

A comparison of the renewable energy and energy storage sectors in Germany and the United States, with recommendations for engineering teaching practices.

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A comparison of the renewable energy and energy storage sectors in Germany and the United States, with recommendations for engineering teaching practices.

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Abstract: The German Energiewende is the planned transition by Germany to a low carbon, environmentally sound, reliable, and affordable energy supply. This paper reports on a U.S. faculty international study program, which took place in May 2019, to explore the intersection of the German renewable energy and energy storage sectors. The international program included eleven instructional faculty from throughout the United States on a two-week learning and discovery experience starting in Frankfurt and ending in Munich, Germany. This paper provides an overview of the German renewable energy and energy storage landscape in comparison to the United States. Emphasis is placed on differences related to the historical context, policy and regulatory differences, and technology advances in the renewable energy and energy storage sectors. The comparison of Germany and the U.S. provides a nice example for faculty and students to investigate how technology readiness, regulatory policies, and economic forces all intersect to establish markets for a multinational industry. Findings from the international program and their impact on the education practices of faculty in the United States are provided, with a focus on academic curriculum, teaching practices, and career pathways for the energy industry.

1. Introduction and Background

The German Energiewende is the planned transition by Germany to a low carbon, environmentally sound, reliable, and affordable energy supply [1-4]. The transition focuses on three major technological pillars of renewable energy, energy efficiency, and energy management. The latter pillar is to be achieved through a combination of energy storage, demand response, grid upgrades, and new smart communications and controls technology.

The purpose of this paper is to provide an overview of the Center for Renewable Energy Advanced Technological Education (CREATE) international learning exchange with Germany. Funded by the National Science Foundation, the CREATE international project aims to explore the interface of the renewable energy and energy storage sectors in Germany, with the goal of improving energy education in the United States. This paper reports on the U.S. faculty professional development program that took place in May 2019. The international delegation engaged eleven instructional faculty from throughout the United States on a 15-day learning and discovery experience that focused on the cities of Stuttgart, Freiburg, Wildpoldsried, and Munich, Germany.

This paper has two objectives. First, it provides an overview of the German renewable energy and energy storage landscape in comparison to the United States. Emphasis is placed on differences related to the historical context, energy infrastructure, public policy, and organization of electric service providers and employers. The comparison of Germany and the U.S. provides a nice example for faculty and students to explore how technology readiness, regulatory policies, and economic forces all intersect to establish markets and industry practices for the renewable energy and energy storage industries. Second, this paper examines how the German experience

has impacted the teaching practices of the CREATE faculty participants. The findings of the project have resulted in subsequent modifications to academic curriculum, teaching methods, and career pathways in renewable energy and energy management programs incorporating energy storage technology. The guiding research questions examined are as follows:

- How is the energy landscape in Germany different from the United States?
- How has the CREATE project influenced educational practices for the participants?
- How can these findings more broadly shape energy education teaching practices for instructors across the United States?

2. Methods

The complete methodology for the international professional development program is described in detail by Slowinski et al. [5, 6], and is outlined only briefly here. A collaborative autoethnographic approach was used by participants to explore the guiding research questions. Autoethnography employs self-reflection to explore the contextual and lived experiences of individuals, which allows for a greater and deeper understanding of perspectives associated with individual participants [7]. Applying a collaborative approach encourages participants to share their prior knowledge and teaching experience to collectively advance understanding and magnify project impacts.

2.1 Participant Information

Participants in the May 2019 study in Germany included eleven renewable energy educators. Participants were chosen through a competitive application and evaluation process that was developed through previous CREATE international projects. Participants were chosen from around the United States, with attendees from Florida, Illinois, Indiana, New York, North Carolina, Oregon, Washington, and Wisconsin. Colleges represented a range in student numbers from 5,000 to over 40,000. Most of the participants teach at community and technical colleges, while one teaches at a university, another teaches high school, and one currently directs a non-profit solar energy training association. The group was composed of experts from a cross-section of fields, including building automation, energy management technology, green and sustainable building practices, solar and wind energy. The educational programs that they implement provide a variety of academic credentials, including technical diplomas and certificates, associate, bachelor, and master's degrees, and various types of industry certifications. This paper summarizes perspectives from the study participants and reports their insights on how emerging energy storage technology will impact their respective courses, programs, and disciplines.

2.2 Research Design and Data Collection

Participants explored Germany's energy landscape using four key learning experiences: i) contextual background study on the German energy and educational sectors, ii) pre-departure orientation with German facilitators, iii) international study and learning abroad in Germany, and iv) Post-travel reflection and evaluation upon return to the U.S. The scaffolding of pre- and post-travel activities to help participants process and internalize the learning experiences abroad were

based on best practices in international education gathered through previous CREATE international programs [8]. These four components are briefly summarized here:

i) In the Spring 2019 semester, participants completed a six week online and virtual learning experience to provide an introduction to the German energy and educational sector and to provide context for the upcoming study abroad experience. The online course included required readings, research assignments, and online discussions. Five topical units were covered:

- Unit 1: German Government System
- Unit 2: German Energiewende (Energy Transition)
- Unit 3: German Education System
- Unit 4: German Vocational Education and Training
- Unit 5: Introduction to German Approaches to Energy Storage.

ii) Prior to departure for Germany, participants spent two days in Washington, D.C., at the Heinrich Böll Foundation. Here, participants received presentations on Germany's Political System by Bastian Hermisson, Executive Director of the Heinrich Boell Foundation, on Germany's Educational System by Knut Panknin, Program Officer for the Friedrich Ebert Foundation, and on the German Energiewende by Nora Löhle, Program Director for Energy and Environment at the Heinrich Böll Foundation.

iii) The international study abroad consisted of a two-week learning experience in Germany, which included visiting 18 organizations and institutions currently working on energy storage. The sites visited and their technological focus areas are listed in Table 1. After each visit participants completed a site report reflecting on prompted questions that included:

- What was unique about this site or the work being done there?
- What was your biggest take-away from this visit?
- Did this site provide insights or information you will integrate into your teaching?
- Other comments or notes.

iv) Upon return to the U.S., participants completed a final reflection and evaluation of their time spent in Germany. A follow-up survey was given six months later to assess and quantify impacts on teaching practices that had resulted from the experience abroad.

Through the various activities, the study participants gained perspective on renewable energy and energy storage advances in Germany based on the country's history, culture, and political structure. The following sections summarize the German experience and report on the findings that participants plan to use in their teaching and curriculum.

