ETH Zürich

Master in Comparative and International Studies

Energy Politics Group

Topics in Public Policy: Governing the Energy Transition

US Battery Storage Dataset 1999–2019

A Dataset on Technology and Application Specificity

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1 Introduction

In the changing world of the 21st century, in which renewable energies are becoming increasingly indispensable and electric vehicles gain prominence, new challenges arise. The wind does not always blow, and the sun does not always shine. Renewables are often produced decentralized and locally. Electric vehicles still suffer from battery limitations in size and range. Despite a broad range of renewable energy production methods and rapid improvements in electric vehicle technology, a significant challenge remains: electric energy can hardly be stored efficiently in vast quantities. Hence, in order to successfully govern the energy transition, battery storage is crucial, and so are the policy solutions to get there.

Battery policies should be "smart" by targeting distinctive levels of technology and application (Beuse, Schmidt and Wood, 2018). A policy cannot only be either technology-neutral or technology-specific. Instead, it can target technology on different specificity levels (Azar and Sandén, 2011). A policy can be formulated very broadly and target the economy at large. Such a policy could, for instance, aim at mitigating climate change or at promoting a sustainable economy, without further specifying with which technologies theses goals should be achieved. In the field of energy storage, policies can address specific storage technologies, such as electrochemical or thermal energy storage. Alternatively, a policy can be formulated very specifically by targeting a subset of technologies, such as lithium-ion batteries or lead-acid batteries. Finally, on the most specific technology level, a policy can be directed at the design of technology, including battery designs like lithium iron phosphate or zinc-air batteries.

As for its application specificity, a policy can focus on applications on various levels. Either the policy is applicable economy-wide, or it targets a specific industry, such as the automotive sector, the military, or the electric power sector. Alternatively, more specific policies address certain applications of technology, such as battery electric vehicles, power reliability, or power quality. Finally, policies on the sub-application level can, for instance, push green school busses or topics related to the power-reliability for end-consumer.

The academic debate on the design choice of energy storage policies has so far been a theoretical one. Empirical evidence on how technology and application specificity are represented in the design of policies is missing. The US Battery Storage Dataset will be a first step towards closing this gap. It provides data on 341 battery storage bills from the US Congress between 1999 and 2019, focusing on the technology and application specificity of the bills as well as the policy instruments adopted to address energy storage.

Understanding policy design choices is essential for governing the energy transition. From a technological perspective, it is crucial to give a new technology the time to learn without risking the premature lock-in of an incumbent technology (Schmidt et al., 2016). From a policy-making perspective, it is relevant to understand the politics, the political process, of policy-making and to learn about the factors which drive political decision-making. Furthermore, analysing the development of design choices in terms of US battery storage policies allows investigating whether a political learning process takes place over time. Ultimately, in order to enable new technologies to enter the market, policy-makers need to understand, learn, act, and react accordingly by providing a smart political framework.

First, I will describe the data source. Secondly, I will give an overview of the data collection methods, followed by a discussion of the coding challenges. Thirdly, I will discuss some descriptive and exploratory results. The paper ends with an outlook for further research.

2 Data

The basis of the US Battery Storage Dataset are bills and laws related to energy storage. The period of analysis covers the time from the 106th Congress (1999–2000) to the 116th Congress (2019–2020) (Nr. 1 in Figure 1). The data is retrieved from the Congress.gov homepage (Congress.gov, 2019), which provides information on the US Congress and its legislation since the 93rd Congress (1973–1974). In order to find the bills and laws related to battery storage, I chose the two search terms “energy storage batter” and “‘electric vehicle’ battery” (Nr. 2 in Figure 1). The search terms were included in the text, and word variants were allowed (Nr. 3 in Figure 1). Any legislative action was considered (Nr. 4 in Figure 1).

The selection was later reduced to bills only, excluding resolutions and amendments. The selections of relevant bills were downloaded as .csv files (Nr. 5 in Figure 1) and transformed

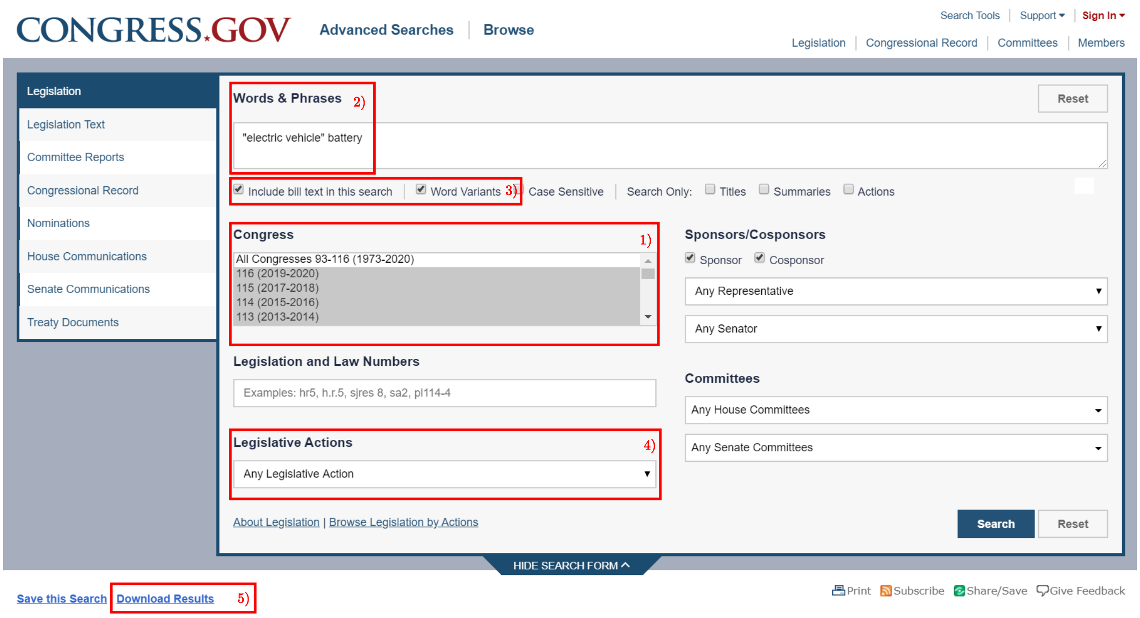

Figure 1: Search box on the Congress.gov homepage. The red numbers represent the settings which were considered for the definition of the bills and laws related to energy storage.

into an Excel spreadsheet. 271 bills resulted from the search for "energy storage batter", 506 from the search for "'electric vehicle' battery" (last download: 8.12.2019). The 258 bills which appeared in both selections were merged, resulting in a corpus of 519 documents. I downloaded this selection of documents and saved them as PDFs for further analysis. Finally, I skimmed the texts for their relevance, since some bills included the search terms in a different context, such as assault and battery, or battery in a military context. As a result, I considered 341 of the 519 bills to be relevant.

The downloaded Excel file provided by the Congress contained some basic information on the bills: They reported on the introduction status of each bill, distinguishing between bills which were introduced only, those which passed the House or the Senate, and those which became law. They also reported on the year of introduction and the name of the sponsor of the bill as well as the number of co-sponsors, the date of the latest action taken, and a list of committees involved. This information provides a useful framework for the actual coding of technology and application specificity, as well as of the policy instruments utilised to address battery storage.

3 Methods

To code the level of technology and application specificity of a bill, the Energy Politics Group (EPG) of ETH provided me with two dictionaries. I will first introduce these two dictionaries, before describing the data collection approaches, discuss the limitations of the dataset and the major coding challenges I faced. The final codebook is attached in Appendix B.

3.1 Dictionaries

Policies target different technology levels (Master Thesis Extract, 2019; Schmidt et al., 2016; Schmidt and Sewerin, 2018). They can be divided into five categories. The Technology Specificity Dictionary provided by the EPG represents the different specificity levels with examples of energy storage (Figure 2). It is the basis on which I coded the US energy storage bills. Throughout the empirical analysis of the bills, I discovered additional entities relevant to classify the bills correctly. Consequently, I expanded the original dictionary by adding the new terms (highlighted in italics in Figure 2). When different specificity levels were addressed by one policy, only the most specific application level mentioned was coded as 1, the other levels were coded as 0.

