They contain the materials: Nickel, manganese and cobalt and are seen as one of the most promising cathodes for e-mobility applications.

The sub-system "Production & supply chain" has a common structure (e.g. see Sterman 2000) and is kept quite simple due to the fact that the main emphasis of the model lies

on the sub-systems "Employee market" and "Raw material market". Nevertheless it is necessary to transform the production orders into the final battery. Therefore the sub-system consists of three parts which are depicted in Figure 3-3.

The actual transformation process takes place in the "Production & supply chain", whereat the production rate is dominated by three possible constraints: The existing material capacity, the production capacity of the staff and the installed production capacity. Last named is determined in the part "Capacity adjustment" and follows the demand for batteries in kWh. Because of the novelty of the production processes for EV batteries, production rejects are playing a prominent role and cannot be ignored. This fact is taken into account by the "Production yield" which improves over the course of time from 70 % up to 95%. The rejects are transferred into the sub-system "Raw material market" and are there available for recycling. Finally the third part, "Order rate" offers information about the gap between the current production and the incoming orders.
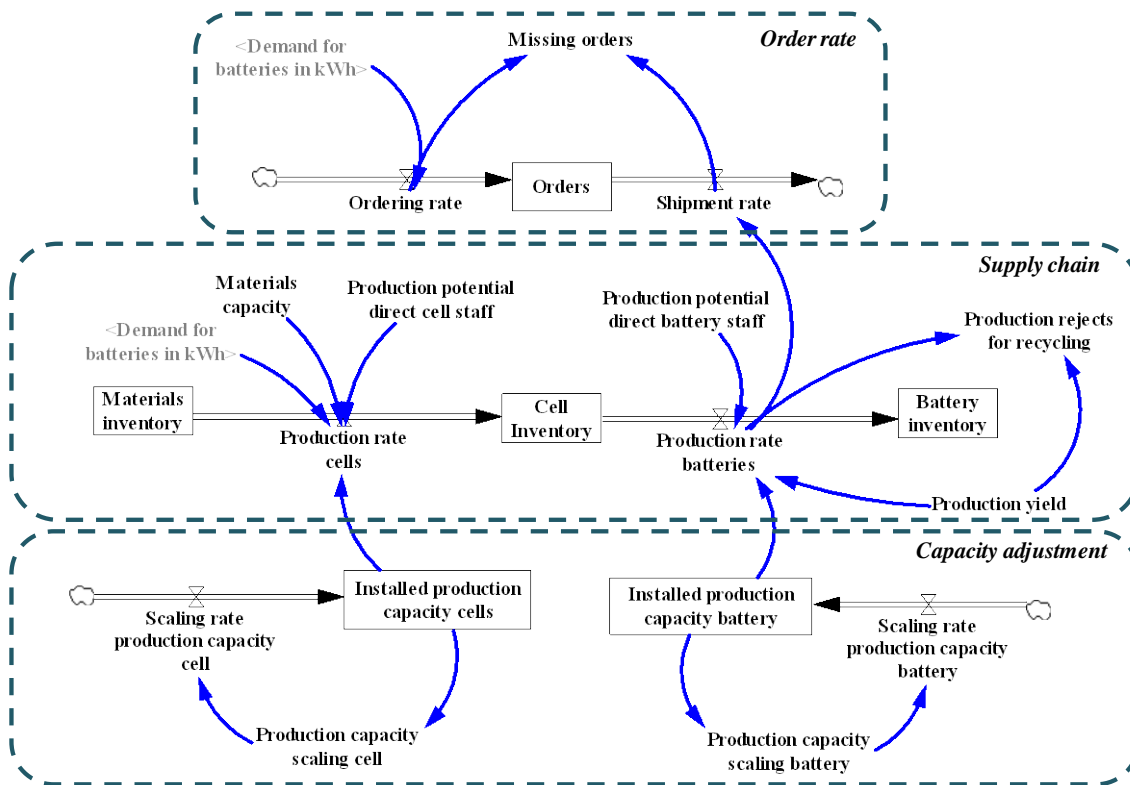

Figure 3-3: Parts of the sub-system "Production and supply chain"

The third sub-system "Employee market" represents one of the major parts of the model. As seen above, the production potential of the staff is one of the limiting factors for the production rate. So it is evident, that for a successful production of electric vehicle batteries, a sufficient availability and productivity of employees is essential. To achieve the necessary reliability for the employment rates, current data from the German "Federal Institute for Employment" were evaluated for the professional groups (see

Destatis 2012). It was taken into account, that cell production and battery production are different knowledge areas and hence, different qualifications are needed. While the emphasis in the cell production lies on chemistry close-by qualifications, the demand for the battery production is by nature from the field of electronics. To consider these different demands for qualification the sub-system includes for each group one adjustment part. The part for the cell staff is illustrated representatively in Figure 3-4.
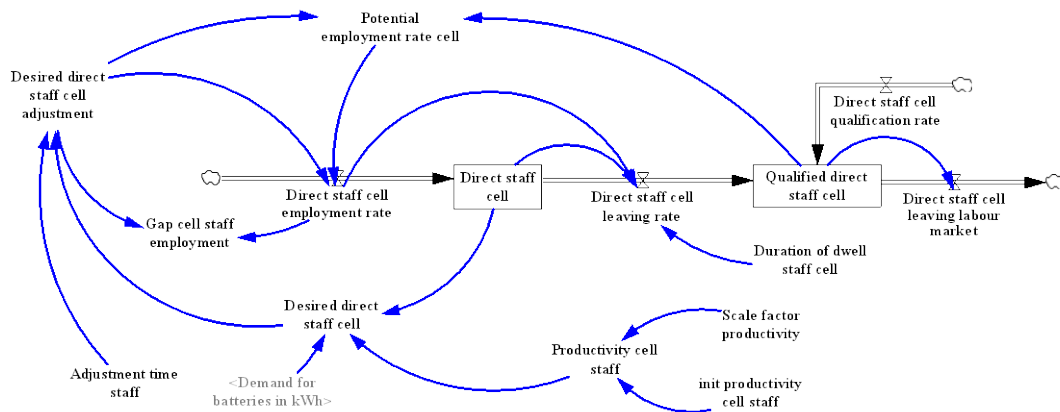

Figure 3-4: The cell staff employment as part of the sub-system "Employee market"

The cell staff adjustment is regulated by the demand for batteries, the available qualified staff and by the "Scale factor productivity". Each employee is able to process a certain amount of kWh. This could lead to the assumption, that with a rising amount of kWh the number of employees also rises in linear manner. But by scale effects and the ongoing advances in processing technology, each employee can handle a growing amount of kWh over the time. The initial values for the scale factor and the required employees are based on information from the Argonne Laboratory (see Nelson et al. 2011).

The last sub-system "Raw material market" represents the process of material procurement and the recycling of batteries, from obsolete cars as well as from the production rejects. Also some approaches for modelling the effects of recycling in system dynamics exist (see Vlachos et al. 2007 or Schröter 2006). But the authors are not aware of any approach concerning the recycling of batteries from EV. The sub-system attends to the cathode materials already mentioned above. The different amount of these materials in a cell as well as the possible yield from recycling is based on the "LithoRec"-process (Buchert et al. 2011). Currently there exists, with the exception of some pilot lines, no facility that is able to recycle materials in a way to use them as primary materials again.