Site/Location	Technology Focus
Bosch Battery Storage Site Visit	Grid scale battery storage
EnBW - Energie Baden Wurtemberg	Energy City pilot project for community solar and smart neighborhood battery
University of Stuttgart Institute for Thermal Engineering	Solar thermal storage technology
Stadtwerke Crailsheim GmbH	Seasonal solar thermal storage site
ADS-TEC	Large battery storage units for fast EV charging
Freiburger Verken AG	Flywheel storage for public transportation
Vauban Heliotrope, Solar Settlement, and Sunship	Plus energy buildings
Fraunhofer ISE	Energy storage research laboratory
Freiburg Solar Info Center	Clean energy business incubator
Vauban Green City	Car-free and low energy footprint neighborhood
Badenova Energy	Integration of residential solar and storage with smart grid
Burginner Strasse 50 - Passiv haus	World's first passive haus low-income housing development
Reterra Biogas Tour	Community biogas production and storage
Village of Wildpoldsried	Energy independent community
Sonnen GmbH	Residential battery storage and virtual utility
SmarterE Europe Conference	Largest energy exhibition and conference in Europe

Table 1. Sites and technology focal areas for the locations visited as part of the CREATE Energy Storage international project.

3.1 How is the energy landscape in Germany different from the United States?

3.1.1 Historical and Cultural Context

The generation that lived through WWII Germany dealt with massive destruction that included the demolition of much of Germany's energy infrastructure. Those who survived the war had firsthand experience with energy shortages unlike anything the U.S. has experienced in recent history. For example, one gentleman we met told us about his grandfather who had a vehicle

modified to run on wood because their petroleum sector was demolished. The vehicle had a gasifier mounted in the rear bed, and it pulled a trailer behind full of wood chips that could be shoveled into the gasifier to refuel (see Figure 1). The majority of Americans take access to energy, in all of its various forms for granted. In contrast, the experience of the post-WWII generation in Germany cemented within the nation's conventional wisdom an appreciation for the importance of energy resources. This ethos has been instilled in subsequent generations of German citizens through public education, political leadership, and international dialogue within the European Union.



Figure 1. Photo of a WWII era German vehicle with wood gasifier fueling unit.

The Chernobyl nuclear disaster had a huge impact on an entire generation of German citizens. German tour leaders and presenters for the CREATE program reflected on years when they were not allowed to play outside as children because of radiation concerns from the Chernobyl nuclear disaster (see Figure 2). The Green Party and the Energiewende were both initiated in part out of opposition to nuclear power. The German Energiewende began in the 1980s and matured over the past several decades with the growth of the Green Party [9].

The CREATE study group spent several days in the City of Freiburg and learned about Germans' attitudes and awareness of energy issues that developed after WWII and were further reinforced during anti-nuclear protests of the 1970s. Through presentations from the municipality and visits to the city's public transportation authority, CREATE participants learned that Freiburg purposely re-developed its historically narrow streets after WWII to accommodate a light rail train that runs completely on renewable electricity. The number of people who ride the train daily is equal to the population of Freiburg, about 220,000 people. Freiburg has prohibited cars in its downtown since 1969, and even built a new soccer stadium without parking, encouraging train and bike transportation to stadium events. "Green City Freiburg," as it promotes itself, also lives up to its sustainable reputation by investing millions of Euro into new and refurbished Passiv Haus energy efficient housing developments, as well as a net-zero energy City Hall.

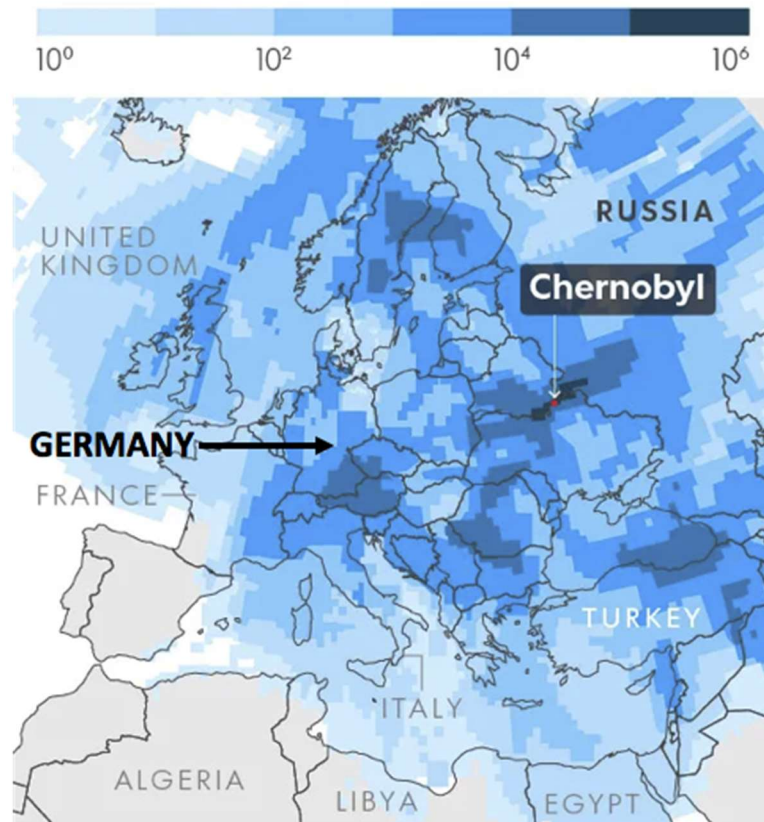


Figure 2. Model estimates of Cesium-137 radioactive isotope concentrations (shown in Becquerels/square meter) found in soil fallout resulting from Chernobyl nuclear disaster [10].

Energy is top of mind for German citizens. Most German homes and buildings are not constructed with central air conditioning. Lack of air conditioning means that summer peak electric loads are much smaller in Germany, hence summer daytime excess production by solar photovoltaics is more pronounced than in the United States. One of our participants told us that the German energy professionals' biggest fear is that too many of their citizens will spend time abroad in the U.S. and return home demanding central air for new German construction projects.

In the village of Wildpoldsried, Germany, energy consciousness has also nurtured a desire for community energy independence. Since the 1990s, Wildpoldsried's residents and the local government have invested in a portfolio of renewable energy that includes biomass forest products, biogas heat and electricity from dairy farms, and electricity from solar, wind, and hydropower [11]. This community now produces more than seven times the amount of energy that it consumes. Wildpoldsried is now a municipal power utility provider to the German high voltage grid, exporting energy to its neighbors (see Figure 3). This community is widely cited and visited by international groups because of its transition to renewable energy.