Policies that are related to battery technology and target no specific economic sector, or policies which target various economic sectors, are coded on the economy level. Policies that address particular categories of battery technology within a sector are coded on the field level. If one or several single battery specific technologies are targeted, the technology level is chosen. I additionally added policies related to electric vehicles (e.g.plug-in electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles) to this category, since they focus on electric mobility, but not on specific technologies. This implies that such policies are applicable to any battery technology. The sub-technology level includes policies that consider a specific subset of technology. Policies targeting “advanced batteries” were added to this category. Finally, policies located on the design level address specific design components of the technology.

Besides focusing on different levels of technology specificity, policies also include different

Level	**Examples of technologies**
Economy	Neutral
Field	Energy storage
Technology	Electrochemical energy storage, thermal, mechanical, chemical, electrical/electromagnetic, *electric vehicles (PEV, PHEV, HEV)*
Subtechnology	(Lithium-ion battery, lead-acid battery, nickel-based batteries, flow batteries, metal air batteries, molten salt batteries, supercapacitors); (molten salt thermal storage, ice thermal storage, latent heat thermal storage); (flywheels, pumped hydro, gravity batteries, compressed air energy storage); (power to gas, hydrogen, biofuels); (capacitors, superconducting magnets), *advanced batteries*
Technological design	(LFP (lithium iron phosphate), NMC (nickel manganese cobalt), NCA (nickel cobalt aluminum), LCO (lithium cobalt oxide), LTO (lithium titanate), LMO (lithium manganese oxide), solid state LIB, VRLA (valve regulated lead acid) battery, nickel metal hydride battery, nickel cadmium battery, nickel iron battery, vanadium redox flow battery, zinc bromine flow battery, organic flow battery, lithium-air battery, aluminum-air battery, sodium sulphur battery, sodium-nickel chloride (Zebra) battery, *lithium-polymer battery, LTC (lithium thionyl chloride), zinc-air batteries*

Figure 2: Technology Specificity Dictionary from the Energy Politics Groups (EPG) at ETH Zürich. Newly identified entities are highlighted in italics.

application levels (Schmidt and Sewerin, 2018). They can be categorised into four levels. Figure 3 shows the levels with examples of different applications. My analysis of the bills has revealed additional categories, which will subsequently be described. In case a policy targets different levels of application specificity, only the most specific technology level was coded as 1, the other levels were coded as 0.

If a policy affects all applications of a technology, and does not distinguish between different applications, it is considered as application neutral. If it addresses the applications within a distinct sector of the economy, the bill is coded on the industry level. Additional to the dictionary, I have identified the military sector as an industry promoting the development of battery storage. Policies on the application level address single or multiple applications within a particular field of industry. As additional subcategories of the automotive industry, the application-tier covers policies related to plug-in electric vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles, as well as non-road equipment (example in H.R.2158 (2009)). As subcategories of the military industry, combat vehicles, and lithium-ion battery safety research on special operation forces (SOF) underwater systems have been identified. On the sub-application

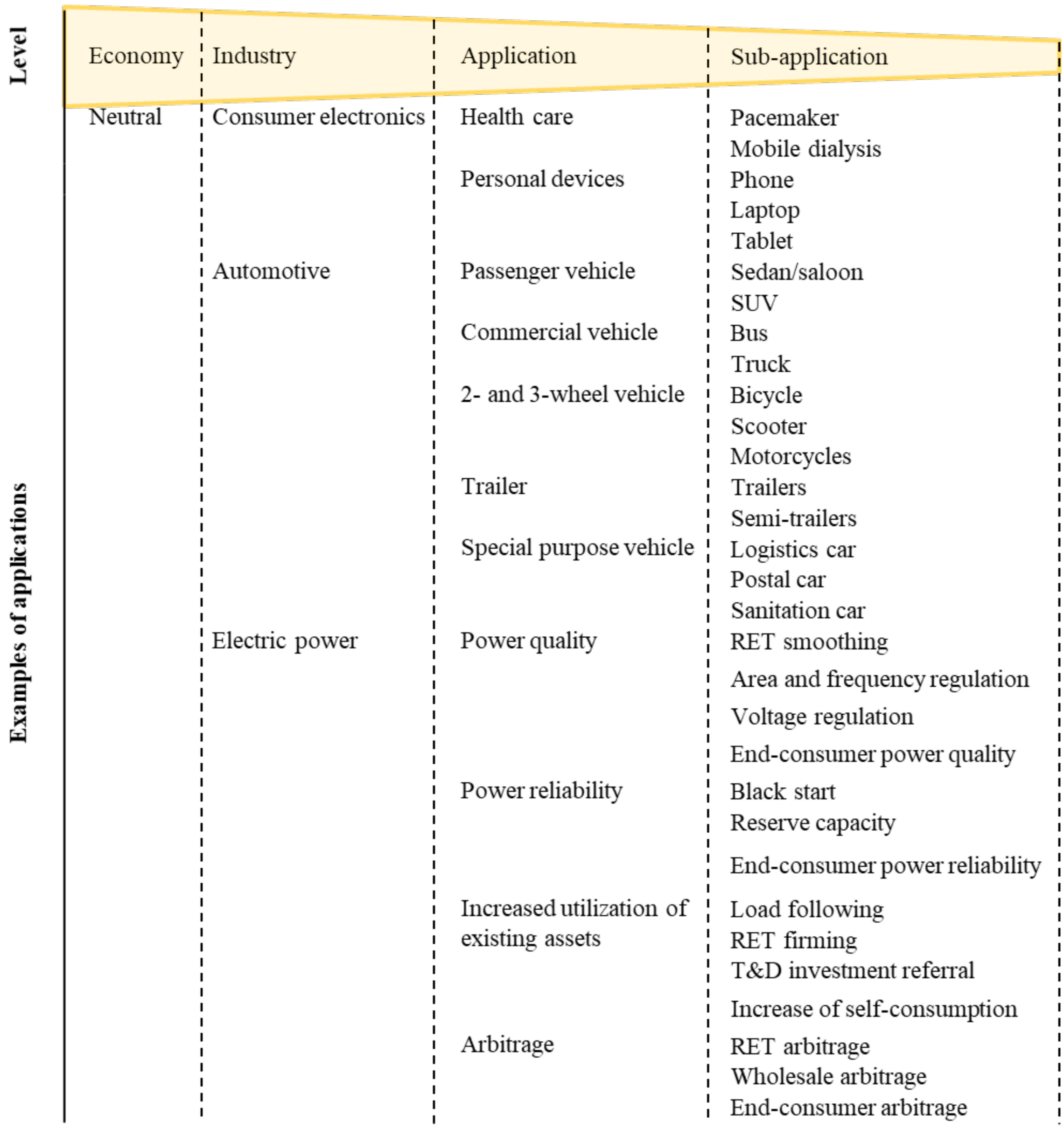

Figure 3: Original application Specificity Dictionary from the Energy Politics Groups (EPG) at ETH Zürich. Some additionally identified categories are described in chapter 3.1 Dictionaries.

level, policies target a specific subset of an application. As newly identified sub-application of non-road equipment, lawn, garden and forestry power equipment (example in H.R.2158 (2009)) is included.

Besides information on technology and application specificity, I collected data on policy instruments utilised to address battery storage technology. I distinguished between eight different policy types (Ingold et al., 2016; IEA, 2019; Schmidt and Sewerin, 2019). If more than one instrument targets a battery storage technology or application, I coded all of them as 1.

