From Running to Energy: Human Powered Energy Generation for an Illuminated Running Vest

(Technical Paper)

Transitions Management in Renewable Energy Generation: How Government Can Support Socio-Technical Transition through Protective Spaces

(STS Paper)

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Introduction

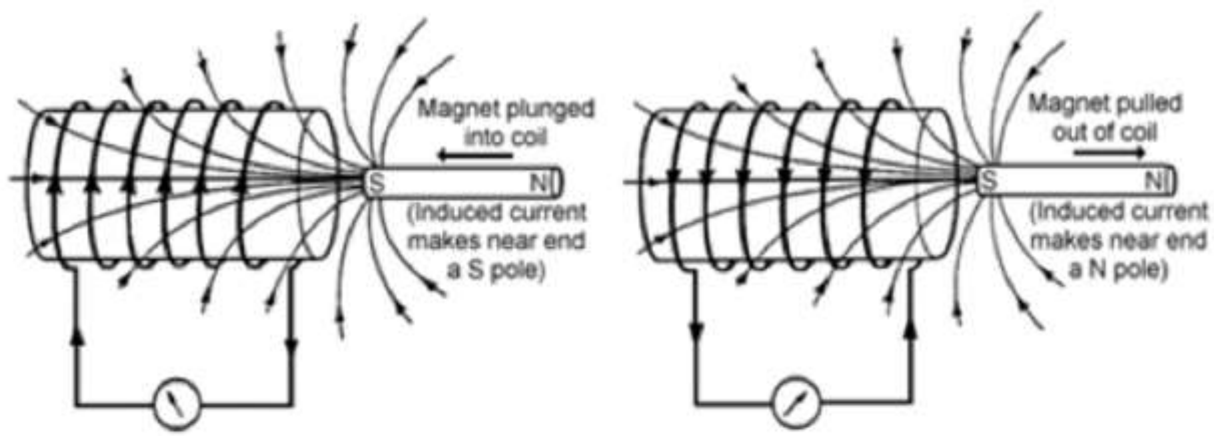
Reports form the International Panel on Climate Control (IPCC) detail that a path to zero carbon output needs to happen in the near future to avoid a 3 to 4-degree Celsius increase in global average temper, the current path the earth is on (Harvey, 2018). A 1.5 degree increase in global average temperature is the best-case scenario. Each .5 of a degree increase in global average temperature results in significant amplification of environmental consequences such as flooding, deadly heat waves, agricultural losses, habitat losses, human displacement and much more (Plumer, 2018). There is a desperate necessity to begin deep decarbonization, which means reducing global carbon emissions entirely. Renewable energy (RE) provides one way to reduce carbon emissions, yet it makes up a very small part of the grid energy profile. REs struggle to compete with existing energy sources due to issues of reliability, making them less desirable than carbon-emitting sources (Waters, 2019). Innovations in battery storage handle the problem of reliability for REs, but the current battery costs result in much higher energy prices. Global emissions are still rising, and the IPCC reported 1.7% growth in emissions in 2018, revealing that the earth has not even begun to reduce the yearly emissions due to theses drawbacks of REs (Roberts, 2019). At a moment when our planet needs to be reducing carbon output as soon as possible, we continue to burn fossil fuels as our primary form of energy at an alarming rate, creating more devastating consequences for the near future.

The technical topic will focus on developing a running vest with embedded energy generation capabilities powered by the running motion of joggers. The minor vertical movement of the runner charges a capacitor, which then feeds power to a LED strip on the vest to safely alert drivers of their presence. This will allow users to access and use entirely renewable and carbon-emission-free energy while dictating the source of their energy. The STS topic will focus on the policy side of innovation, evaluating literature and cases regarding governments conducting transitions management, defined as "long-term visions, which function as a framework for formulating short-term objectives and evaluating existing policy" (Rotmans, 2001, 23). Specifically, the research will focus on one form of transitions management: the formation of protective spaces. Protective spaces allow innovations to develop and improve performance, while reducing costs, without the pressure of competing with existing technologies, so they may be best supported for a large-scale transition and diffusion. The research will work to provide a framework for the possible application of "protective spaces" to the RE with battery storage movement.

***Technical Topic* - From Running to Energy: Human Powered Energy Generation for an Illuminated Running Vest**

A clear path towards a carbon-neutral future requires electrifying everything. This would entail removing fossil fuel-based devices, and replacing them with electrically-powered substitutes (Roberts, 2018). This transition has begun to take place in cars, furnaces, stoves, and many other devices. Pulling electricity from the grid yields less carbon emissions compared to burning fuels onsite because the grid consists of some carbon-neutral energy sources. As the grid continues to incorporate more carbon-neutral energy forms, electrified devices will result in less carbon emissions. Consumers often overlook one fact: carbon-neutral energy only makes up 15% of the energy sources on the national power grid (EIA, 2019). These electrified devices are still operating on largely fossil fuel-based power, and they are only marginally better for the environment. While people are under the impression that using electricity is better for the environment, it is still very harmful and results in carbon emissions largely unknown to the consumers. Consumers wish to electrify their devices, evidenced by the wide scale uptake of electric vehicles, but the vehicle itself is still emitting large amounts of carbon at the source of that energy. Consumers have no control over the source of the electricity and energy coming from the grid, and that leads to consumers having no strong option to reduce their carbon footprint.