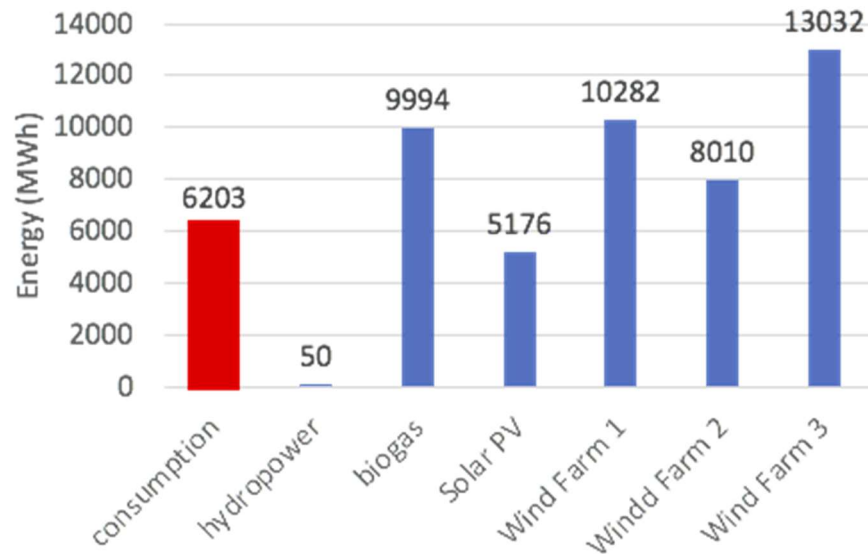


Figure 3. 2018 Energy consumption and production for the energy independent community of Wildpoldsried, Germany

Participants also learned about the student-led climate strikes that have been spreading throughout Germany and Europe since August 2018 [12] (see Figure 4). The group witnessed firsthand the energy of this movement, as exhibited by the Freiburg Youth Initiative party seeking to influence the local municipal elections [13]. The cultural phenomenon was further elevated by the international recognition of Swedish climate change activist Greta Thunberg and Fridays for Future in late 2019, even capturing the attention of the U.S president's Twitter feed.



Figure 4. Student Led Climate Strike in Freiburg, Germany

3.1.2 Energy Infrastructure

Unlike in other parts of the world, in Germany, renewable energy has largely been replacing nuclear production. The anti-nuclear sentiment that began with the Chernobyl fallout was heightened in the aftermath of the Fukushima disaster, which accelerated the German nuclear phase-out. As of Dec 31, 2019, Germany will have only six operating nuclear reactors remaining (see Figure 5), and these are all scheduled to be decommissioned by 2022 [14]. In contrast, renewable energy in the U.S. has largely been supplanting coal. In both cases, these are baseload generation sources that are being displaced, so the need arises to use energy storage or other types of dispatchable generation (e.g., natural gas) when winds are calm and the skies are cloudy.

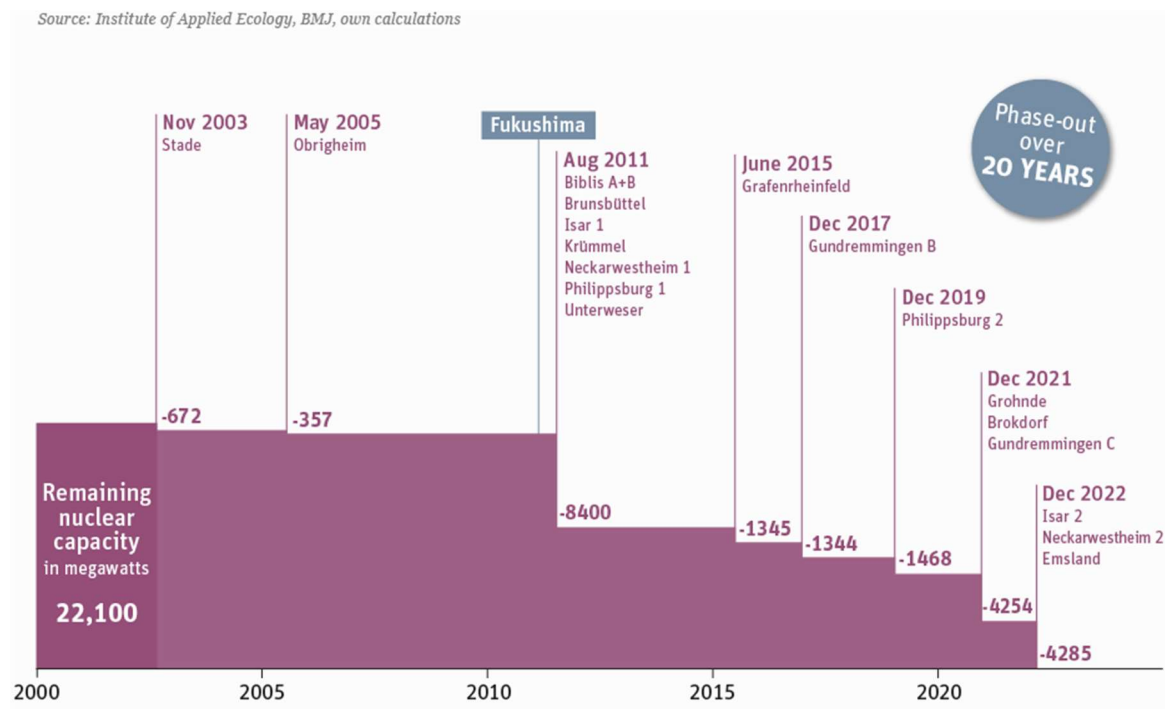


Figure 5. Reactor decommissioning schedule for the German nuclear phaseout

German power distribution lines are usually buried underground, and the German grid is among the world's most stable and reliable [15]. This is in contrast with the U.S., where most of our lines are overhead, and outages due to extreme weather are both common and increasing in frequency and severity. The 2019 California wildfire outages are perhaps the most extreme example of this phenomenon. As a result, the U.S. energy storage market is being fueled to a much greater extent by consumers who are seeking backup power sources for emergency resilience. Emergency power is not really a concern in Germany.

Renewable energy production in Germany hit new records in 2019 immediately preceding and following the CREATE program abroad. On Easter Monday 2019, renewables provided 77% of the energy consumed in Germany for the entire day [16], and it is not an unusual occurrence for spot prices of electricity to dip below zero for several hours on days when there is abundant wind and sun [17]. Production of renewable energy in Germany is now so great that the renewable sector is branching out beyond just electricity and into space heating and transportation. Energy

storage is playing a key role in this development, as it enables both fuel switching from fossil resources and temporal load shifting to save solar energy produced during the day for use heating homes and charging vehicles at night. Thus, energy storage is becoming a key enabling technology for the expansion of renewables in Germany. Currently, 50% of all solar systems sold in Germany are installed with batteries [18]. This is a strong contrast to the U.S., where currently only 4% of distributed solar photovoltaic installations include battery storage [19]. There are multiple variables related to battery-based energy storage that are being studied and standardized. Visits to German battery producers and end-users emphasized the importance of technological advances to address energy and power density, efficiency and heat loss, cycle life, safety, and the ability to monitor battery status through smart control systems. Further product development to address these issues will help to grow the energy storage industry in Germany and the rest of the world.