A state can make use of the following policy instruments: *Regulatory instruments* aim at changing the behaviour and activities of relevant stakeholders by directing the flow of money. These instruments include order and prohibition, regulation, codes and standards, licences, charges, and obligation schemes. For economic instruments, I distinguished between *taxes*, *tariffs*, and *general economic instruments*. The first group includes policies which aim at changing the behaviour and activities of relevant stakeholders based on tax breaks, tax credits and other interventions which include taxes, whereas the second group refers to tariffs. The third group is based on market mechanisms and includes the provision of financial and fiscal incentives. These instruments include subsidies, loans, emission trading rights and direct investment, as well as fees, grants, provisions and credits. Instruments which aim at direct state activities are coded as *organisation*. They include state-owned enterprises (i.e. state investment bank or state-owned utilities), state-investment (i.e. infrastructure) and public enterprises, as well as the creation of new advisory or government bodies. *Research, development and deployment* policies address battery storage with finance and incentivise research, development and deployment of new technologies. They include demonstration projects, research programs and research funds. *Information and education* instruments aim at increasing knowledge among the relevant stakeholders. These policies include education and job creation related to energy storage, batteries and electric vehicles, information provision and campaigns, advice and performance labels as well as supporting information and implementation aid provided by existing government bodies. Finally, *voluntary approaches* aim at increasing voluntary activities of relevant stakeholders. They include public, voluntary schemes, unilateral commitments of the private sector, round tables and fora.

3.2 Data Collection Approaches

In order to find a precise and efficient way how to code the technology specificity, application specificity and instruments of the bills, three approaches were considered, two machine learning approaches and a manual one. In a first step, I applied two text mining approaches, Non-negative Matrix Factorisation (NMF) and Probabilistic Latent Semantic Analysis (PLSA), to a subset of US battery storage bills. This analysis was part of a semester project in the "Methods of Unsupervised Machine Learning" class under the supervision of Professor Marco Steenbergen at University Zürich. These text mining methods can be useful to get a general idea of the broader context of the bills. However, a bill often includes different levels of application and technology and several instruments. The context in which words such as "battery" and "energy storage" appear matters. The two text analysis methods are not able to capture these nuances. As a result, even with a very strict and time-consuming preprocessing of the data, these methods are not accurate enough to fill out the cells of the data frame.

The second and more accurate approach was to code the data manually. Manual coding has the advantage that it is more specific than the tested text mining approaches because the context in which the bills mention battery storage technologies can be taken into account.

In order to find the most specific level of technology and application specificity of a bill as well as the instruments used, I developed the following procedure: I first read the abstract of the bill, which summarises its content and usually mentions the most important policy instrument. Secondly, with the keyboard shortcut "ctrl + F", I searched for the terms "battery" and "bat" (in case the term battery was split by a hyphen), "energy" and "storage". Finally, reading the paragraphs in which the terms usually appear, clarified the level of technology specificity. In order to figure out the level application specificity, I scrolled up to the title of the section in which the search term appeared. Additional instruments, which were usually mentioned in these lines, were added. A bill was only considered to be relevant if all three categories were present. This was sometimes not the case in short bills with lots of amendments. The development of this approach required some learning-by-doing but turned out to be relatively efficient. Nonetheless, some challenges remained, which will be discussed in the next chapter.

3.3 Coding Challenges and Limitations

Although manual coding appeared to be better suited to create the data frame compared to the tested text mining approaches, it bears various challenges regarding the coding process, the content of the bills, and the formal characteristics of the body of texts.

The major challenge in terms of converting the information of the bills into a data frame was to "develop a feeling" for the coding. Despite the clearly categorised dictionaries, I first had to develop an understanding for the different terms of the dictionaries as well as for the structure and wording of the bills. Further, I had to generate an efficient and effective approach to find the right keywords in the bills. This was a process of constant learning, accompanied by trial and error, and required me to train myself in order to recognise patterns in the wording and structure of the bills.

Regarding the content of the bills, coding the levels of application specificity was mostly straightforward. More challenging was coding the technology specificity. A policy usually targets a list of technologies. The difficulty was to figure out whether this list was exemplary (e.g. indicated by an "or"), and thereby addressed the technology level, or whether it was exhaustive (e.g. indicated by an "and"), and thus provided evidence for a policy targeting the sub-technology level. Since I only realised these differences towards the end of the coding, I did not make any distinction in this regard and coded all policy which included a term from the sub-technology on the sub-technology level[1]. Further analyses should consider this distinction and develop a consistent approach. Moreover, I found a few terms in the bill texts which were related to technology and application specificity but were not part of the dictionaries yet. The newly added terms are listed and discussed in subsection 3.1 Codebooks. A few of these terms caused some discussions, for instance around the term "advanced batteries". While in some bills, an advanced battery is vaguely defined as "a battery that is a secondary

[1] Example: "Such term may include hydroelectric pumped storage and compressed air energy storage, regenerative fuel cells, batteries, superconducting magnetic energy storage, flywheels, thermal, and hydrogen storage, or combination thereof [...]" ((S.3935, 2010)). This list of technologies is kept rather general ("technology level"), but it recognises different technologies by explicitly mentioning them ("sub-technology level").

(rechargeable) electrochemical energy storage device that has enhanced energy capacity" (e.g. (S.1220, 2011)), other bills use the term without any definition. It can, therefore, be assumed that advanced batteries are likely to include technologies that are more advanced than the traditional lead-acid batteries, nickel-based batteries, or pumped hydro. Thus they exclude some technologies on the sub-technology level while including others. Consequently, I located bills addressing advanced batteries on the "sub-technology level." Finally, different paragraphs in one bill mentioned different policy instruments which targeted a variety of technology or application levels. For each bill, I only coded the lowest specificity level, but at the same time, I coded all the instruments targeting technology and application specificity. Consequently, some of the instruments in the data frame address more general specificity levels than the one coded in the data frame. This limitation could be overcome by considering different paragraphs of the bill separately; however, this is hardly feasible in a manual coding approach, but could instead be done using advanced machine-learning.

Formally, I excluded amendments in the initial bill search. Nevertheless, 118 of the 341 relevant bills turned out to still include some sort of amendment, recognisable because it was mentioned so in the abstract, or because some parts of the bill were crossed out. I incorporated such amended bills as long as they included a technology and application specificity level targeted by an instrument. Consequently, there are different versions of a bill included in the data frame, e.g. once with House, once with Senate amendments. I have not found a systematic way of how to avoid such multiple counts. Furthermore, data provided by the Congress contained some basic information on the bills, such as the committees involved in introducing a bill. Over time, some of the committees' names have changed, and alongside these name, probably also their area of responsibility. Finally, due to the selection of search terms, there is likely to be a bias towards bills addressing electric vehicles. Not included in this analysis are search terms focusing, for instance, on battery storage related to electric power or consumer electronics. For further analysis, such additional search terms could easily be added in order to get a more extensive and balanced collection of bills.

4 Results

4.1 Corpus Description

US policies go through different implementation phases before they potentially become laws. The four phases in brackets refer to Figure 4. A sponsor and several co-sponsors introduce a bill. They are either part of the House of Representatives or part of the Senate (*Introduction*). A committee of the House formulates the first draft. In the House, the draft is then debated, voted on or amended. If it passes by a simple majority, it is forwarded to a committee in the Senate (*Passed the House*). After release, the Senate discusses, votes on and amends the draft. Again a simple majority is needed for the bill to pass (*Passed the Senate*). A conference committee existing of representatives of the House and the Senate works out any differences between the two versions of the bill. The House and the Senate approve the resulting version. Finally, the President has ten days to sign (*Became Law*) or veto the final bill (House.gov, 2020).