Nevertheless with a rising amount of electric vehicles and recyclable batteries this is only a matter of time. But due to the lack of required information concerning the reuse as primary materials, there is, although this option is in the model integrated (indicated by the dotted arrow in Figure 3-1), no feedback from recycled material back into production. However, the influence of the recycled material on the future material procurement can be depicted and the recycled material is available to be sold on the stock market, which enables an analysis of the net present value. For this analysis, informa-

tion from an existing recycling centre by the Belgian enterprise "Umicore" are used (see EUWID 2011). Furthermore it is possible to examine the share of the required material in its annual global production. The according data is taken from U.S. Geological Survey (see USGS 2013). Figure 3-5 depicts representatively the recycling of lithium.
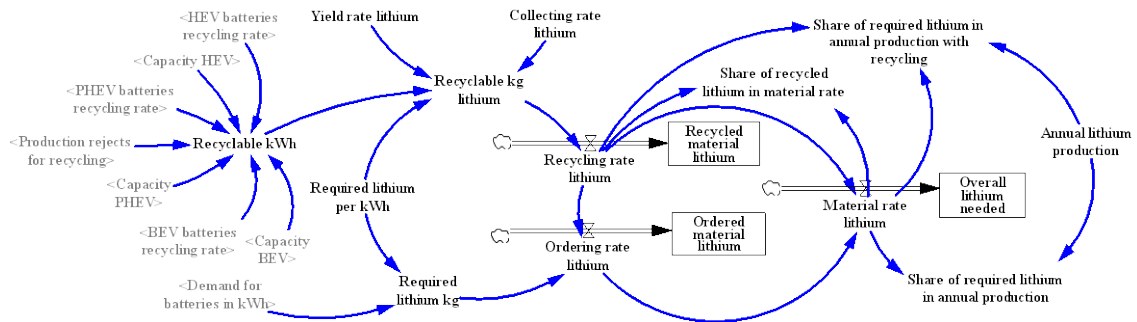

Figure 3-5: Lithium recycling as part of the sub-system "Raw material market"

Based on the "Recyclable kWh", the "yield" – and "collecting rate", the recyclable material can be determined. The "material rate lithium" is designed in a way to use all of the recycled material before ordering additional material.

The four sub-systems are already sufficient for a first model to depict the dynamic hypothesis, carry out simulation runs and gain first insights in the dynamic effects on raw materials and employment.

4 Dynamic effects on raw materials and employment

In order to test the dynamic hypothesis and to generate a deeper understanding of the system's behaviour, various simulation runs and tests were conducted. Some exemplary runs are shown in the following and interpreted to build first hypotheses. The relevant variables changed for the tests are listed in Table 1.

The information about the "Potential customers" is derived from a model developed for the "Office of Technology Assessment at the German Bundestag" which is based on the European transport model "ASTRA" (see Fermi et al. 2012 and Schade et al. 2012). Numbers for the initial employees as well as the productivity factor are calculated from information given in Nelson et al. 2011. The rates for the collection of batteries until the year 2016 are published in the EU's "battery directive 2006/66/ec" (see European Union 2006). For the model it is assumed, that after 2016 the development of the rates continues in the same manner as before. Finally, the information about the qualification rates is published in the German statistical yearbook (see Destatis 2012). It is assumed that for the cell staff, apprentices and graduates from chemical professions match the requirement profile, while for the battery production electrical professions are more suited. Furthermore machine and systems operators are able to work in both areas with an equal share.

	Potential customers HEV	Potential customers PHEV	Potential customers BEV	Initial employees cell	Initial employees battery	Qualification rate cell	Qualification rate battery	Productivity factor	Collecting rate batteries
Base run	12.055.516	4.987.941	3.605.359	198	63	158	509	0.1	0.25 (2012)/ 0.45 (2016)/ 0.65 (2020)/ 0.85 (2024)/ 0.95 (2028)
Oil age	14.459.089	6.189.727	98.786	198	63	158	509	0.1	0.25 (2012)/ 0.45 (2016)/ 0.65 (2020)/ 0.85 (2024)/ 0.95 (2028)
Electric age	14.293.346	6.652.062	4.870.639	198	63	158	509	0.1	0.25 (2012)/ 0.45 (2016)/ 0.65 (2020)/ 0.85 (2024)/ 0.95 (2028)
Adjustments in simulation	-	-	-	-	-	247	-	0.5	0.95

Table 1: Overview of the variables and constants used for the simulation runs

Due to the fact that not all graduates are going to work in the field of battery production, it is expected, that every fifth graduate is willing to work in the battery production. However, it is considered that from these potential employees only further 20 % possess the required qualification level. In the following the model and its behaviour will be shown by means of the "Base run" scenario.

4.1 Results of the „Base run" scenario

The "Base run" scenario starts, as shown in Table 1, with a lower number of potential customers for HEV and PHEV compared to the other two scenarios. Nevertheless it is estimated that BEV will also play a dominant role in the observed period. Figure 4-1 depicts the diffusion of the different kinds of electric vehicles as well as the resulting demand for produced kWh battery capacity, which is needed to equip the vehicles with an according battery. It can be observed, that the diffusion of the HEV shows the fastest growing curve. This is reasonable because of the lower costs for HEV batteries. The HEV reach their peak between 2019 and 2020 before they steadily deplete. The PHEV are growing more slowly and peak in 2022. Their number will finally level off at a value around 450.000 vehicles. The demand for BEV is beginning to rise at the same time when the HEV growth curve begins to turn. They develop slowly but constantly, until they reach the same level as the PHEV in 2030.

Figure 4-1 shows the impact of the diffusion of all types of electric vehicles on the total demand of batteries and hence, on the battery capacity measured in kWh. The demand follows the rise of the Hybrid electric vehicles but while their number declines, the demand for batteries stays on comparable level. The reason for that lies in the higher amount of kWh needed for PHEV or BEV. While HEV only contain a battery with 3 kWh, the PHEV are equipped with a 15 kWh battery and BEV even with 30 kWh. By means of that, the lower number of those is able to compensate the effect of falling demand for HEV.

To serve the market with the desired amount of batteries an equivalent number of employees is needed to produce them. The potential for a high degree of automation is

higher in the battery production than in the cell production. Due to that fact we assume, that an employee in the battery production is able to produce a higher amount of kWh than an employee in the cell production. This effect results in different numbers of employees for each stock. The employees required to produce the desired kWh shown in Figure 4-1 are depicted in Figure 4-2.
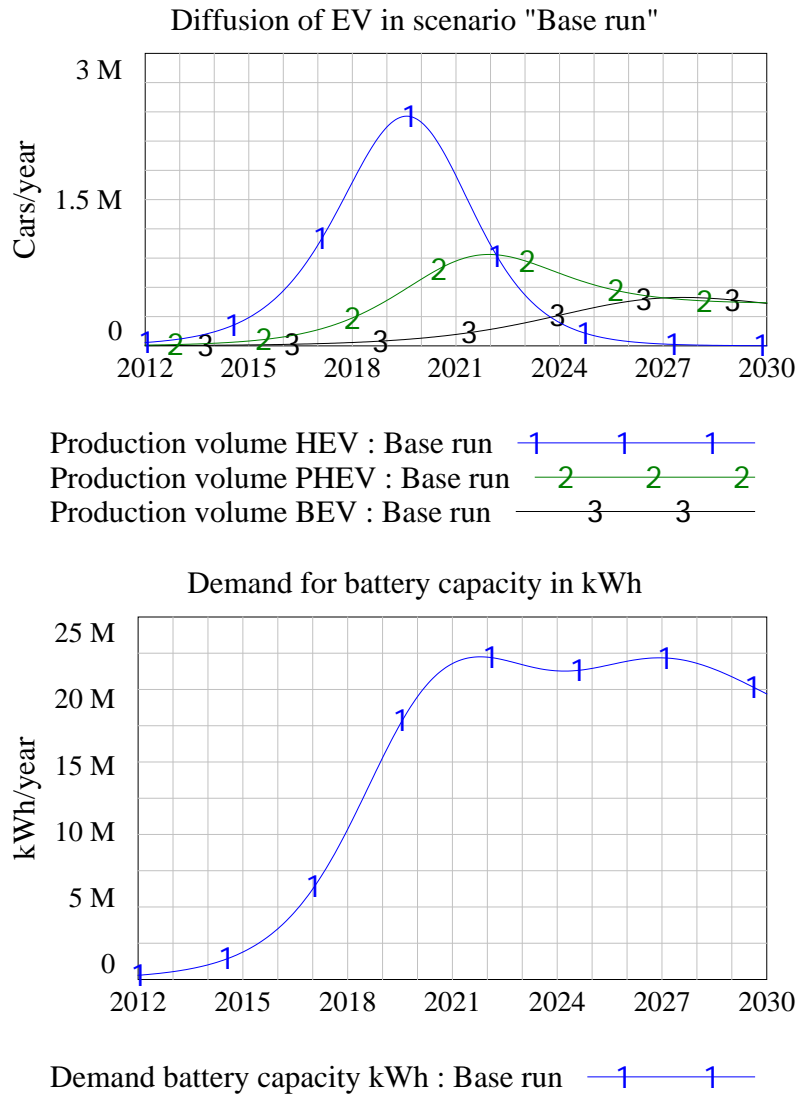

Figure 4-1: Diffusion of electric vehicles and the involving demand for batteries measured in kWh, for the "Base run".