3.1.3 Public Policy

The scientific facts underlying climate change are generally not disputed in Germany, and renewable energy is supported by all political parties, except the far-right ultra-nationalist AfD party. Renewable energy is supported because it is clean, sustainable, and broadly recognized as an economically beneficial investment. It is agreed by the vast majority of the country that renewable energy is good for the nation and that it ensures a solid future for Germany. The German parliament is made up of six major parties (see Figure 6), and the Greens are a centrist party. As such, they are often sought as partners to form coalition governments. While the governing parties that comprise various parliamentary coalitions might disagree about the details of the implementation of the German energy transition, there are few German politicians that are steadfastly opposed to renewable energy.

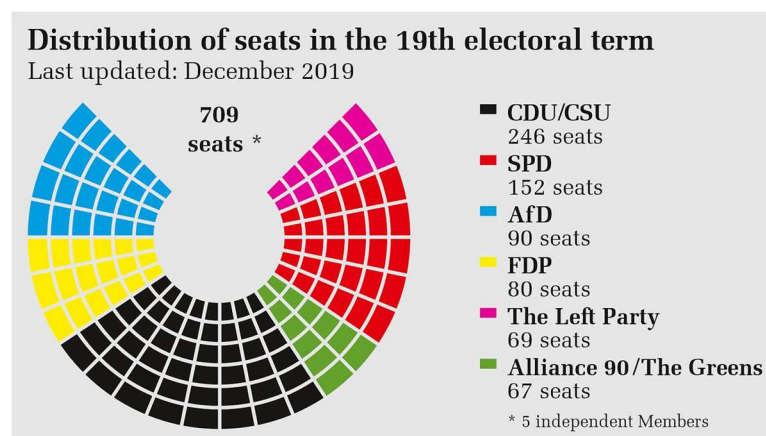


Figure 6. Distribution of political parties in the German Parliament, 2019. Note the Green Party is a centrist organization that forms part of the current coalition government.

Currently, coal and nuclear power are both being phased out in Germany. The Bonn marketing and social research company EuPD Research produced a January 2020 report that states Germany must create 50,000 new solar jobs by 2030 to replace current coal and nuclear power production. There is great concern about the future of communities in Germany that are dependent on coal mining for economic activity. The country is currently developing programs

to re-educate and re-employ people from the coal sector, and some major energy storage initiatives have recently been announced for historic coal-producing regions.

The German national government implements a federal ordinance, the Energie Einsparung Verordnung (EnEV), which mandates energy efficiency standards for buildings. The standards were recently revised to make buildings more energy-efficient, implementing the European “nearly zero-energy standard” and mandating that heating systems for existing buildings must be replaced upon 30 years of use. CREATE participants learned about Passive Haus building standards that, when applied to new construction or retrofit, can reduce a building's energy use by 80% or more, even in relatively cold climates. In Freiburg, the group also learned about the municipality's local Low Energy Housing standards, which were executed through private law contracts with developers. Participants highlighted technologies they witnessed for the first time in Germany, including window blinds mounted on building exteriors to reduce indoor summertime heat gain, vacuum-capsule insulated wall panels to eliminate conductive heat transfer, and heat energy recovery on bathroom and kitchen ventilation and piping. Participants were also interested to learn about phase change energy storage materials for interior walls using a paraffin encapsulated wallboard. The concept is similar to one of adding thermal mass to a building to moderate temperature changes through the absorption and release of thermal energy. The paraffin wallboard product takes advantage of the latent heat of fusion associated with the paraffin phase change, which is much larger than the specific heat associated with temperature changes in traditional thermal mass applications.

The Energiewende transition plan is also being adapted to adjust goals from past decades to account for new advances in technology. Recent slumps in the European wind power markets, create both a challenge and an opportunity to increase solar power in lieu of wind to attain Germany's energy targets. However, to meet future power demands with solar electricity, Germany now must work to increase the 52-gigawatt cap it placed on solar electricity production through the Renewable Energy Sources Act (EEG) [20].

Renewable energy has been an attractive investment for consumers in Germany in part due to the high retail electric rates that are paid, which are roughly double the average cost per kilowatt-hour that is paid in the United States. The growth of renewable energy in Germany was furthermore fueled by public policy that established Feed-In-Tariff incentives for customer-owned generation that provided a fixed price for renewable electricity [21]. The first Feed-in-Tariff contracts were awarded in 2004, and these locked in the value of renewable energy generation for a twenty-year contract duration. The Feed-In-Tariff rates were reduced annually from 2004 until 2014 to reflect changes in market pricing, which further encouraged self-consumption of renewable electricity and promoted energy storage with some early adopters (see Figure 7). Since 2017, the German renewable energy market has moved towards a model of technology-specific deployment corridors with prices determined through competitive auctions. The past incentives were quite successful, and there are currently more than one million homes in Germany that already have rooftop solar systems. The Feed-In-Tariff agreements for many of these systems are now nearing their end, and this creates a large pool of potential customers for energy storage retrofit installations [22].

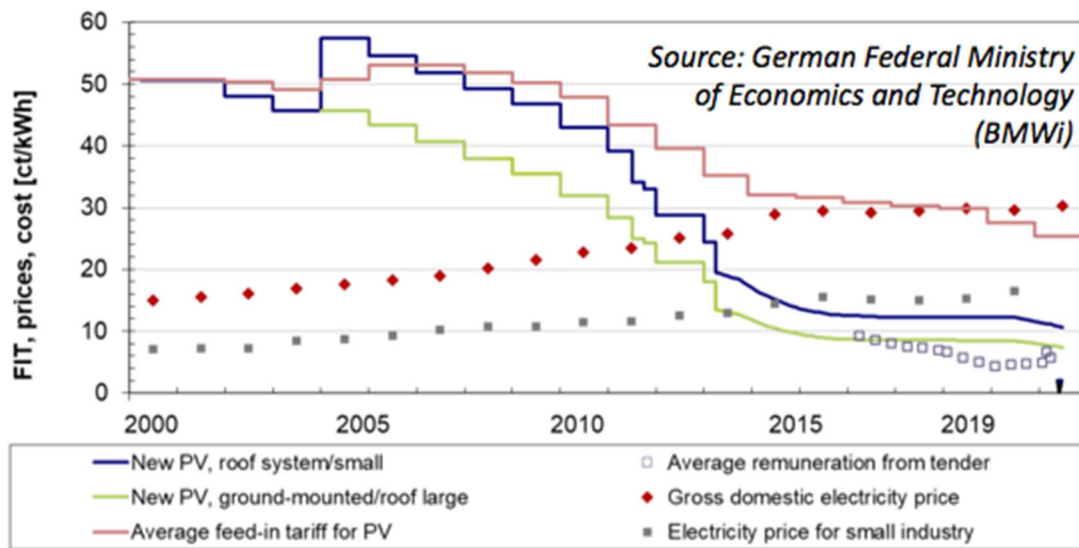


Figure 7. German Feed-In-Tariff (FIT) for solar PV power as a function of commissioning date through 2014, average remuneration for the subsequent solar PV auctions since 2016, domestic and small industry electricity prices, and the average tariff paid for solar PV over time.