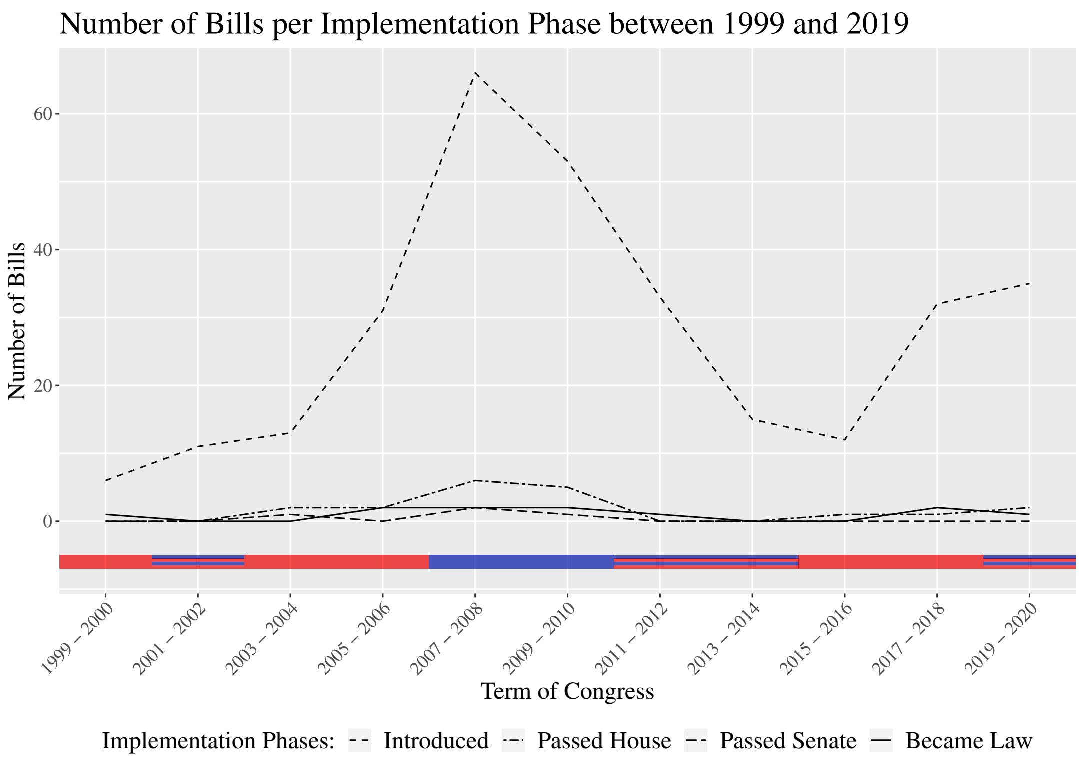

Figure 4: Number of bills per implementation phase between 1999 and 2019. The bar represents whether the majority in the Congress was held by the Democrats (blue), the Republicans (red), or mixed (striped).

Figure 4 gives evidence for how difficult it is for an introduced bill to pass the House or the Senate. Between 1999 and 2019, 307 of the 341 (90 percent) relevant US battery policies were introduced only, but then did not find enough support or ran out of steam without passing the House. In consequence, only 19 of the 341 (5.5 percent) bills passed the House, 4 (1 percent) passed the Senate, and 11 (3.5 percent) became laws. Some correlation between the party holding the majority in the Congress (House and Senate) and the number of introduced bills can be observed in Figure 4. In times the Republicans hold the majority in the Congress, the number of introduced battery storage bills sharply increases, whereas it tends to decrease in the years in which there is a majority of Democrats in the Congress. In years in which the Democrats hold the majority in one parliamentary chamber, while the Republicans hold it in the other one, the number of introduced bills tends to stagnate or decrease.

There was a peak of introduced bills between the 110th (2007–2008) and 111th (2009–2010) Congress, and also more bills passed the House. Besides the party composition of the Congress, other reasons are likely to have influenced these developments. A US internal reason for this sharp increase could potentially be the launch of the first Tesla in 2008. This argument is related to the technology-politics feedback loop literature, which argues that industry development influences politics and eventually policy-making (Schmidt and Sewerin, 2017). A driver for the decrease could be the external shock of the financial crisis and its aftermaths, which shifted the attention of the parliament away from technological change and development towards internal affairs. Finally, regarding the executive, a clear correlation can be observed. In times of a Republican president, the number of battery storage bills sharply increases, whereas, in times of a Democratic president, the trend is the opposite way around (cf. Figure 11, Appendix A). Whether policy-makers learn over time, and to what extent policies have changed in terms of technology and application specificity, will be discussed in the next chapters.

4.2 Technology Specificity

The levels of Technology Specificity, shown in Figure 5, represent the lowest specificity level of each battery storage bill between 1999 and 2019. According to this evaluation, over time, the bills become more diverse in terms of addressed technologies and technology levels. For instance, in the early 2000s, only two propositions targeted the design level by promoting a credit for demonstration purposes of zinc-air battery bus technology, whereas the remaining bills predominantly supported credits for electric vehicles (technology level). The high proportion of technology specific policies in the first decade of the 2000s is due to the large share of policies addressing electric vehicles and results from the choice of search terms. Over time, the share of policies targeting the technology level has decreased and has in large parts been replaced by policies addressing the sub-technology level. Consequently, there is some evidence for policy learning over time; however, this hypothesis should be tested in additional research.

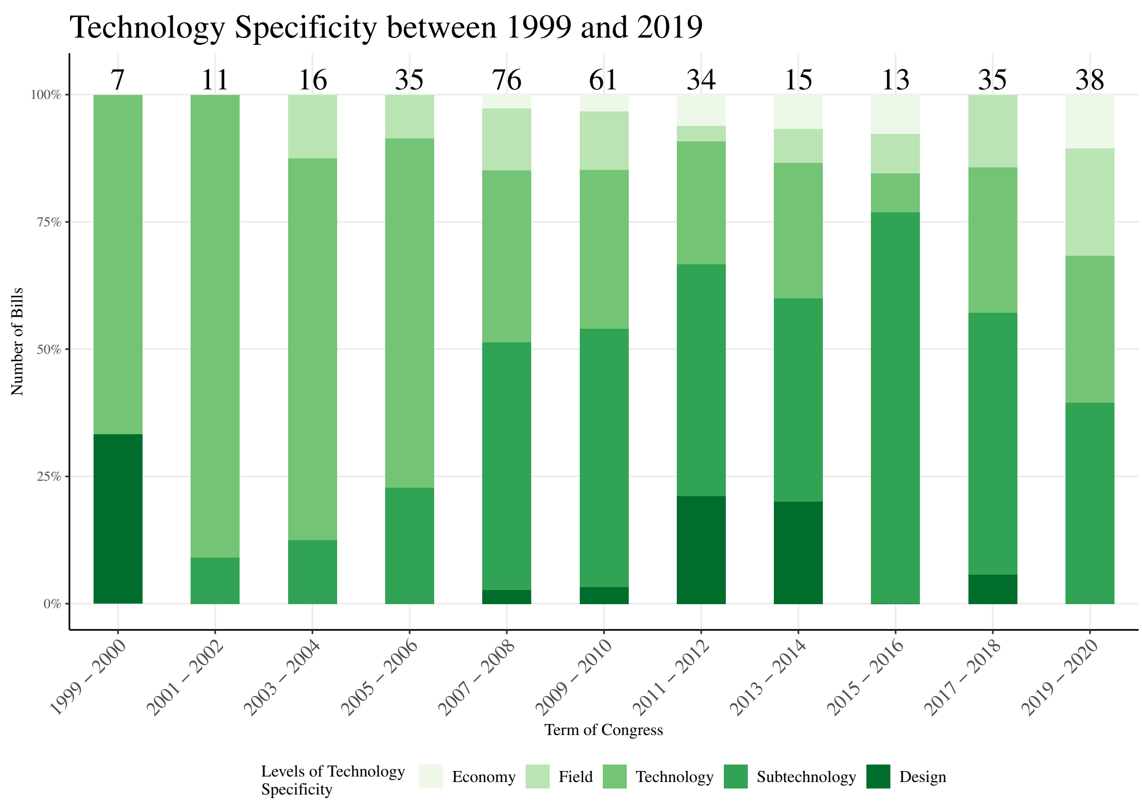

Figure 5: Number of bills per term of Congress, grouped by the share of Technology Specificity level. The numbers on top represent the number of bills per term of Congress.

Comparing the number of bills proposed by Democrats and Republicans shows that the former introduced almost twice as many bills (217) compared to the latter (119). Independent parliamentarians introduced the remaining four bills. The Democrats proposed a majority of bills on the sub-technology level; the Republicans predominantly focused on the technology level. The number of bills for the House and the Senate is more balanced. Representatives of the House proposed 173 bills, those of the Senate 168; both proposed bills on the technology and sub-technology level. The peak around the 110th Congress (2007–2008) is present in all four graphics. The blue and red bar in Figure 6 C gives some evidence that the number of introduced bills had increased when the Republicans held the majority in the House and had decreased when the Democrats did so. However, this trend is only partly mirrored in the Senate.