The effect of different productivity levels gets clear by analyzing at the relation between the cell staff and the battery staff. The required number of employees in cell production is with a value of 770 more than three times higher. The required indirect staff levels at around 80 employees. While the graph for the battery and indirect staff flattens and follows the curve of demand, the curve for the cell employees is still constantly rising. The reason for that anomaly can be detected on the lower diagram of Figure 4-2. While there

are no recruitment deficits for the battery and indirect staff, the cell production suffers under an insufficient recruitment rate beginning with the year 2016.

Development of the employee stock in scenario "Base run"

Direct staff cell : Base run ——1——1——1——1——1——
Direct staff battery : Base run ——2——2——2——2——2——
Indirect staff : Base run ——3——3——3——3——3——

Recruitment deficits in the scenario "Base run"

Gap cell staff : Base run ——1——1——1——1——1——
Gap battery staff : Base run ——2——2——2——2——2——
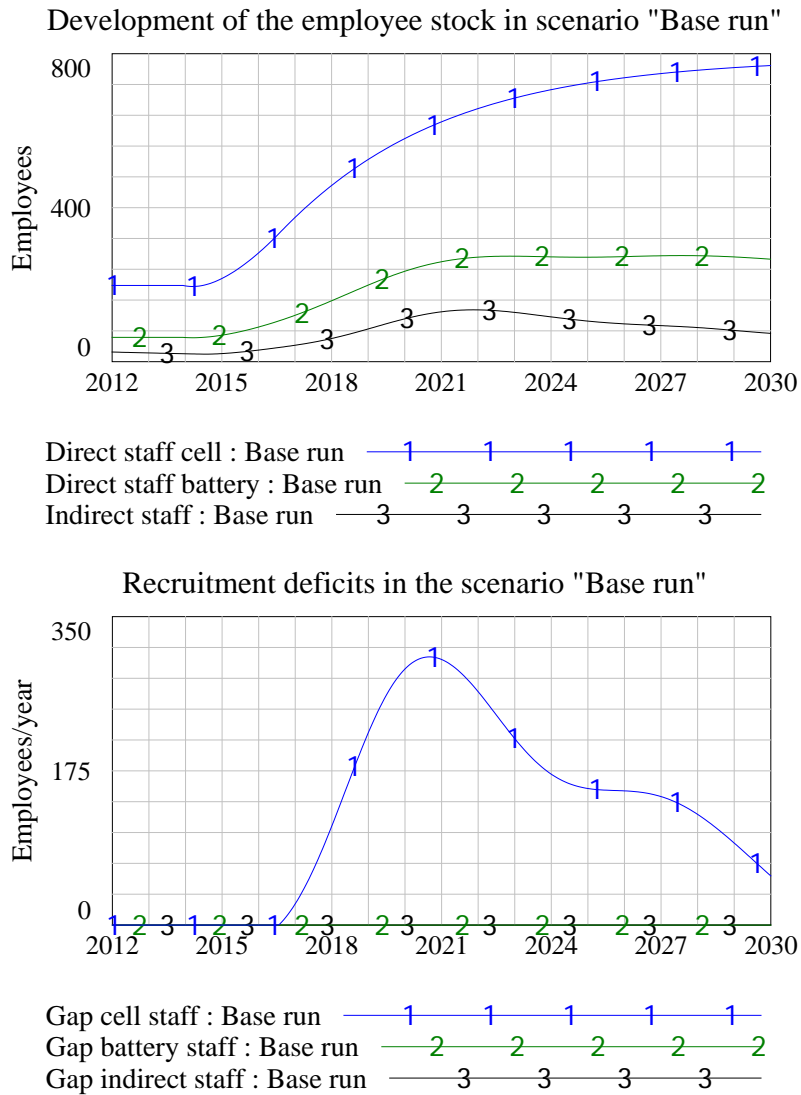Gap indirect staff : Base run ——3——3——3——3——

Figure 4-2: Development of the employee stock and the deficits in recruitment

Besides the dynamic effects on employment, the recycling constitutes the second emphasis of the model. To generate a better understanding, the required material for the battery production is compared to the annual global production in the year 2012. Three materials which are all contained in the cathode of the observed cell type were closer examined: Lithium, cobalt and nickel. Their share in production according to Figure 4-1 is depicted in Figure 4-3.

The development for required material is similar to the demand curve. But while the share of nickel constantly lies under 1%, the share of lithium and cobalt constitute nearly 10% of the annual production, only for Germany. The lower diagram of Figure

4-3 explores how this big share can be in influenced by establishing recycling activities for used and rejected batteries.

Although collecting rates were introduced before, values between 25% and 45% show no effects on the share of the annual production. The development of both curves proceeds similar until 2020 when the collecting rate rises to 65%. The steadily rise is cut down and peaks in 8% share of the annual production. Afterwards, further two changes in the collecting rate take place and lead to an instantly drop in share. Finally, in the year 2030, the share e.g. for cobalt dropped down on 2 %, compared to 8.2 % without recycling measurements before.

Share of required material in its annual production

Share of required lithium : Base run ——1——1——1——
Share of required cobalt : Base run —2——2——2——2—
Share of required nickel : Base run ——3——3——3——3—

Share of required material in its annual production with recycling

Share of required lithium with recycling : Base run ——1——
Share of required cobalt with recycling : Base run ——2——
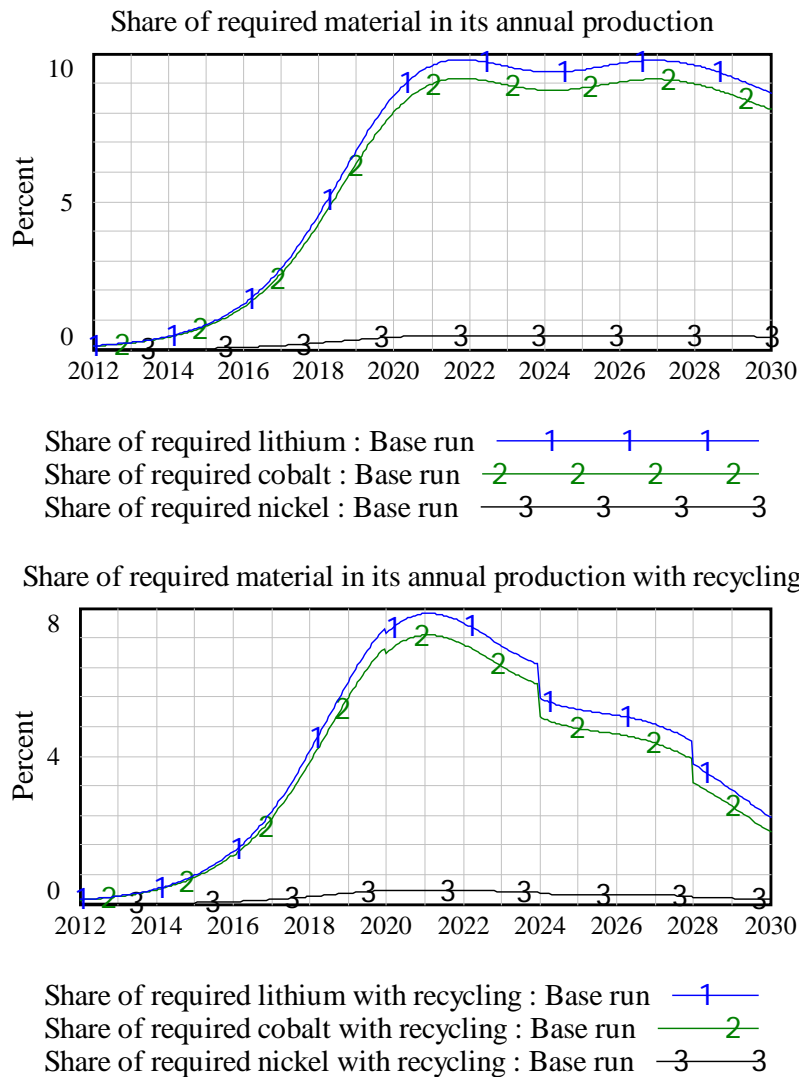Share of required nickel with recycling : Base run —3——3—