3.1.4 Ownership and Organization of Energy Providers

In Germany, the generation, transmission, and distribution of electricity are conducted by different entities – the utilities are not vertically integrated. In the U.S., this is very different depending on where you live. In many parts of America, a single large utility may provide all electric services. In contrast, the German Energiewende has been advanced in large part by local electric power cooperatives. More than 180,000 German citizens are members of over 1000 energy co-operatives, representing a huge private investment of capital into the German electrical sector. As Deputy Mayor Günter Mögele was eager to point out in Wildpoldsried, this shift in the ownership form is driven by a strong desire for energy independence and local community engagement.

Similarly, district heating systems are often run by German municipal utilities to benefit the local community. This facilitates increased efficiency of power production using combined heat and power (CHP) and large-scale thermal energy storage. Germany powers CHP units with fossil fuels (coal and natural gas), but increasingly these units are being converted to run with biomass and biogas fuel sources. The participants learned about district heating provided by renewable biomass and biogas power plants in Freiburg and Wildpoldsried and were also able to visit a large scale solar thermal seasonal energy storage system in Crailsheim (see Figure 8 and Figure 9).



Figure 8: In the German town of Crailsheim, 7,300 m² of solar thermal flat plate collectors provide 50 % of the heat for 260 homes. Heat energy is captured and stored seasonally in a 37,500 m³ underground thermal borehole system.



Figure 9. Surface entrance to the Crailsheim underground seasonal energy storage system.

Large-scale battery energy storage systems are capable of storing intermittent renewable energy production and providing electric grid support in the form of voltage and/or frequency regulation. Site visits in Germany included examples of large-scale lithium-ion battery banks that could function to support power quality on the distribution power grid while facilitating the integration of intermittent solar and other renewable energy production. For example, the multinational German engineering and technology company Robert Bosch GmbH operates a large-scale battery bank test station at their headquarters near Stuttgart. Visits to Bosch and other manufacturers demonstrated how automated controls could balance power demand at the building level, prioritize the consumption of renewable power over fossil sources, access stored energy at times when renewables were in short supply, and provide power quality support services to the local distribution grid operator. Management of renewable energy production and consumption, and implementation of electric transportation both stand to benefit from local energy storage and more detailed sub-metering. One of the more interesting examples of this type of hyper-localized energy management involved a pilot project conducted by Energie Baden-Wurtemberg for a single neighborhood block that shared a community storage battery, along with ten electric cars capable of vehicle-to-grid smart charging with real-time pricing. The sophisticated control and monitoring system implemented by the local distribution grid operator

provides a rich data set with very granular data that is now being analyzed to extract consumer behavior patterns. This data will be used to inform future neighborhood energy storage initiatives.

Another interesting model for energy storage ownership and market participation was illustrated by the Sonnen Virtual Utility. Sonnen is a manufacturer of residential energy storage systems, and the CREATE team visited the Sonnen world headquarters in Wildpoldsried (see Figure 10). Sonnen currently has over 37,000 customers in Germany who own residential lithium-ion battery systems ranging in size from 2 to 20 kWh. Sonnen maintains two-way communication and controls with these customers and has networked them together to form a virtual utility. By aggregating these customer's capacity, Sonnen was able to enter the German grid balancing market in 2018, doing business alongside major German utilities such as RWE and E.ON. The company provides grid services such as voltage and frequency regulation, and wholesale power in 1 megawatt (MW) blocks of flexible production or storage, up to a maximum of 100 MW. This unique business model allows residential owners of energy storage systems to benefit financially from the wholesale power markets that they would otherwise not be able to participate in as individual energy providers. The innovation has attracted major investments from the Shell Petroleum company, which acquired Sonnen to expand this business model shortly before CREATE's visit [23]. While the Sonnen virtual utility structure would likely not be viewed as permissible (or even legal) in most American regulatory territories, variations of this model have recently been piloted in Arizona and Utah, which could serve as templates for further expansion into the U.S. marketplace [24, 25].



Figure 10. An engineer at Sonnen GmbH explains the company's integration of renewable energy, energy storage, and electric vehicle charging technology

Sonnen's activity spurred further grid edge innovations in Wildpoldsried. The German Ministry of Economic Affairs and private energy industry giant Siemens teamed to implement two consecutive projects called IRENE 1 and 2. These projects explored the operation of the village as a smart, self-contained regional electricity distribution system, treated as an islanded micro-grid, and capable of being used as a "topological power plant" [26]. These projects were followed in Wildpoldsried by additional energy ownership innovations through the PEBBLES (peer-to-peer trading based on blockchains) pilot being executed in partnership with the electrical utility EnBW [27]. Along with the Wildpoldsried energy campus, consisting of various aggregates, load banks, flexible interconnected grid strings, multiple energy storage systems, and inverter and transformer couplings, the community provides a unique asset for such

technological field trials. The PEBBLES project has created a peer-to-peer trading system between energy producers and consumers that serves to stabilize the local electric network (See Figure 11). The project is transforming the electricity market to consider the price and technology preferences of the participants, as well as the condition of the local distribution grid. Users can enter their trading preferences via a smart phone app, and a software agent automatically generates bids based on consumption and generation forecasts. The goal is to automate local energy trading while optimizing energy transactions to better serve the electric grid and enhance its stability.