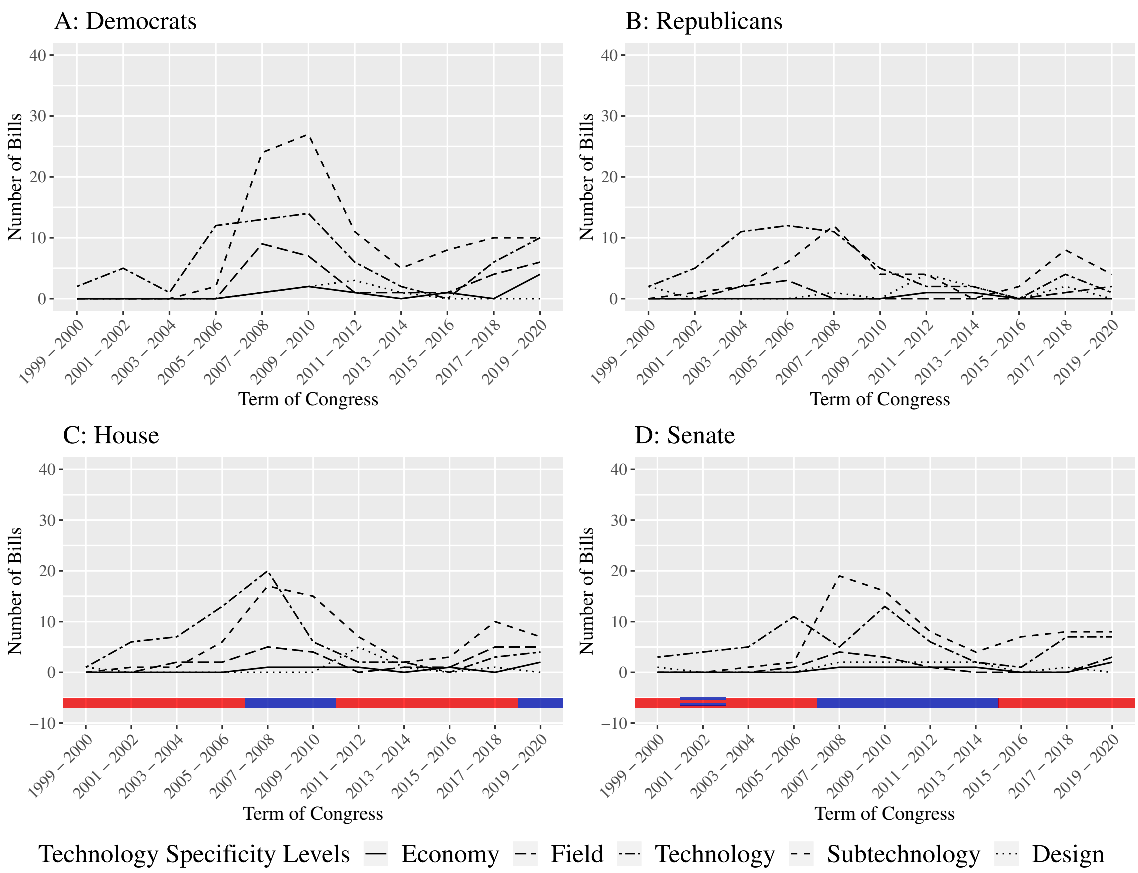

Figure 6: Number of bills per implementation phase between 1999 and 2019, grouped by their level of Technology Specificity, and by initiation by Democrats and Republicans, and House and Senate, respectively. The bars represent which party, Democrats (blue) or Republicans (red), holds the majority in the House and the Senate, respectively. Between 2001–2002, the seats in the Senate were equally shared between Democrats and Republicans.

4.3 Application Specificity

The levels of Application Specificity, shown in Figure 7, represent the lowest specificity level of each bill between 1999 and 2019. Due to the explicit search for electric vehicles, the share of bills targeting the application level is again the largest, especially in the early 2000s. Similar to the development of technology specificity, the applications addressed by the bills have become more diverse over time. However, while there was a tendency towards more specific policies regarding Technology Specificity, it seems that policies have become more abstract regarding their level of Application Specificity. In conclusion, there has been a change in focus away from policies focusing on the application level and towards policies which target a broader range of applications, especially applications on the industry and economy level. To what extent this shift is related to policy learning, and how this relates to the observed shift in the levels of technology specificity, could be the starting puzzle for further research.

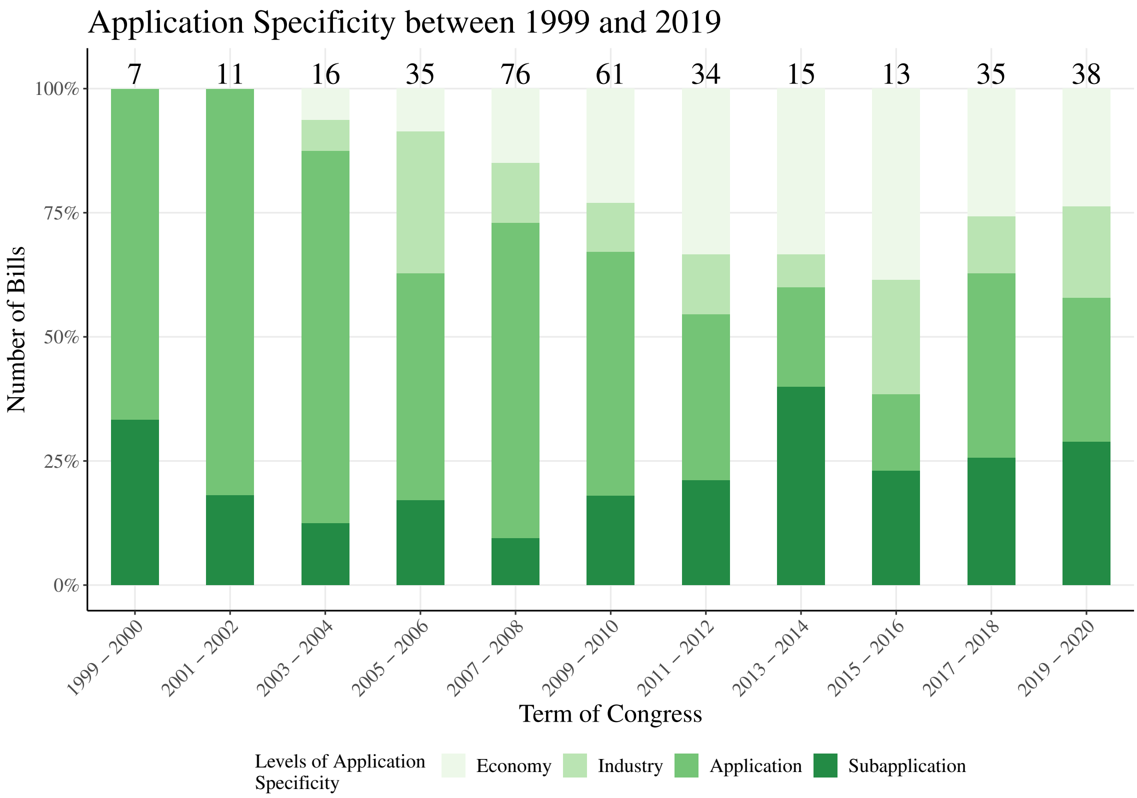

Figure 7: Number of bills per term of Congress, grouped by the share of Application Specificity level. The numbers on top represent the number of bills per term of Congress.

Comparing the Democrats and the Republicans, and the House and the Senate, respectively, there are no considerable differences in terms of application specificity. As shown in Figure 8, for all four samples, mainly battery storage policies on the application level have been proposed in the first decade of the 2000s. There is a clear peak in all four figures between the 110th (2007-2008) and the 111th Congress (2009–2010). Only in recent years, this trend has changed, and policies targeting the economic and the sub-application level have become more prominent.