Figure 4-3: Share of required material in annual production with and with recycling

Consequently, we can determine that recycling slows down the demand for raw materials for the battery production and may help saving resources. But this is just one side of the medal. Recycling not only has to fulfil the claim to be ecological reasonable but

economical, too. To analyse recycling from an economical point of view, it is necessary to take most battery materials or those with the biggest share in value into account. Therefore the observed materials were complemented by aluminium, copper and stainless steel (type 1.4301). Their share in the battery (see Buchert et al. 2011) was converted into the specific share per kWh. Together with current data from the stock market the value of the recycled material can be calculated. To be able to recycle these materials, recycling centres and -capacity is required. The required invest and the installed recycling capacity is derived from a recycling centre from "Umicore" in Hoboken. The investment is calculated with 25M € and the capacity with an equivalent of 150.000 car batteries (see EUWID 2011). Based on the described data and assumption, the net present value for recycling is determined in Figure 4-4.

The net present value keeps falling until the year 2024 due to high number of HEV batteries, which only contain a small number of materials but require additional invest for recycling capacities. After 2024 the effect of batteries with a higher capacity becomes visible. The curve of the net present value turns and reaches a positive value in the year 2028.
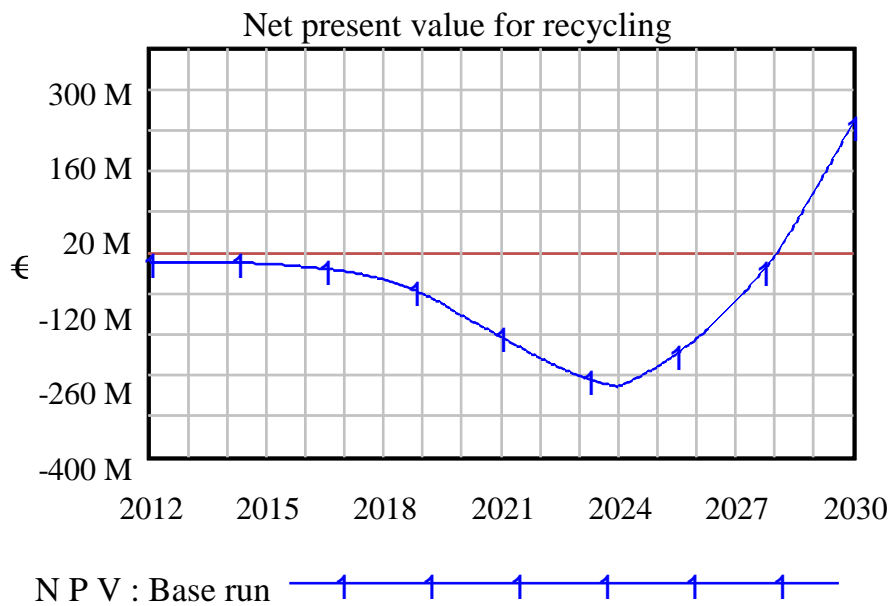

Figure 4-4: Net present value for the recycling of EV batteries in scenario "Base run"

However the general development of the electromobility is hardly to predict. To examine the effects of alternative futures on raw materials and employment we will take further two scenarios into account: "Oil age" and "Electrical age". The scenarios will be shortcut in following with: OA (Oil age), EA (Electrical age) and BR (Base run).

4.2   Effects on employment

The input values for the following scenarios are listed in Table 1. The difference in potential customers for EV results in a different development of the overall demand for battery capacity. As shown in Figure 4-5 the OA scenario shows a volatile course of the graph. While the EA scenario rises in a constant manner. Settled between both scenarios, concerning amount and development, lies the BR scenario.
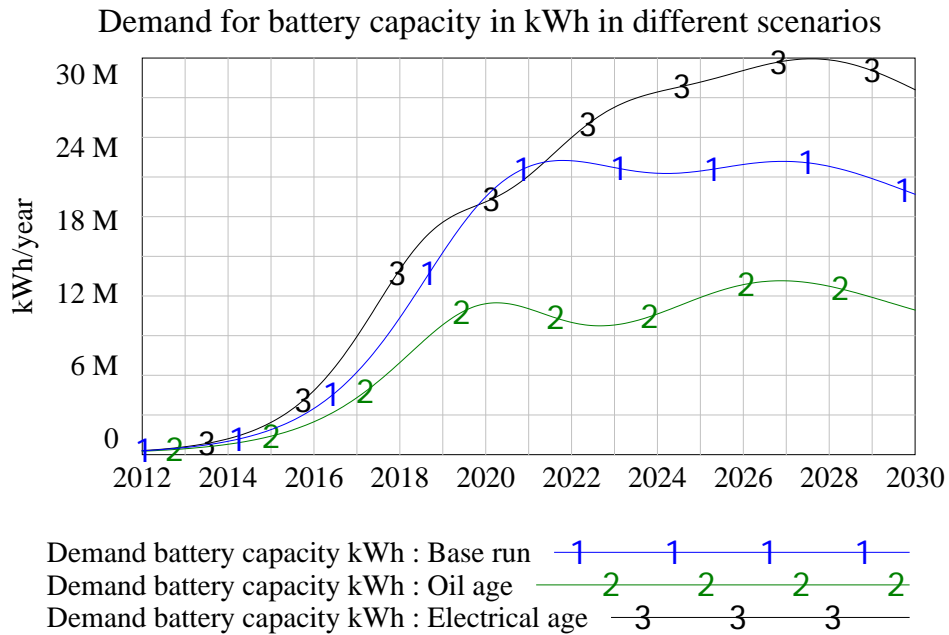

Figure 4-5: Overall demand for kWh under different scenarios

The following Figure 4-6 shows the evolution of the cell staff. While the battery- and indirect staff showed no deficits in recruitment the cell employees need to be closer examined.

Figure 4-6 shows that the development of employees in the OA scenario follows the graph for battery demand. In contrast, the graphs of the scenarios BR and EA converge to a specific amount. The lower part of Figure 4-6 gives the reason for that behaviour. While there is only a low number of missing employees for the OA scenario, a big gap exists between desired and recruited employees for the other two scenarios.