Figure 11. Lithium-ion battery units and community electric vehicles are managed as part of the PEBBLES peer-to-peer energy trading system in Wildpoldsried, Germany

3.1.5 Energy Education in Germany

The German dual-schule education system fosters the integration of higher education with workforce apprenticeship programs (see Figure 12). More than 400 professions in Germany have apprenticeship pathways, and 60% of German workers participate in apprenticeship programs. The system is fostered by a high level of engagement and financial investment by private employers, and many countries have looked to the German system as an model to emulate [5, 28]. The international study group met apprentices at two electrical utilities and two battery companies who were working with renewable energy and energy storage applications. Student apprentices were working on projects that used smart home appliances and small-scale battery storage to balance neighborhood power grids. Apprentices also shared their work with eMobility projects, which involved the installation of battery storage along with residential electric vehicle charging stations that were remotely controlled by the utility. In contrast, traditional apprenticeship programs in the United States have primarily served the construction and skilled trades. In recent years, labor shortages for the STEM professions and the skilled technical workforce have prompted the U.S. Department of Labor to provide \$100 million in funding to engage employers nationwide in creating new apprenticeship opportunities across a wide range of occupations and industry sectors [29]. This initiative is still small relative to Germany, and it remains to be seen if American industry is prepared to engage and invest in its workforce to the extent that Germany has. Nevertheless, it will be interesting to see if the DOL initiative grows to include the renewable energy sector in the U.S., and if the effort can increase apprenticeship participation for American workers.

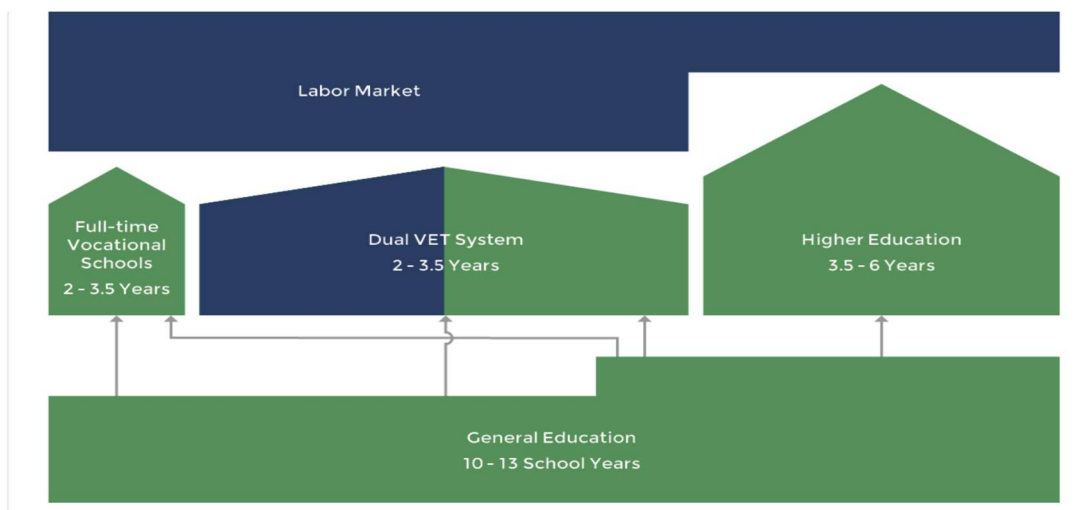


Figure 12. Simplified structure of the German dual-schule education system.

3.2 How has this project influenced educational practices for participants?

In post-trip self-evaluations, the CREATE participants indicated they perceived significant learning gains across a wide range of energy storage topics. The highest reported gains were for Utility-Scale Energy Storage, and the lowest were for Seasonal Energy Storage, but the differences between the subtopics were rather small and not very significant. See Figure 13.

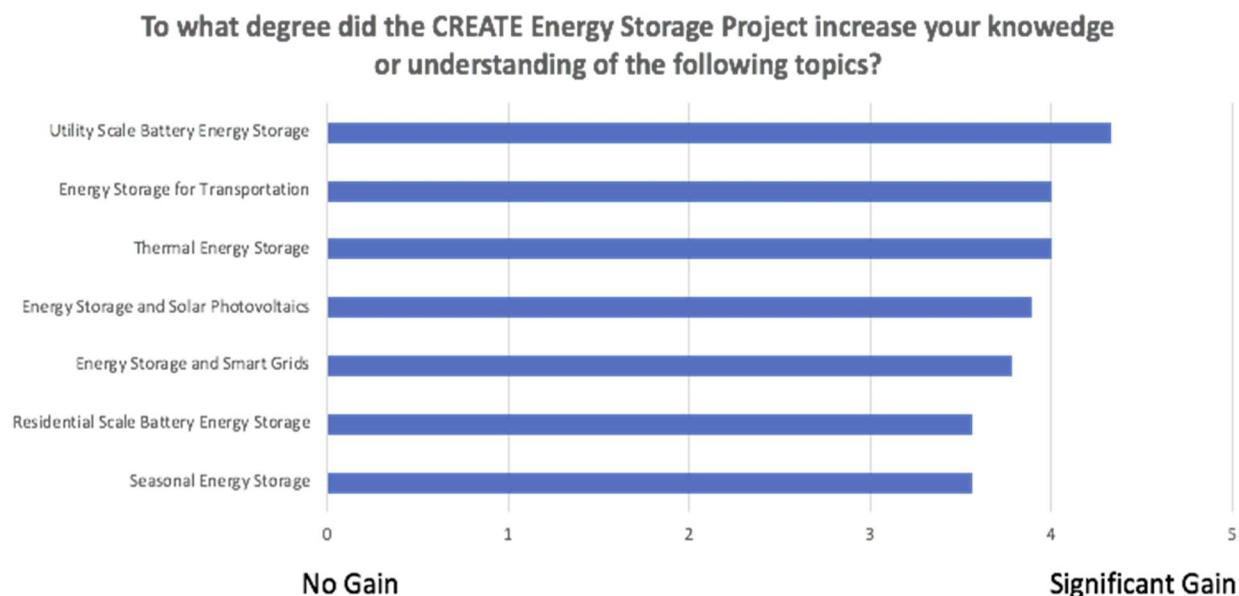


Figure 13. CREATE participant survey responses indicated significant gains in understanding of energy storage concepts and topics.

As of fall 2019, the participants had shared the energy storage knowledge that they gained with nearly 1000 individuals, approximately 300 of whom were students. This number is certain to

grow over time as the participants teach more courses and interact with a larger number of future students (see Table 2).

Target Audience/Group	Total Number
Students	298
General Community Members	203
Educators	187
Energy Professionals	156
Business and Industry Contacts	67
Government Agency Workers/Regulatory Officials	39
School Administrators	24
Elected Officials	3
TOTAL	977

Table 2. CREATE participants estimated the number of people with whom they shared energy storage information, insights, and details from the German experience.

When considering future changes anticipated in their instructional practice, all of the CREATE participants foresaw adding energy storage lecture content to their curriculum in the next one to five years. Faculty also indicated that it was very likely that they would add new lab activities, and that they would seek further professional development in energy storage technology. Significant numbers of faculty also thought it was likely that they would create new courses in energy storage and that they would find it necessary to acquire energy storage hands-on tools or equipment (see Figure 14).