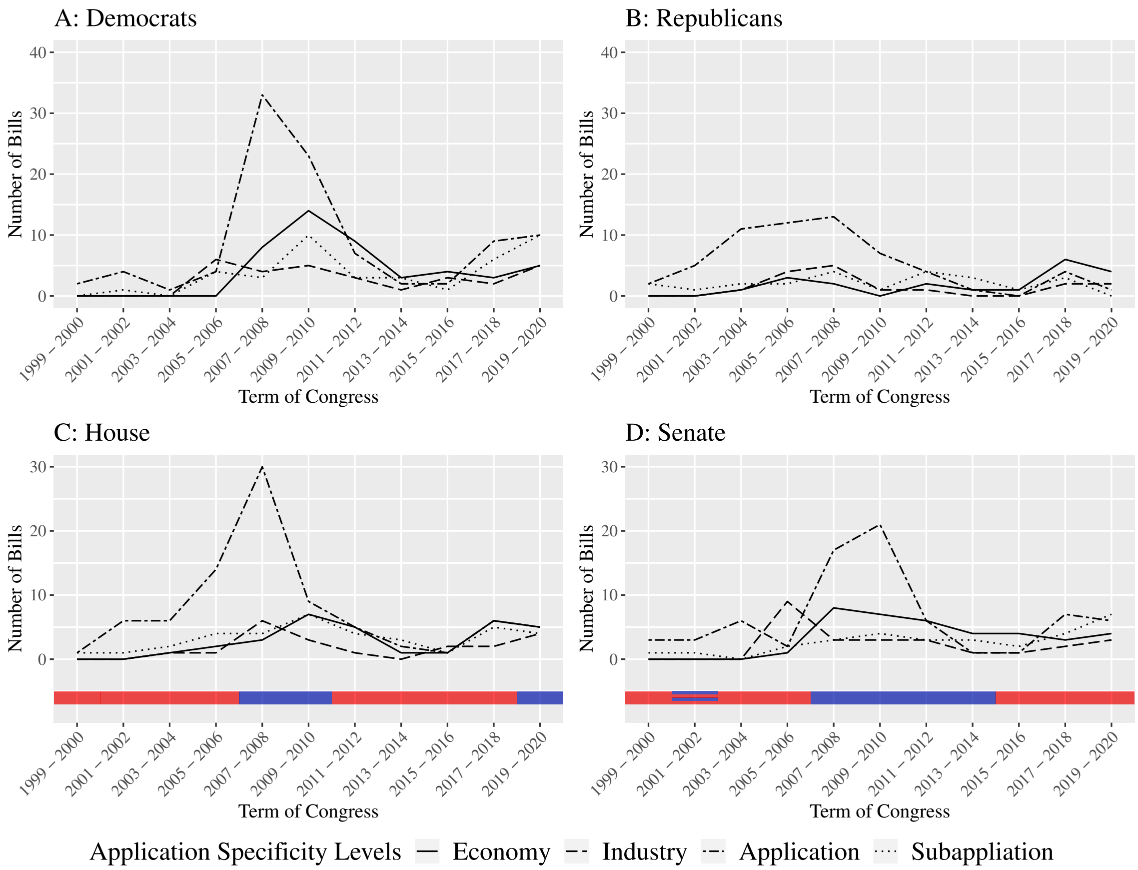

Figure 8: Number of bills per implementation phase between 1999 and 2019, grouped by their level of Application Specificity, and by initiation by Democrats and Republicans, and House and Senate, respectively. The bars represent which party, Democrats (blue) or Republicans (red), holds the majority in the House and the Senate, respectively. Between 2001–2002, the seats in the Senate were equally shared between Democrats and Republicans.

5 Explorative Analysis

In this section, I will present and discuss some explorative results. A quick look at the instrument types in Figure 9 shows that over the last 20 years, and especially during the peak of the 110th Congress (2007–2008) as well as in recent years, predominantly general economic instruments, taxes and research, development and deployment instruments have been used to address technology and application specificity. In Appendix A, two figures show the correlation between Instruments and Application Specificity and Instruments and Technology Specificity, respectively, however, these figures do not display any clear trends in this regard.

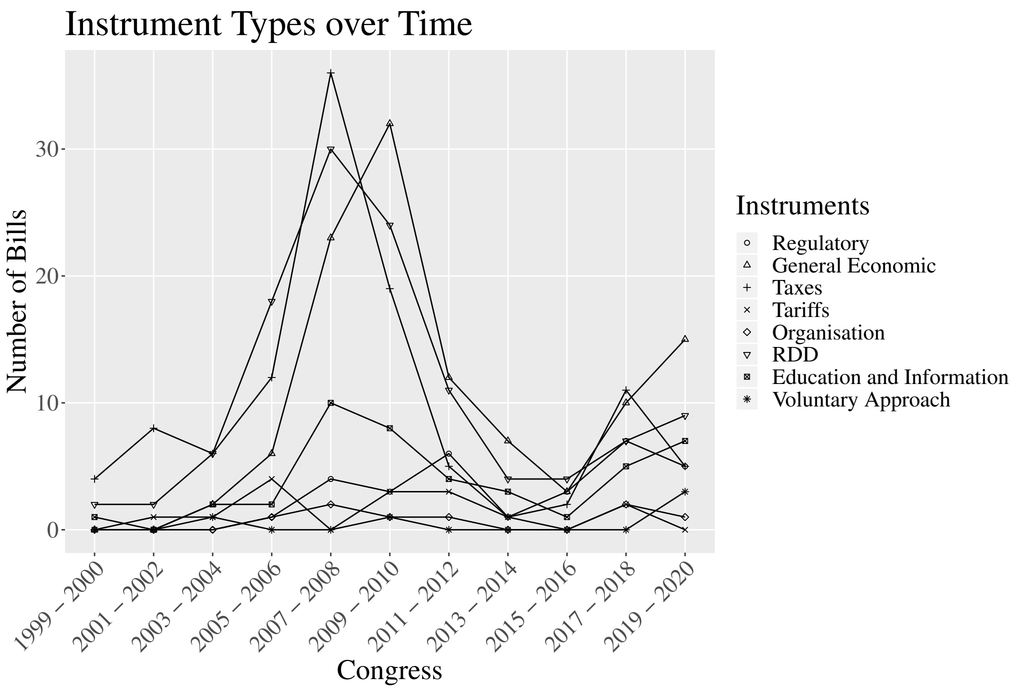

Figure 9: Distribution of policy instrument types addressing technology and application specificity over time.

In Figure 10, I correlated the technology and the application specificity levels with each other. On the one hand, there is a tendency that more application specific policies are positively correlated with more technology specific policies. On the other hand, there is also some correlation in the opposite direction, indicating that policies that are more specific on the technology level are less specific on the application level. These opposing trends are the result of 341 US

Applicaton \ Technology	Economy	Field	Technology	Subtechnology	Design
Economy	0.184	0.062	-0.372	0.219	0.112
Industry	-0.027	0.143	-0.070	0.022	-0.053
Application	-0.177	-0.192	0.397	-0.117	-0.140
Subapplication	0.068	0.068	-0.043	-0.068	0.117

Figure 10: Correlation between Technology and Application Specificity levels. Positive correlation between specificity levels are highlighted in green; negative correlations are highlighted in orange.

battery storage policies aggregated over the last 20 years, without taking into account any time trends, changes in policy design or policy learning.

6 Conclusion

In this paper, I have described how and why I collected data on US battery storage between 1999 and 2019, explicitly focusing on technology and application specificity.

The explorative and the descriptive results presented in this paper indicate that there is a correlation between technology specificity and application specificity. The explorative analysis indicates that a more abstract level of technology specificity could either be correlated with more abstract or with more specific level of application specificity. In contrast, the descriptive results are more explicit. Regarding US battery storage policies between 1999 and 2019, there is a trend towards an increase in abstraction in the applications, while the trend in terms of technology specificity points into the opposite direction. In other words, battery storage policies in the early 2000s have predominantly targeted the application and sub-application level, whereas they have become more diverse in the past years, including a shift towards a higher share of policies targeting the economy and industry level. Over the same period, a shift towards more specific policies could be observed in terms of technology specificity.