Direct cell staff in different scenarios

Direct staff cell : Base run —1— 1 — 1 — 1 — 1
Direct staff cell : Oil age —2— 2 — 2 — 2 — 2
Direct staff cell : Electrical age —3— 3 — 3 — 3

Gap in cell staff employment

Gap cell staff : Base run —1— 1 — 1 — 1 — 1
Gap cell staff : Oil age —2— 2 — 2 — 2 — 2
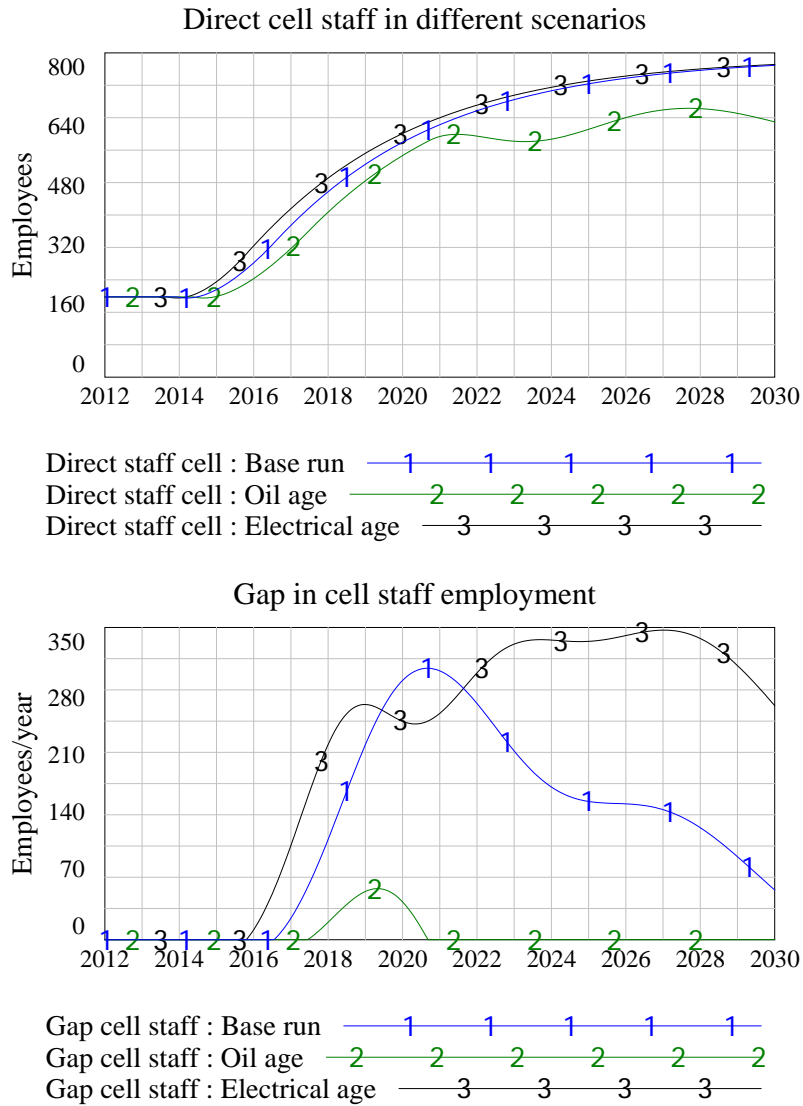Gap cell staff : Electrical age —3— 3 — 3 — 3

Figure 4-6: Direct cell staff and recruitment deficits under scenarios

To reduce or even negate the gap in recruitment the influence of two possible options are tested in the following. First in Figure 4-7 the effect of an increased productivity of the cell staff is analysed. This could come from a higher level of automatisation or scale effects and is expressed by the "Scale factor productivity". This factor will be raised from 0.1 to 0.5.

Direct staff cell with higher productivity

Direct staff cell : Base run with higher productivity ——1——
Direct staff cell : Oil age with higher productivity ——2——2
Direct staff cell : Electrical age with higher productivity —— 3

Gap in cell staff employment with higher productivity

Gap cell staff : Base run with higher productivity —1——1—
Gap cell staff : Oil age with higher productivity ——2——2
Gap cell staff : Electrical age with higher productivity —3——
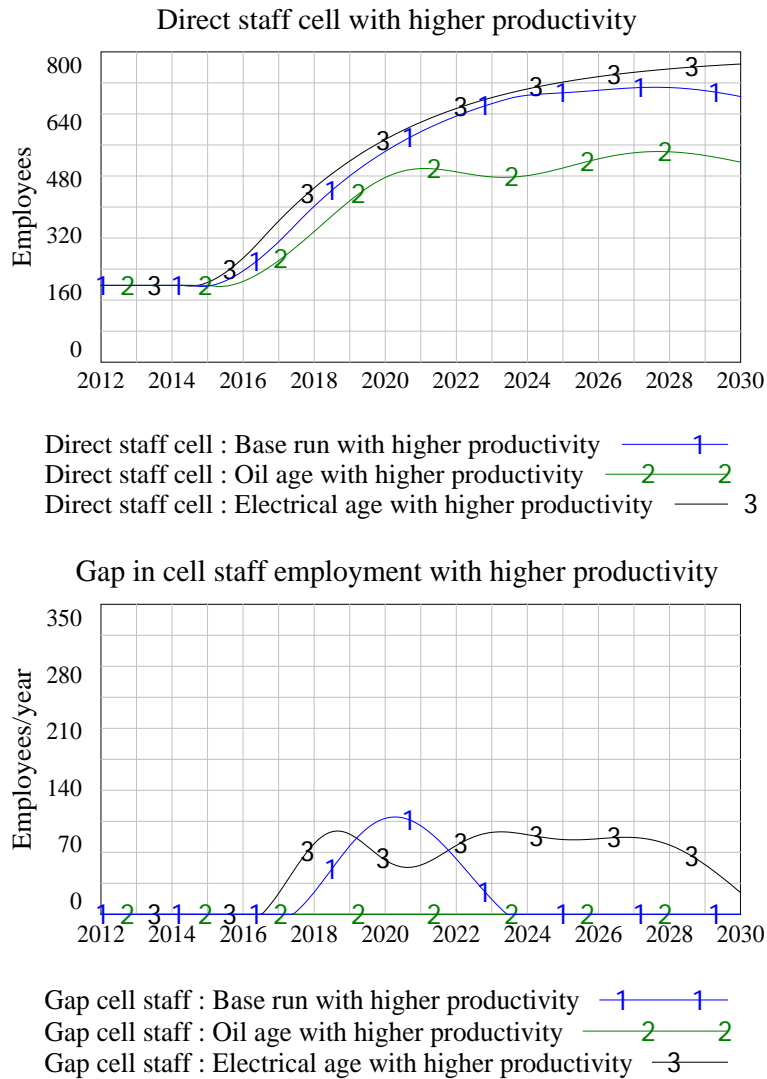
Figure 4-7: Effect of an increased productivity on the recruitment deficit

By an increased productivity the gap in recruitment can be cleared in the OA scenario. Furthermore, the deficit in the scenarios BR and EA can be reduced be a third. But nevertheless there still exists a deficit in those scenarios.

The second option constitutes an increased qualification rate for cell employees. Therefore the rate is adjusted according toTable 1. It is now assumed, that every fourth graduate is willing and qualified to work in the cell production. The effect of this measure is depicted in Figure 4-8. The productivity is reduced back to the initial value.