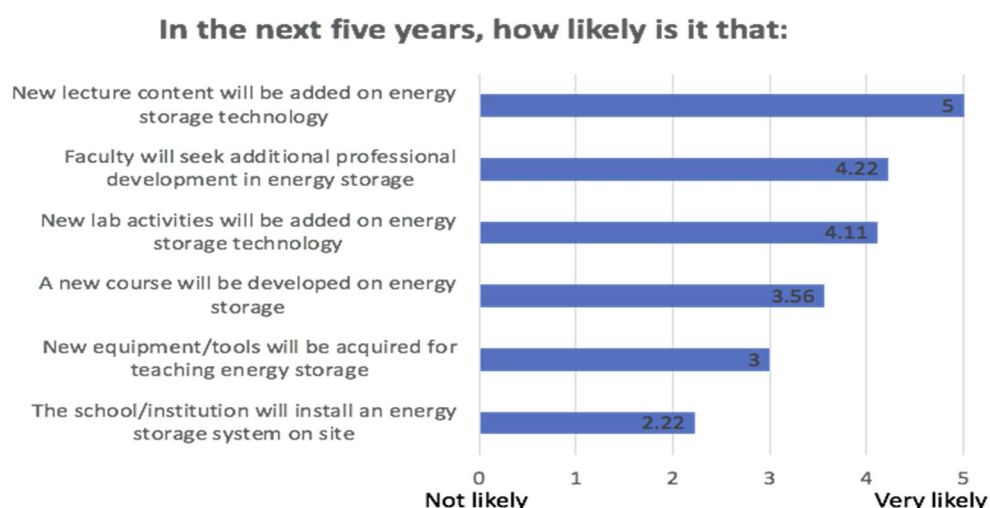


Figure14. Anticipated impacts of the CREATE energy storage project on participants' teaching practices in the next 5 years.

An example of the type of impact resulting from the CREATE Energy Storage Project is illustrated by Northeast Wisconsin Technical College (NWTC). The Energy Management and Solar Energy Technology programs at NWTC are being enhanced with energy storage to support

the college's goal to internationalize all curriculum. As part of this initiative, energy management instructor Jennifer Brinker will be providing a presentation for students about energy storage lessons learned from the CREATE Germany program.

NWTC's Energy Management Technology curriculum includes building energy modeling and considerations for efficient design. Going forward, students will compare and contrast U.S. building energy codes with Germany and the E.U. which now require a Passive Haus standard. Through comparing efficiency standards, students will learn about innovative design strategies and building materials. Students will discuss examples from the various projects seen in Freiburg, including technology such as vacuum capsule wall structures for insulation, phase-change interior walls for thermal energy storage, and air-sealing, heat recovery, thermal mass, and district heating applications for more efficient space heat.

NWTC students learning about building automation controls will also investigate micro-grid and advanced energy metering technologies such as those used in Germany. Lessons will include discussion of Wildpoldsried, where blockchain technology is used to meter energy production and consumption. Micro-grid management controls can also apply to district heating, and students will be taught about the Freiburg Solar Information Center that uses fluid heat flow sensors to meter the amount of heat that is consumed by individual tenants from a local CHP plant. As a result of the CREATE project, NWTC students will now add heat flow sensors and heat flow metering considerations to their analysis of building automation technologies.

The current Energy Management Technology curriculum at NWTC also involves utility rate and energy bill analysis. New lessons will compare and contrast standard U.S. power rates with German rate structures. Examples include the various German "tenant electricity" projects, which highlight an apartment complex renewable energy project that provides 60% of the electricity needed on site. Mieterstrom means "micro-grid" in German, and the idea with these behind the meter projects is that residents can generate their own energy on-site through a community-owned system, relying on the external distribution grid only to supplement the remainder of their needs through metered power.

In addition to the work being done at NWTC, several other schools also have energy storage initiatives underway that have benefitted from the CREATE Energy Storage project. Shoreline Community College has taught a battery-based solar installation class for the past several years, and in spring 2020, Shoreline is launching a new energy storage class that will feature Tesla battery technology. Heartland Community College and Madison Area Technical College are also in the process of developing new energy storage classes. In December 2019, Madison College also started the process of building a new energy storage lab. The school aims to acquire the remaining battery equipment and have the lab-ready to teach in the fall of 2020. Given the stated expectations of the other participants in the project, we anticipate that several more schools from this study will launch new energy storage initiatives in the upcoming years, which will hopefully serve as models for other educational institutions in the U.S.

3.3 How can these findings shape recommendations for best teaching practices on energy storage in the United States?

The SmarterE and InterSolar conference attended by the CREATE participants in Munich featured over 1,450 exhibitors filling 100,000 square meters of exhibition space. The event attracted more than 50,000 visitors from 162 countries, making this event the single largest platform for the energy industry in the European continent. Renewable energy is becoming the dominant form of energy in Germany, and it is also the fastest-growing source of energy in the U.S., which will likely parallel (but not exactly mirror) Germany's experience.

Comparison of the German and U.S. energy sectors provides an example for students to explore how technology readiness, regulatory policies, and economic forces all intersect to establish markets for an industry. For multinational businesses involved in engineering, project development, or technical sales, it is essential to know your clients and the business environment in which they operate. Products, business models, and sales and marketing plans developed for one country cannot be assumed to easily translate to another. Germany represents an early adopter market, providing an important window to demonstrate technologies and market innovations that might not yet be available or economical in the U.S.

The energy storage market is developing quickly in synergy with that of electric vehicles, as evidenced by the Sono Motors Sion solar electric car and others exhibited at the SmarterE Europe event. Also, the development of advanced energy monitoring and smart control systems allows for the integration of renewable energy, storage, electric demand management, and vehicle charging for residential, commercial, and industrial consumers. These sectors will likely overlap and further intertwine over the next decade. Engineers working in these disciplines will be advised to keep their eye on the related sectors that are rapidly converging.

Although many of the German energy storage manufacturers that CREATE met with did not currently have products available in North America, they were universally optimistic about introducing them here in the near future. The U.S. market was seen as prime for energy storage technology. The recent power outages in California raised awareness of the environmental urgency in America, and magnified the business opportunity for renewable energy paired with energy storage [30]. This creates a multi-national employment opportunity for engineers who are both familiar with the idiosyncrasies of the U.S. market, and the intricacies of German energy storage technology.