My team plans to develop an energy generation and storage device within a running vest, powered by running motion. Our design consists of a linear generator, which converts the kinetic energy of running motion to electrical energy through magnetic induction. In other words, a magnet moving through a coil of wire induces an electrical current, as shown in the figure below



(Wiley, 2016).

Figure 1: Schematic of magnetic induction used to induce a current by moving a magnet through a coil of wire

The natural vertical bouncing of jogging motion moves the magnet through the coil, and springs on either end of the magnet work to amplify and maintain the magnet's movement through the coil. The challenge of this design requires transforming the voltage output from the linear generator (alternating current) to an output that can be used by the LED's (direct current). The bridge rectifier and capacitor work to smooth that induced alternating current from the generator, so it may be discharged to the LEDs as shown in the schematic below.

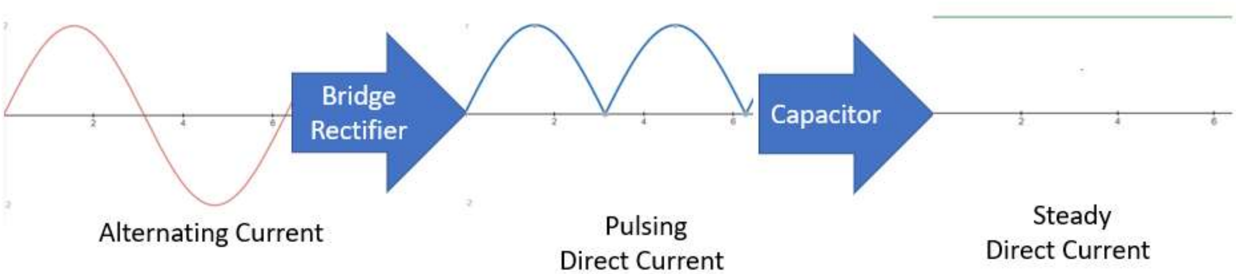


Figure 2: Schematic representing current coming from linear generator, and the ways that the bridge rectifier transform the output voltage, so it may be used by the LEDs

The electronics (generator and capacitor) will be enclosed in a 3-D printed plastic casing designed to keep water out. The entire casing will be seamlessly integrated into a running vest with LED strips attached to draw attention from oncoming drivers, and the electronics casing along with LED strips may be removed from the vest so the user can wash it. The product will be designed with ease of manufacturing in mind by minimizing the number of parts required. Advancements in battery and capacitor technology continue to increase the efficiency, capacity, charging time, and discharging time (Climate Reality Project, 2019). We anticipate that as these technologies continue to develop, devices like ours can be made smaller, cheaper, more practical, and more powerful with no tradeoffs.

This form of energy generation can guarantee zero carbon emissions without a heavy upfront investment. Consumers currently have no input regarding the source of energy that comes through the plugs in their wall, while this device allows the user to have full knowledge and understanding of the source of their energy. This kind of individual generation creates a new category within the energy field: “prosumers,” meaning the consumers are also producing their own energy, which allows consumers to actually dictate the source of their energy (Siosanshi, 2018). A large-scale uptake of this device would lead to reduced grid energy consumption and the grid’s inherent carbon emissions, which is a step closer to carbon-neutrality.

STS Topic - Transitions Management in Renewable Energy Generation: How Government Can Support Socio-Technical Transition through Protective Spaces

Phasing out carbon-based energy production is the necessary future of the energy realm. There is a requirement for a large-scale sociotechnical transition to achieve this goal. Renewable energies are picking up traction, but they are still not quite as attractive as fossil fuel-based power for two reasons: cost and reliability. The imbalance of solar and wind energy generation

Figure 3: A general hourly grid energy demand curve (blue) and solar generation curve (orange/yellow) (Groves, 2019).