Figure 4-8 shows the major effect of this measure. All graphs are following now the curve of demand. This already indicates, what the lower part of Figure 4-8 confirms. There no longer exists a deficit in recruitment.
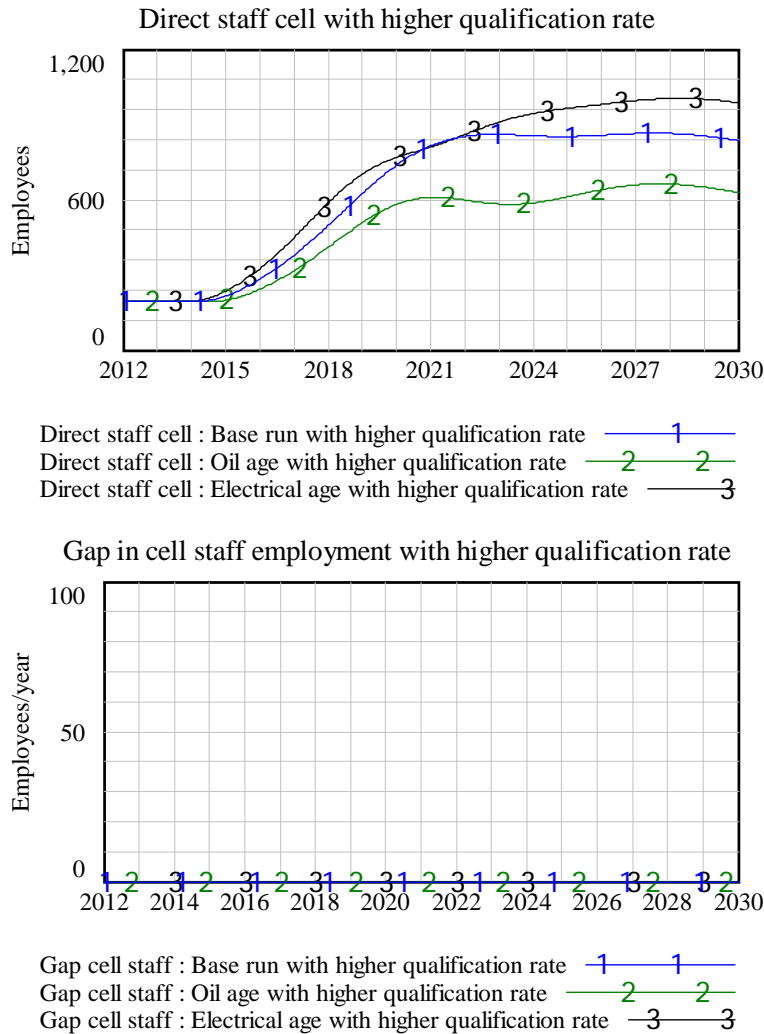
Direct staff cell with higher qualification rate

Direct staff cell : Base run with higher qualification rate ———1———
Direct staff cell : Oil age with higher qualification rate ——2——— 2——
Direct staff cell : Electrical age with higher qualification rate ———3———

Gap in cell staff employment with higher qualification rate

Gap cell staff : Base run with higher qualification rate ——1——— 1——
Gap cell staff : Oil age with higher qualification rate ——2——— 2——
Gap cell staff : Electrical age with higher qualification rate ——3——— 3——

Figure 4-8: Effect of an increased qualification rate on the employment deficit

4.3   Effects on raw materials

Similar to the extended analyses done in chapter 4.2, this chapter focuses on the effects on raw materials under different scenarios. Therefore Figure 4-9 depicts the share of required cobalt in its annual production, with and without recycling. The reason why the emphasis lies on cobalt is on the one hand, that its share in production is very high (see Figure 4-3) and on the other hand, cobalt not only posses an economical value, it is additionally characterized as a "critical raw material" by the European Union.

As already examined in the BR scenario, the recycling has a major effect on the share of required cobalt on its annual production. The impact of this effect varies according to the scenarios. While in the OA scenario the share is reduced by nearly 3,5 %, the impact in the EA scenario is with a reduction of 7,8 % down to a value of 3,65 % unmistakable.

By introducing recycling measurements the peak share in the EA scenario (2027) can be reduced from 12,2% to 6 %.
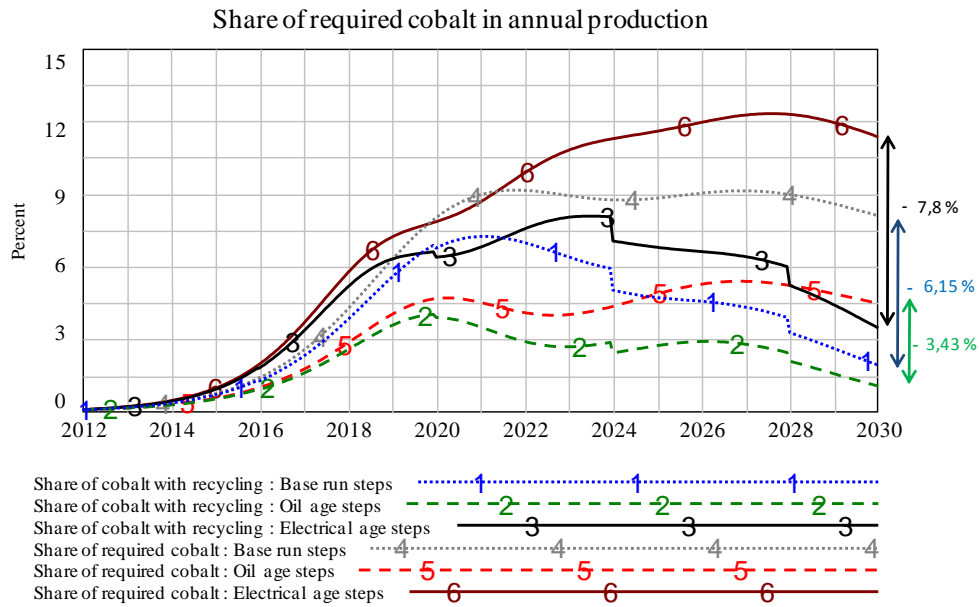
Share of required cobalt in annual production

Figure 4-9: Share of cobalt in the annual production under different scenarios

In order to achieve insights about the economic appropriateness of the recycling, the net present value for the different scenarios is depicted in

Figure 4-10. It can be observed, that the NPV of the EA scenario declines faster than in the BR scenario. The reason for that can be found in the high initial number of HEV. However, after the curve turns, the NPV reaches the same value in 2030 like in the BR scenario. In contrast, the NPV of the OA scenario stays constantly negative and ends up in the year 2030 with a value of -430 million €

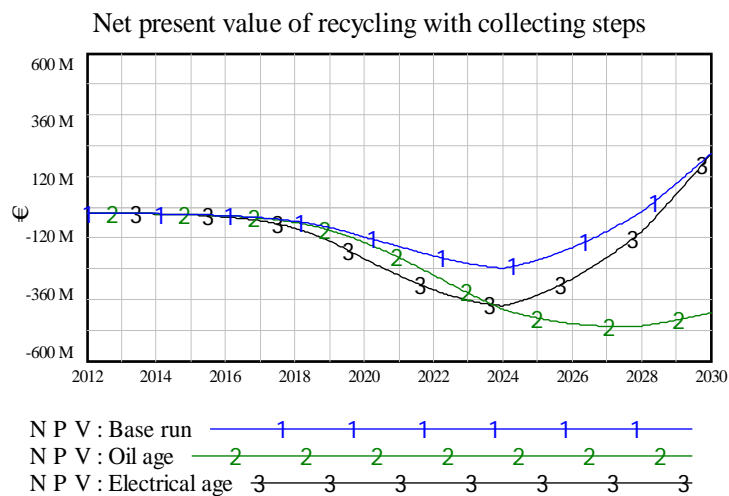Net present value of recycling with collecting steps