Obtaining knowledge on the interplay between technology and application specificity is essential for three reasons. First, it contributes to the theoretical debate on how different specificity levels are mirrored in the design of battery storage policies in the US. The US Battery Storage Dataset adds some empirical evidence to this academic debate. Second, it is vital to learn about factors which drive political decision-making to better understand the politics behind policy-making and policy learning. Lastly, from a technological perspective, it is crucial that new technologies are explored, developed, and can diffuse in an environment which allows them to enter the market without risking a premature lock-in of an incumbent technology. Consequently, to govern the energy transition, policy-makers need to enable new technologies to enter the market, which requires the provision of a smart political framework.

The US Battery Storage Dataset is an ongoing project and can be expanded with additional variables in order to investigate factors which drive the policy-making process over time. Some extra data collection and transformation would allow exploring the shared support among members of parliament for different bills, depending on attributes such as gender, sponsors' political ideology, committee membership of sponsors or social and economic information on the states they represent. Social Network Analysis and Regression Analysis, or Process-Tracing of a single bill (e.g the Clean Air Act, or the Energy Policy Act of 1992 and 2005) in combination with interviews could shed more light on the trends in US battery storage bills over the last 20 years.

Based on the present analysis, further research is needed to examine the drivers of change in policy designs, investigate how successful policies differ from the ones which were introduced only, and investigate why there was a peak in the number of policies in the 110th Congress (2007–2008). In other words, are more application specific policies associated with more or less technology specific policies? How did external factors like the financial crisis influence the introduction of battery policies? Is there evidence that the financial crisis behaved like an external shock and thereby shifted the policy focus away from technological change and development, towards more salient internal affairs? And how did technological change such as launching the first Tesla in 2008 influence politics and finally the design of battery storage policies in the US? The results of this paper trigger new questions and pave the way to further research.

Acknowledgement

I want to thank Professor Tobias Schmidt, Sebastian Sewerin and Nicolas Schmid for their support. I was grateful to develop this paper under their supervision and discuss and solve with them open questions. Furthermore, I would like to thank Abhishek Malhotra and Martin Beuse from the EPG for their additional support.

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A Appendix

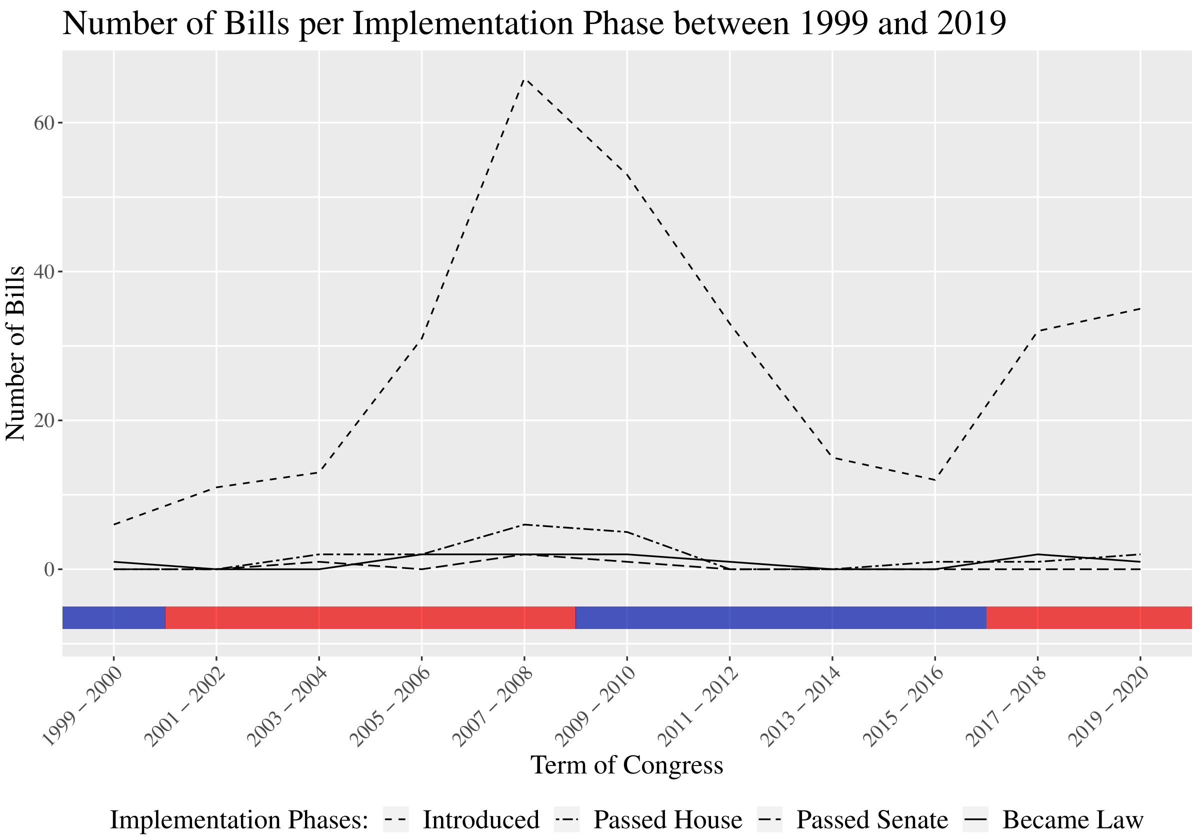

Figure 11: Number of bills per implementation phase between 1999 and 2019. The bar represents whether the president in office is a Democrat (blue) or a Republican (red). The four presidents are Bill Clinton (1993–2001), George Bush (2001–2009), Barack Obama (2009–2016), and Donald Trump (2016–ongoing).

Technology \ Instrument	Regulatory	Economic: General	Economic: Taxes	Economic: Tariffs	Organisation	RDD	Information & Education	Voluntary Approach
Economy	0.109	-0.098	-0.097	-0.041	-0.030	-0.071	0.167	0.242
Field	0.025	0.102	-0.057	-0.075	-0.054	-0.113	0.009	0.193
Technology	-0.070	-0.185	0.183	-0.019	0.080	-0.024	-0.167	-0.095
Subtechnology	0.011	0.142	-0.056	-0.007	-0.013	0.141	0.073	-0.103
Design	0.019	0.062	-0.077	0.205	-0.037	-0.005	0.068	-0.029

Figure 12: Correlation between Technology Specificity levels and instruments.

Application \ Instrument	Regulatory	Economic: General	Economic: Taxes	Economic: Tariffs	Organisation	RDD	Information & Education	Voluntary Approach
Economy	0.234	0.064	-0.248	-0.071	0.020	-0.067	0.120	0.061
Industry	-0.060	-0.047	-0.100	-0.084	-0.060	0.120	-0.044	0.097
Application	-0.081	-0.075	0.271	0.001	-0.027	0.121	-0.087	-0.064
Subapplication	-0.074	0.091	0.014	0.148	0.071	-0.166	0.038	-0.060

Figure 13: Correlation between Application Specificity levels and instruments.

B Appendix

Codebook

1. General Information

ID: Distinct number for each bill.

URL: The link to each bill on the www.congress.gov webpage.

Legislation Number: Distinct number of each bill, i.e. H.R. 1022 for a bill introduced by a representative of the House, or S. 2882 for a bill introduced by a representative of the Senate.

S/H: The label S shows that the Senate deals with the bill, H show that the House of Representatives deals with the bill.

Relevance: Bills which are related to energy storage, batteries and electric vehicles are categorised as 1, all the other bills which were returned in the search are not considered as relevant.

Congress: The data frame covers the period from the 106th Congress (1999-2000) to the 116th Congress, (2019–2020) (current state: January 2020).

Years: The period of Congress is displayed, ranging from 106 to 116.