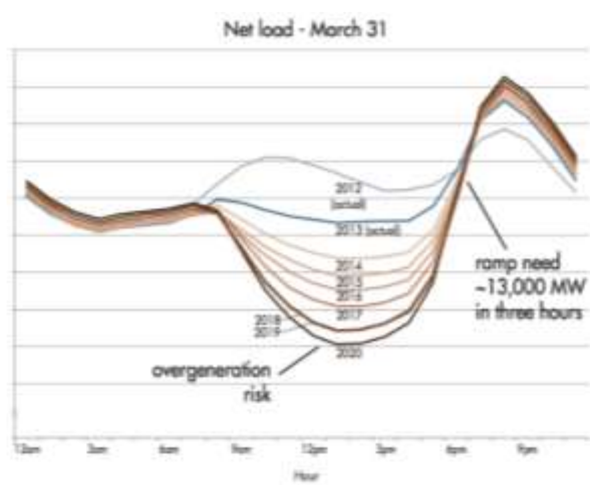


Figure 4: The remaining grid energy demand curve after solar energy generation. (Roberts, 2018).

compared to energy demand puts a lot of stress on fossil fuel-firing plants, such as gas and coal to deliver peak energy generation (Waters, 2019). Figures 3 and 4. below details the ways in which solar energy strengthens a reliance upon fossil fuel-based energy.

Figure 3 demonstrates the solar energy generation (yellow and red), and the energy demand curve (blue) over the course of a day. Figure 4 depicts net load or, more simply put, the remaining energy to be dispatched after solar serves some of the demand. This creates a large ramp to meet the evening peak in the net load, and only fossil fuels can fill that gap. Fossils Fuels can only deliver that need because they can easily generate energy when it is needed on short notice, unlike RE.

To address issues of reliability, battery storage allows for excess energy to be stored when energy is not needed (around midday) and discharged at will to fulfill the afternoon demand peak. This storing and strategic discharging method fixes the unreliable power production, eliminating the necessity of fossil fuel-based energy sources (Jones-Albertus, 2018). A full RE transition is reliant upon battery storage to make RE sources more reliable. Unfortunately, battery storage comes with a large cost, nearly 3 to 4 times the cost of standard fossil fuel-based prices (Lazard, 2018). RE alone struggles to compete with the existing fossil fuel-based technologies due to unreliability, and the battery technology paired with RE struggle to compete on the grounds of cost. These drawbacks hold carbon-neutral energy sources to only a minor portion of energy generation profile, leaving room for more carbon to be emitted into the atmosphere.

Jan Rotmans defines the framework for considering large scale sociotechnical transitions called transitions management, the goal of which is to assist and operate a transition given a certain objective and existing structure. He clarifies the concept when explaining that transitions management requires "long-term thinking (at least 25 years) as a framework for shaping short-term policy." He also assigned the responsibilities within his framework when saying that "government can and should assume a leading role in transitions management" (Rotmans, 2001, 26). Frank Geels builds off of Rotmans' work when introducing a multilevel perspective (MLP) framework to understand how a sociotechnical transition such as deep decarbonization develops. He argues that "acceleration of sociotechnical transitions involves three mutually reinforcing processes: increasing momentum of niche innovations, weakening of existing systems, and strengthening exogenous pressures, which when aligned can create windows of opportunity" (Geels, 2017, 1243). In connecting the work of Rotmans and Geels, one can see that a government's leadership role in transitions management best fits into the MLP at the third level, the "exogeneous pressures." In this sense, the combination of their works identifies a narrower framework for government's involvement in a sociotechnical transition, such as deep decarbonization. They demonstrate that governments have a responsibility to enact short-term policies to pressurize and support the future transition to REs.

In another work, Geels identifies a specific form of transitions management when explaining that "the creation of 'protective spaces' is a useful and important means of encouraging emerging innovations because they shield these innovations from the pressures imposed by the existing systems and give them time to mature" (Geels, 2018, 26). These "protective spaces" are formed and supported by government action, as Rotmans suggests earlier. For example, German solar, wind and nuclear energy were able to flourish after the 2000 Renewable Energy Act, which established a 20-year long feed in tariffs. In other words, the government promised to purchase energy form any carbon-neutral sources at higher prices than carbon-emitting sources, and this allowed RE's to develop and improve before truly competing with fossil-fuel based energy sources. This policy wholly supported renewable energy innovation in Germany, and it eventually led to Germany earning the title of "the first renewable energy economy" (Burgermeister, 2009). This case demonstrates that a protective space approach as a form of government-induced "exogenous pressure" has vastly changed the future of REs in Germany, and it aided the acceleration of deep decarbonization in a country that leads the world at the moment.

The STS research will provide a better understanding of pathways, led by governments, to large-scale transitions in the field of energy towards a carbon neutral future. The research will build off of works by Geels and Rotmans regarding transitions management, but it will differ by narrowing the scope to only protective spaces. This work will evaluate cases of government-installed protective spaces as they assisted sociotechnical transitions across multiple fields. Finally, it will provide a framework for applying protective spaces to innovations in RE with battery storage as a means of reaching a carbon-neutral energy future.