Figure 4-10: Net present value of recycling with collecting steps

As shown in the two figures above, recycling offers a great ecological potential, while the economical is in the medium term not given. For that reason the following Figure 4-11 compares the default collecting rate with a rate starting in the year 2012 with a value of 95%. The fundamental idea behind that assumption is that the customers lease the batteries. After the leasing period, the battery goes back to the manufacturer. By this means the battery stays in the property of the enterprise, by what such a high collecting rate can be achieved.
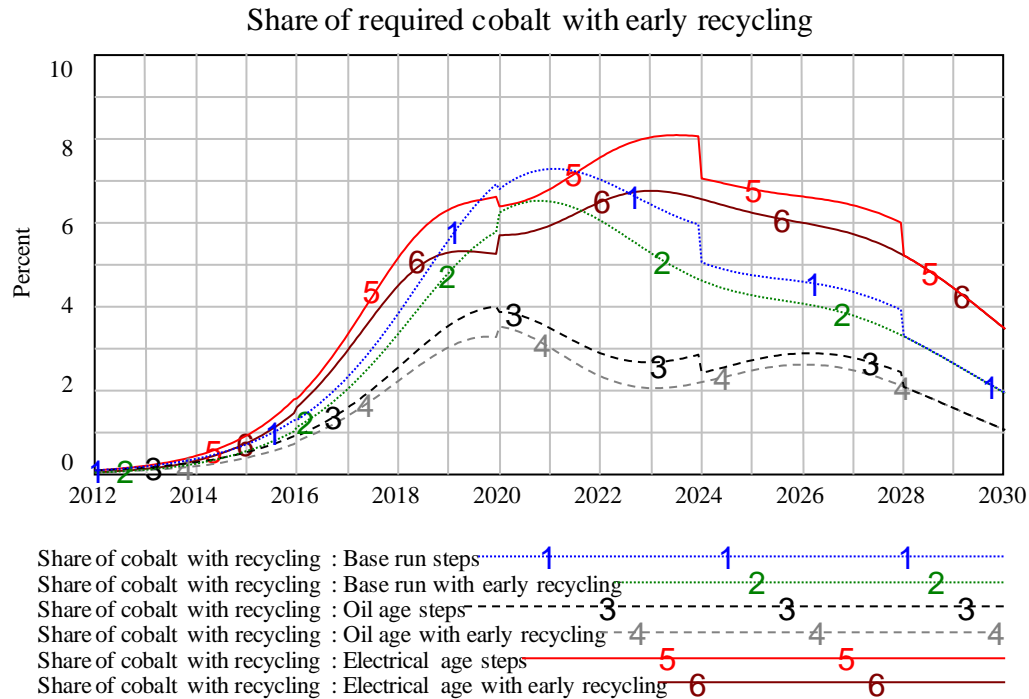

Figure 4-11: Effect of an early high collecting rate

On the first glance, it becomes obvious, that the early recycling concept leads to a lower share in the middle of the observed period. Both concepts end up with the same value. This is reasonable because both have a final value of 95%. A specific occurs in the year 2020. While the share drops in the "collecting step" concept, it raises in the "early recycling" concept.

It was mentioned above, that rejected batteries are available for recycling. With the progress in production technology, the yield increases. This happens in the years 2016 and 2020. However, in the year 2020 the yield is only increased by 10 % to its final value of 95%. But in contrast to the year 2016 where no effect is visible, this increase coupled with the higher production rate leads for the "early recycling" concept to a step in the share. This effect also takes place in the "collecting step" concept, but there it is negatetd by the increased collecting rate which is introduced at the same time.

As a result from Figure 4-11 in the "early recycling" concept the share of required cobalt is lower. In Figure 4-12 the economical effect of this higher recycling rate in the midium term is depicted.
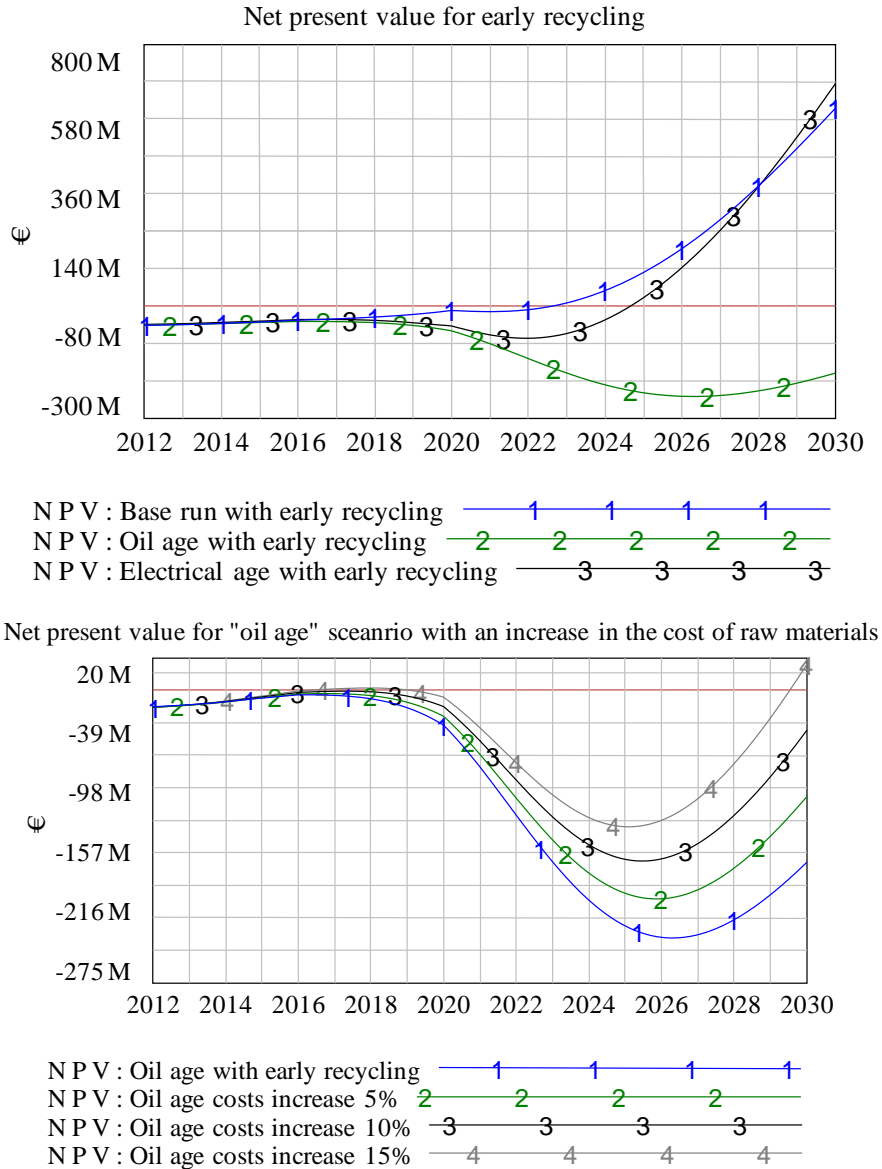
Net present value for early recycling

N P V : Base run with early recycling — 1   1   1   1
N P V : Oil age with early recycling — 2   2   2   2   2
N P V : Electrical age with early recycling — 3   3   3   3

Net present value for "oil age" sceanrio with an increase in the cost of raw materials

N P V : Oil age with early recycling — 1   1   1   1
N P V : Oil age costs increase 5% — 2   2   2   2
N P V : Oil age costs increase 10% — 3   3   3   3
N P V : Oil age costs increase 15% — 4   4   4   4

Figure 4-12: Net present value for an early recycling concept and the influence of rising costs for raw materials

The higher and earlier recycling rate inflicted by the "early recycling" concept has a strong impact on the net present value of the scenarios. Both, the BR and the EA scenario reach an economical level in the medium term of the observed period. While the BR scenario reaches that level some years earlier because of the constant level of demand, the EA scenario reaches a higher final net present value due to the still steadily rising demand. Only the OE scenario stays negative. In a further step the effect of rising costs for raw materials and their influence on the NPV of the OA scenario are examined.

While in the previous simulations was assumed that the costs stay on today's level, they are now considered to rise with a rate of 5 %, 10 % or 15 % per year.

The net present value of the OA scenario as shown in the lower part of Figure 4-12 stays negative. Only if the costs for raw materials would increase with a rate of 15 % per year, the net present value would reach the positive range just before the period ends.

5 Conclusions and Outlook

This paper presents a simulation model which demonstrates the automotive Li-ion battery supply chain in Germany for the next decades. The model is able to show the dynamics and long-ranging impacts of different EV diffusion scenarios on the battery supply chain and its environment. Consequently, the model gives first insights into future trends and their effects on employment and on raw materials.