Multiple participants commented that witnessing the operation of German energy storage systems and power grids strengthened the need for U.S. curriculum that addresses power quality, demand management, and smart controls for automating communications and facilitating transactions between power producers and end-users. There was considerable discussion among participants about how blockchain financial transactions might be applied in the United States, and how energy program curricula might be modified to include real-time pricing, and cloud-based power and energy metering strategies.

4. Future Work and Conclusion

The CREATE project will continue its work in the upcoming years to facilitate the integration of energy storage technology into energy education programs. An industry-based energy storage job task analysis is being developed and will be released later this year. Energy storage educational webinars are also being produced, and recordings are available on the CREATE website. Faculty professional development workshops are also being planned to launch in 2021. Interested individuals should consult the Center's webpage at www.CreateEnergy.org for additional information.

The overarching conclusion from the CREATE Energy Storage Project was a broad recognition by all of the participants for the growing role that energy storage will play over the next decade in facilitating the growth of renewable energy technology. Today, Germany is clearly on the leading edge of this trend, but it is quite clear that energy storage technology will soon find a much larger role in the North American marketplace as well. Educators seeking to prepare their students for employment in this area should begin the process now of adapting curriculum and modifying academic programming to account for the integration of energy storage technology.

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6. References

- [1] L. Quitzow, W. Canzler, P. Grundmann, M. Leibenath, T. Moss, and T. Rave, "The German Energiewende—What's happening? Introducing the special issue," ed: Elsevier, 2016.
- [2] W. Fischer, J.-F. Hake, W. Kuckshinrichs, T. Schröder, and S. Venghaus, "German energy policy and the way to sustainability: Five controversial issues in the debate on the "Energiewende"," *Energy*, vol. 115, pp. 1580-1591, 2016.
- [3] L. Gailing and A. Röhring, "Germany's Energiewende and the spatial reconfiguration of an energy system," in *Conceptualizing Germany's Energy Transition*, ed: Springer, 2016, pp. 11-20.
- [4] BMWi, "Energy concept for an environmentally sound, reliable and affordable energy supply.," *Federal Ministry of Economics and Technology. Berlin, Germany.*, 2010.
- [5] M. Slowinski, K. Walz, and K. Alfano, "Renewable Energy Technician Education: The Impact of International Faculty Collaboration," in *Proceedings of the ASEE Annual Conference and Exposition*, 2016.

- [6] M. Slowinski, G. Temple, and K. A. Walz, "International Faculty Professional Development: Utilizing Online and Hybrid Environments to Deepen Learning and Grow Community," *ASEE Annual Conference Proceedings, Montreal, QC*, Submitted 2020.
- [7] K. W. Guyotte and N. W. Sochacka, "Is this research? Productive tensions in living the (collaborative) autoethnographic process," *International Journal of Qualitative Methods*, vol. 15, p. 1609406916631758, 2016.
- [8] K. A. Walz, M. Slowinski, and K. Alfano, "International Approaches to Renewable Energy Education--A Faculty Professional Development Case Study with Recommended Practices for STEM Educators," *American Journal of Engineering Education*, vol. 7, pp. 97-116, 2016.
- [9] C. Morris and A. Jungjohann, "Energy democracy," *Germanys Energiewende to*, 2016.
- [10] K. Hjelngaard, "30 years later: Chernobyl disaster could trigger more cancer, deaths," *USA TODAY. April 25, 2016.*, 2016.
- [11] S. Reed, "Germany's Shift to Green Power Stalls, Despite Huge Investments," *The New York Times. October 7, 2017.* www.nytimes.com/2017/10/07/business/energy-environment/german-renewable-energy.html, 2017.
- [12] FridaysForFuture, "About #FridaysForFuture," www.fridaysforfuture.org/about. Retrieved Dec 19, 2019., 2019.
- [13] L. Hanel and I. Pohl, "Germany's youth wake up to their political power. ," *Deutsch Welle. August 6, 2019.*, 2019.
- [14] A. Franke, "German nuclear exit continues as planned with next reactor to close Dec 31," *S&P Global - Electric Power, December 27, 2019.*, 2019.
- [15] P. Fairley, "Germany's grid: renewables-rich and rock-solid," *IEEE Spectrum*, vol. 28, 2014.
- [16] J. Wettengel, "Renewables hit record 77 percent of German power on Easter Monday," *Clean Energy Wire, April 24, 2019.*, 2019.
- [17] N. Witkop, "Germany sees third weekend of negative prices," *Montel News, March 18, 2019.*, 2019.
- [18] P. Hockenos, "In Germany, Consumers Embrace a Shift to Home Batteries," *Yale Environment 360, March 18, 2019.*, 2019.
- [19] U.S. Department of Energy, "Solar-Plus-Storage 101," www.energy.gov/eere/solar/articles/solar-plus-storage-101. March 11, 2019., 2019.
- [20] Intersolar Europe, "More than 50,000 New Jobs through Photovoltaics and Storage Technology," www.intersolar.de/en/news-press/for-journalists/press-releases/press-release/more-than-50000-new-jobs-through-photovoltaics-and-storage-technology-3644. December 5, 2019., 2019.
- [21] H. Wirth, "Recent facts about Photovoltaics in Germany 2020," *Fraunhofer ISE*, 2020.
- [22] A. Brautigam, T. Rothaker, and H. Staubitz, "The Energy Storage Market in Germany," *Germany Trade and Invest*, 2019.
- [23] J. Spector, "Oil Supermajor Shell Acquires Sonnen for Home Battery Expansion," *Green Tech Media. Feb 15, 2019*, 2019.
- [24] J. Spector, "Sonnen Brings Its Virtual Power Plant to the US With a 2,900-Home Project - The plan: Build first, find a utility contract later.," *Green Tech Media. Oct 12, 2017.*, 2017.
- [25] P. Kelly-Detwiler, "A Cutting Edge Virtual Power Project In Utah, With Batteries Managed By The Utility," *Forbes. August 27, 2019.*, 2019.

- [26] Siemens, "Siemens IRENE-2 Project Website," <https://new.siemens.com/global/en/products/energy/topics/iren-2.html>. Retrieved Dec 19, 2019., 2019.
- [27] Peebles, "Peebles Project Blog," <https://pebbles-projekt.de/en/blog/>. Retrieved Dec 19, 2019, 2019.
- [28] A. Spees, "Could Germany's Vocational Education and Training System Be a Model for the U.S.?", *World Education News and Reviews*. June 12, 2018., 2018.
- [29] U.S. Department of Labor, "Apprenticeship Grant Announcement," <https://www.dol.gov/featured/apprenticeship/grants>. Retrieved Dec 19, 2019., 2020.
- [30] J. St. John, "US Storage Market Rebounds as Outage-Scarred California Promises Big 2020 Growth," *Green Tech Media*. December 3, 2019., 2019.