Conclusion

The technical research will culminate in a battery storage device that stores charge from running motion and is seamlessly integrated into a running vest. A panel of professors will evaluate the aesthetics, comfort, and ease of use for the device. The STS research will observe the use of protective spaces as they relate to new innovations through the lens of Rotman's transition management framework. The work will yield a clear understanding of transitions management practices, and investigate way in which those practices can apply to the upcoming battery storage movement.

While the technical deliverable only provides enough energy for one small device at a time, a large-scale uptake of the technical concept could lead to significantly reduced grid consumption. This kind of large reduction means less carbon-emitting generation. On the other side, transitions management through the use of protective spaces could support and speed up the movement to RE paired with battery storage, overcoming the problems with RE, and unlocking the potential for a carbon-neutral future.

References:

Burgermeister, J. (2009, April 3). Germany: The world's first major renewable energy economy. *Renewable Energy World*. Retrieved from: https://www.renewableenergyworld.com/2009/04/03/germany-the-worlds-first-major-renewable-energy-economy/#gref

Geels, F, Shwanen, T, Sorrell, S, Benjamin, K, & Sovacool, B. (2018, June). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Research & Social Science, 40*, 23-25. https://doi.org/10.1016/j.erss.2017.11.003

Geels, F, Sovacool, B, Shwanen, T, & Sorrell, S. (2017, September 22). Sociotechnical transitions for deep decarbonization. *Science, 357* (6357), 1243-1244. https://science.sciencemag.org/content/sci/357/6357/1242.full.pdf

Harvey, C. (2018, June 19). World has only 20 years to meet ambitious 1.5-degree C warming threshold. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/world-has-only-20-years-to-meet-ambitious-1-5-degree-c-warming-threshold/

Hess, J. (2018, June). Energy democracy and social movements: A mutli-coalition perspective on the politics of sustainability transitions. *Energy Research & Social Science, 40,* 177-289.

Jones-Albertus, B. (2017, October 12). Confronting the duck curve: How to address over-generation of solar energy. Office of Energy Efficiency and Renewable Energy. Retrieved from: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

Divya, K, & Ostergaard, J. (2009). Battery energy storage technology for power systems—An overview. *Electric Power Systems Research, 73*(4), 511-520. https://doi.org/10.1016/j.epsr.2008.09.017

Mclaren, J. (2019). Identifying potential markets for Behind-the-Meter battery energy storage: A survey of U.S. demand charges. *National Renewable Energy Laboratory.* Retrieved from: https://www.nrel.gov

Plumer, B, & Popvich, N. (2018, October 7) Why half a degree of global warming is a big deal. *The New York Times.* Retrieved from https://www.nytimes.com/interactive/2018/10/07/climate/ipcc-report-half-degree.html

Roberts, D. (2017, October 27). The key to tackling climate change: Electrify everything. *Vox.* Retrieved from: https://www.vox.com/2016/9/19/12938086/electrify-everything

Roberts, D. (2018, October 11). Utilities have a problem: The public wants 100% renewable energy, and quick. *Vox.* Retrieved from: https://www.vox.com/energy-and-environment/2018/9/14/17853884/utilities-renewable-energy-100-percent-public-opinion

Roberts, D. (2019, June 26). The global transition to clean energy, explained in 12 charts. *Vox*. Retrieved from: https://www.vox.com/energy-and-environment/2019/6/18/18681591/renewable-energy-china-solar-pv-jobs

Rotmans, J, & Kemp, R. (2001, February). More evolution than revolution: Transition management in public policy. *Foresight 3*(1), 15-31.

Sioshansi, F. (2018, October 5). Electricity's future: Mostly behind the meter distributed generation. *Energy Post.* Retrieved from: https://energypost.eu/electricitys-future-behind-the-meter-distributed-generation/

Thompson, A. (2019, July 1). Utility-cale energy storage will enable renewable grid. *Scientific American* Retrieved from: https://www.scientificamerican.com/article/utility-scale-energy-storage-will-enable-a-renewable-grid/

Waters, C. (2018, May 9). This "duck curve" is solar energy's greatest challenge. *Vox.* Retrieved form: https://www.vox.com/2018/5/9/17336330/duck-curve-solar-energy-supply-demand-problem-caiso-n

(2018, January). Clean energy is building a new American workforce. *The Environmental Defense Fund.* Retrieved from: https://www.edf.org/energy/clean-energy-jobs

(October, 2018). Global Warming of 1.5 C. *International Panel on Climate Change.* Retrieved from: https://www.ipcc.ch/reports/

(2019). Lazard's levelized cost of storage analysis—Version 4.0. *Lazard.* Retrieved from: lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf

(2019). What is US's electricity generation by energy source? Retrieved from: https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

(2019, September 11). Energy storage continues to grow and get more affordable. *The Climate Reality Project*. Retrieved from: https://www.climaterealityproject.org/blog/energy-storage-continues-grow-and-get-more-affordable