First findings show, that there may be a shortage of chemists for the production of lithium-ion cells in future. The expected growth of labour productivity and improvements of the economies of scale may countervail an employee shortage for small or medium-sized sales volumes. Rapid or great market diffusions however will probably lead to lack of qualified staff in Germany.

The demand for lithium and cobalt will be on a very high level in future. This could be especially a problem for cobalt, which is classified as a critical raw material from the EU (European Union). A possibility for slowing down this effect is a faster and earlier increase of the defined recycling quotes. If those quotes are too low the demand of raw material increases inexorable, which may lead to a shortage and an increase of prices of some relevant resources. Higher recycling quotes ensure solid production rates of batteries in the next decades.

Summing up, we can formulate the following findings as hypotheses:

> ➢ A fast and great diffusion leads to a gap of available employees in cell production, whereas employees in battery production seem to be no limiting factor

> ➢ The employment gap in cell production may be slowed down by increasing the productivity level until the year 2020

> ➢ The remaining gap may be closed by increasing the qualification rate up to 150 percent compared to the value of 2012

> ➢ Depending on the scenario, the demand for raw materials may be reduced up to 50 percent in the year 2025 and 75 percent until the year of 2030 by means of recycling activities

> ➢ An early introduction of high recycling quotes is essential to avoid the "recycling gap" during the stages of great diffusion between the years of 2020 and 2028

> ➢ An early introduction of high recycling quotes rises the economic potential of battery production extremely

However, this study gives just some insights, basing on a first system dynamic simulation model. The system structure of the supply chain in reality is much more complex than the structure of our model. Model boundaries may be changed and their impacts on results should be checked. Purchase prices for batteries were not considered, nor were the strategic decisions of companies taken into account. This model should be regarded as a first step and as a base for improved and enhanced battery supply chain models.

Acknowledgment

6   References

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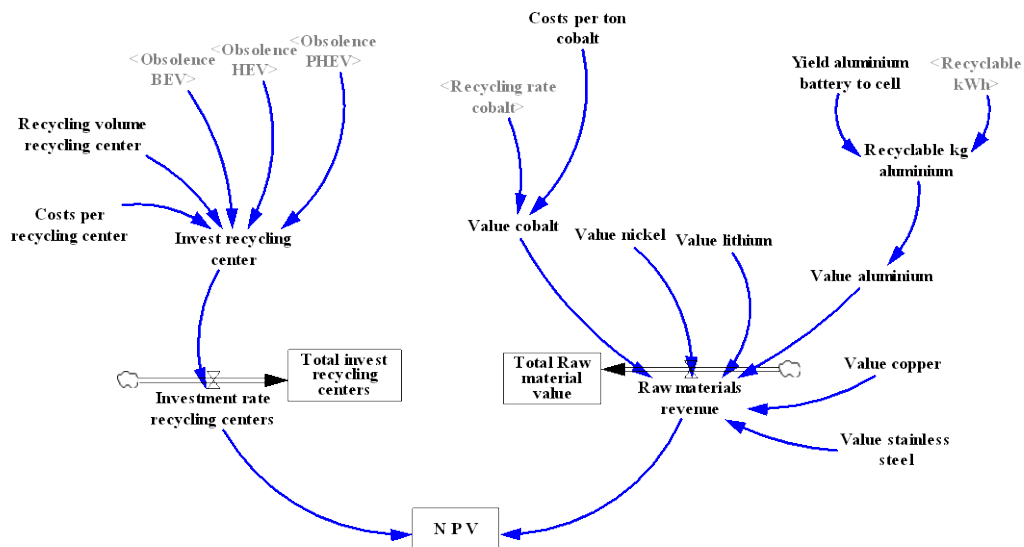
7   Appendix
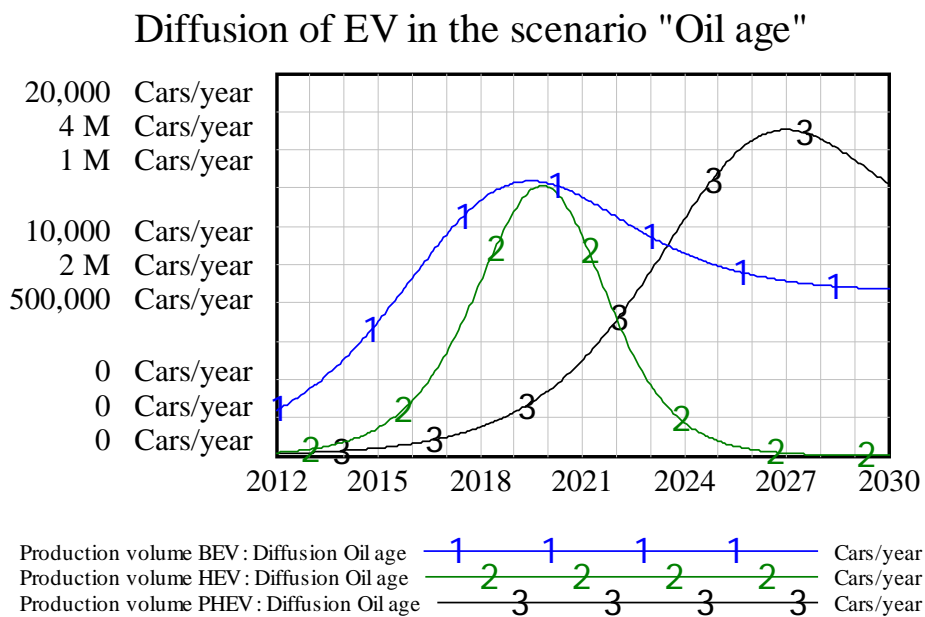

Figure A-1: Net present value

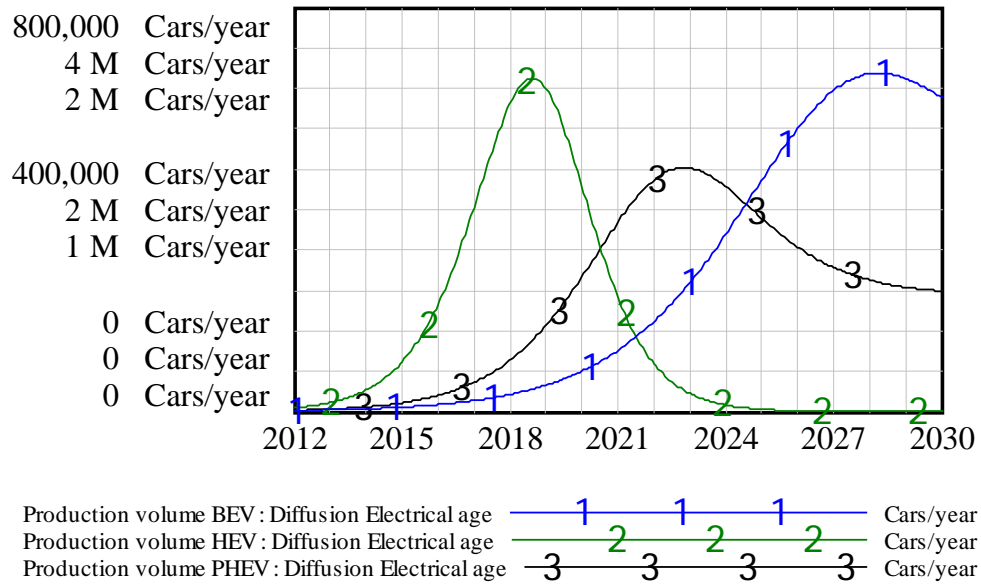## Diffusion of EV in the scenario "Oil age"

Figure A-2: Diffusion in the "Oil age" scenario

Figure A-3: Diffusion in the "Electrical age" scenario