Title: The official title of the bill is listed.

Sponsor: Name of the sponsor of the bill is listed.

R/D/I: The party affiliation of the sponsor is categories as R (Republican), D (Democrat), or I (Independent). **State:** The state which is represented by the sponsor of the bill is listed.

County: The county of the bill's sponsor is listed. The state abbreviation only appears for the representatives of the House and is NA for the representatives of the Senate.

Number of Co-sponsors: The number of co-sponsors is listed.

Introduction Date: The date of the introduction of the bill is listed.

Latest Action Date: The date of the latest action is listed.

Latest Action: The latest action is specified, i.e. to which Committee the bill was referred.

Introduction Status: The latest working status of the bill is presented, categorised as follows:

Introduced, Passed House, Passed Senate, Became Law.

Number of Pages: This variable indicates the number of pages when the bill is downloaded as PDF document (Clinton and Lapinski, 2006).

Amendment: Bills which are amended are categorised as 1, those which do not contain any amendments are categorised as 0.

Content:, A short summary of the key terms related to energy storage, batteries and electric vehicles, is given.

2. Policy Instruments

The policy instrument variables cover eight distinct levels (Ingold et al., 2016; IEA, 2019; Schmidt and Sewerin, 2019). Several instruments can appear in one bill.

Regulatory Instruments: The state uses regulatory authority to change the behaviour and activities of relevant stakeholders by directing the flow of money. These instruments include order and prohibition, regulation, codes and standards, licences, charges, and obligation schemes.

General Economic Instruments: These policies aim at changing the behaviour and activities of relevant stakeholders based on market mechanisms by providing financial and fiscal incentives. These instruments include subsidies, loans, emission trading rights and direct investment, as well as fees, grants, provisions and credits.

Economic Tax Instruments: These policies aim at changing the behaviour and activities of relevant stakeholders based on tax breaks, tax credits and other interventions which include taxes.

Economic Tariff Instruments: These policies aim at changing the behaviour and activities of relevant stakeholders based on tariffs.

Organisation: These instruments are targeted at direct state activities. They include state-owned enterprises (i.e. state investment bank or state-owned utilities), state-investment (i.e. infrastructure) and public enterprises, and the creation of new advisory or government bodies.

Research, Development and Deployment: These policy instruments target, finance and incentivise research, development and deployment of new technologies. They include demonstration project, research programs and research funds.
Education and Information: These instruments increase knowledge among the relevant stakeholders. They include education and job creation related to energy storage, batteries and electric vehicles. They also include information provision and campaigns, advice and performance labels as well as supporting information and aid in implementation by existing government bodies.
Voluntary Approaches: These instruments aim at increasing voluntary activities of relevant stakeholders. They include public, voluntary schemes, unilateral commitments of the private sector, round tables and fora.

3. Technology Specificity

Policies target different technology levels (Schmidt et al., 2016; Schmidt and Sewerin, 2018; Master Thesis Extract, 2019). They can be categorised on five different levels. The lowest level a bill touched upon was coded as 1.

Economy: The policy affects no specific sector, but various economic sectors which are related to battery technology. If the policy is not more specific, it is considered as neutral.
Field: The policy targets particular categories of battery technology within a sector.
Technology: One or several single battery specific technologies are targeted. They may include electrochemical, thermal, mechanical, chemical, or electrical/electromagnetic energy storage. Everything related to electric vehicles which is not further specified falls into this category (e.g.plug-in electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles).
Sub-Technology: The policy targets a specific subset of technology, including advanced batteries. It may include a lithium-ion battery, lead-acid battery, nickel-based batteries, flow batteries, metal-air batteries, molten salt batteries, and supercapacitors; molten salt thermal storage, ice thermal storage, latent heat thermal storage; flywheels, pumped hydro, gravity

batteries, compressed air energy storage; power to gas, hydrogen, biofuels; and capacitors, as well as superconducting magnets.

Technology Design: Technology design: These policies target the design of batteries. This level includes lithium iron phosphate (LFP), nickel manganese cobalt (NMC), nickel cobalt aluminum (NCA), lithium cobalt oxide (LCO), lithium titanate (LTO), lithium manganese oxide (LMO), solid state LIB, valve regulated lead acid (VRLA) batteries, nickel metal hydride batteries, nickel cadmium batteries, nickel iron batteries, vanadium redox flow batteries, zinc bromine flow batteries, organic flow batteries, lithium-air batteries, aluminium-air batteries, sodium sulphur batteries, sodium-nickel chloride (Zebra) batteries, as well as lithium-polymer batteries, lithium thionyl chloride batteries and zinc-air batteries.

4. Application Specificity

Policies target different application levels (Schmidt and Sewerin, 2018). They can be categorised on four different levels. The lowest level a bill touched upon was coded as 1. For more details, cf Figure 14.

Economic-tier: The policy affects all applications of a certain technology and does not distinguish between different applications. This policy is considered to be application neutral.

Industry-tier: The policy targets the applications within a distinct sector of the economy or industry. This level can be divided into the categories consumer electronics, automotive, and electric power.

Application-tier: On this level of specificity, single or multiple applications within a specific field of industry are targeted.

Industry-tier: If the policy is targeted at a specific subset of an application.

Level	Economy	Industry	Application	Sub-application
Examples of applications	Neutral	Consumer electronics	Health care	Pacemaker
				Mobile dialysis
			Personal devices	Phone
				Laptop
				Tablet
		Automotive	Passenger vehicle	Sedan/saloon
				SUV
			Commercial vehicle	Bus
				Truck
			2- and 3-wheel vehicle	Bicycle
				Scooter
				Motorcycles
			Trailer	Trailers
				Semi-trailers
			Special purpose vehicle	Logistics car
				Postal car
				Sanitation car
		Electric power	Power quality	RET smoothing
				Area and frequency regulation
				Voltage regulation
				End-consumer power quality
			Power reliability	Black start
				Reserve capacity
				End-consumer power reliability
			Increased utilization of existing assets	Load following
				RET firming
				T&D investment referral
				Increase of self-consumption
			Arbitrage	RET arbitrage
				Wholesale arbitrage
				End-consumer arbitrage

Figure 14: Original application Specificity Dictionary from the Energy Politics Groups (EPG) at ETH Zürich. Some additionally identified categories are described in chapter 3.1 Dictionaries.

5. Committees

Committees: All the involved committees are listed.

Number Committees: There are often several committees involved in the law-making process. This variable indicates how many committees were involved in the law-making process (Clinton and Lapinski 2006).

List of Committees involved: There are often several committees involved in the law-making process. The rest of the data frame shows on a 0/1 scale which committee was involved in the process of introducing bills which are related to energy storage, batteries and electric vehicles. The following committees were engaged at least once: 1) House: Energy and Commerce 2) House: Commerce 3) House: Education and Labor 4) House: Science, Space and Technology 5) House: Science and Technology 6) House: Science 7) House: Ways and Means 8) House: Armed Service 9) House: Appropriations 10) House: Natural Resources 11) House: Resources 12) House: Transportation and Infrastructure 13) House: Agriculture 14) House: Financial Service 15) House Budget 16) House Veteran's Affairs 17) House: Judiciary 18) House: Foreign Affairs 19) House: International Relations 20) House: Oversight and Reform 21) House: Oversight and Government 22) House: Oversight and Government Reform 23) House: Government Reform 24) House: Government Reform and Oversight 25) House: Education and Workforce 26) House: Small Businesses 27) House: Homeland Security 28) House: Intelligence (Permanent) 29) House: Rules 30) House: Administration 31) Senate: Banking, Housing and Urban Affairs 32) Senate: Finance 33) Senate: Budget 34) Senate: Commerce, Science, and Transportation 35) Senate: Environment and Public Works 36) Senate: Energy and Natural Resources 37) Senate: Armed Services 38) Senate: Homeland Security and Governmental Affairs 39) Senate: Foreign Relations 40) Senate: Judiciary 41) Senate: Health, Education, Labour, and Pension 42) Senate: Agriculture, Nutrition, and Forestry 43) Senate: Appropriations

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