1. Abstract

The world is growing at an exponential rate and with it, our energy demands. To meet modern electricity needs, PSE&G is upgrading its existing 85 year old transmission line between Susquehanna, PA and Roseland, NJ. Unfortunately, the world has changed a lot over the past decades and building transmission lines has become infinitely more complicated. With the relentless construction of residential neighborhoods and the modern creation of designated national/state parks, it has become virtually impossible to build a transmission line without angering numerous groups, each of which believe that its agenda is the most important. In our work to determine the most efficient route for the Susquehanna-Roseland transmission line, we found ourselves with a two-part plan. First, by weighting a variety of factors we deemed crucial, we worked to determine the route that would generate the least social resistance. We created a separate guide for minimizing cost as well, since budget is always a concern as with any engineering project. Second, we applied these guides to the Susquehanna-Roseland project, analyzing the proposed routes using the guides and equations we developed. Ultimately, we found that Alternative A was the poorest choice, ranking last in both cost and social impact. Alternative B and C were found to be extremely close in both aspects, which made differentiating between the two significantly harder. In the end, we chose Alternative B as the optimal route because the majority of the line ran the same path as the existing older route. With all things equal, we decided that building over an existing route, Route B, would generate the least social resistance because the land should be slightly easier to obtain and the route had already been pre-cleared.

2. Introduction

2.1 Background

Electricity is an omnipresent need in our society. The power in transmission lines is based off the voltage and current that travels through the wires. Ohm’s Law, V = IR, describes the relationship between voltage, current, and resistance. Resistance in power lines is based on wires and is constant throughout the grid. Power, the amount of joules that passes through a segment of wire per second, is calculated through P = IV. The quantity most pertinent to the general public is power, which transfers into the electricity used to power light bulbs and ovens.

New Jersey’s electricity is supplied by private companies and enterprises like Public Service Electric and Gas (PSE&G) that control the entire electric grid of the state, from the generation of energy to its delivery at private homes. Energy can be generated from numerous sources, including water, fossil fuels, and the sun. The voltage generated by the power plant will be increased through a step-up transformer, which operates through induction. Two Tesla coils are placed adjacent to each other and a current is run through one coil, which induces a current in the other. An increased number of coils in the secondary coil can step up the voltage by several hundred kilovolts. The current is then sent to the high-voltage (HV) transmission lines. The HV transmission lines are the quintessential power lines seen running along streets and forests that transport power throughout the
electric grid. Current is typically transmitted in three phases along HV transmission lines. The three phases are exactly 120 degrees off from each other, a set-up that ensures a perpetual supply of electricity running through the three wires. Transmission lines can range from 10 to over 200 miles long, delivering energy from the generator to the many recipients of power. When a transmission line nears its destination, the electricity will be pushed through a step-down transformer that acts opposite the step-up transformer, using induction and an adjacent Tesla coil of fewer loops to reduce the voltage to lower voltages more suitable for private use. Following the step-down transformer, the power will be sent into a distribution center, where electricity is split into multiple branches and heads off toward its destination. Typically, houses in a neighborhood will be members of the same distribution. When a power line breaks near a home, all power in the neighborhood will be lost because the entire sub-route is disrupted. After the distribution and another step-down transformer that further reduces the voltage, the electricity will be delivered to the customer. The transmission route analyzed in this paper refers to the HV transmission lines that will deliver electricity from the generator in Roseland, New Jersey to customers in Susquehanna, Pennsylvania.

As the energy demand of New Jersey continues to rise, PJM Interconnection, the regional company in charge of planning the transmission system for most of the east coast, determined that “a new line was necessary to ensure reliable electric service” in the future. Unlike other public works such as roads and highways, electricity is one of the few resources that call for constant perfection. While traffic jams are usually minor annoyances, a single blackout can shut down businesses, destroy crucial computer files, and devastate an entire region. To prevent this disaster, the power grid must have overlaps. Through this set-up, if one line fails, there will still be an alternative way to transmit power. Therefore, in an effort to plan to ahead, PSE&G made the executive decision to upgrade its 108-year-old 230-kV power lines. The proposed Susquehanna-Roseland Power Line will be 500-kV and run forty-five miles between Roseland, NJ and Susquehanna, PA, crossing miles and miles of wetlands, forests, and residential neighborhoods.

The main advantage to higher voltage transmission lines is the reduced power loss.

\[ P = IV \]
\[ P_{\text{Loss}} = I^2 R \]

The power propagated by a set of transmission lines is a constant, as power companies are responsible for delivering a constant number of watts to its customers. Because power is the product of current and voltage, the two are inversely related: if current goes up, voltage must go down and if current goes down, voltage must go up. Resistance in the power loss equation remains constant throughout the transmission line, as the wire’s resistivity will not be altered. Thus, current and power loss are directly proportional: reducing current will reduce power loss. Recalling that current and voltage are inversely related, increasing voltage will consequently decrease current. By amping up the voltage in transmission lines, power loss is minimized. For this reason, it is beneficial for transmission lines to have high voltages.

The efficiency and voltage of the PSE&G’s transmission lines must be increased to ensure steady energy supply for the growing public. The following paper will analyze three alternatives and determine the best route in terms of public opposition and cost.

### 2.2 Issues

Almost immediately after the Susquehanna-Roseland transmission line proposal, the public erupted in protest outraged residents in Pennsylvania and New Jersey formed the Stop the Lines organization. Originally planned to be
finished in the June of 2012, the line has yet to be started, delayed by numerous protests and public hearings.

The primary concern comes from homeowners who display a “Not-in-my-backyard” attitude, an informal term that describes people who wish to have the benefits of utilities without the unappealing structures near their homes. Some concerns are completely legitimate. For instance, studies have shown that having a transmission line near a home can lower property values anywhere from 15-30%.

Other issues are purely based on the undesirable factor that power lines present. Obviously, power lines are ugly to see and may ruin the otherwise rustic feel of the land. Although transmission lines do not present any permanent damage, they can certainly change the feel of the land, especially if they are built near public places like schools and churches. Additionally, power lines may create loud buzzing noises during heavy rains. Although these sounds are far below the decibel limit for ear damage, they are certainly bothersome and the complaints may be somewhat justified.

However, some issues are completely unfounded. For instance, many people claim power lines emit electromagnetic radiation that induces cancer and other health defects. Although a few studies have shown a weak correlation, the overwhelming majority of research has shown no relationship between the magnetic fields of power lines and adverse health effects.

The relationship has little logical basis either: a large power line 100 feet from a house generates a magnetic field of 0.4 microteslas while the natural magnetic field of the earth that we all experience on a regular basis emits between 40 and 60 microteslas, far more than the magnetic radiation of power lines.

Other groups are more concerned with the effect power lines have on the land and environment. Farmers are especially concerned with how the construction of power lines may leach certain chemicals into the soil and impact the crops. Other times, the construction of power lines, which can last up to six months for a specific section, may interfere with the farmer’s irrigation system and prevent proper crop growth. While constructing these lines, heavy equipment is run in and out of the area, making it virtually impossible for a farmer to grow crops in that year. To compensate for the farmer’s crops, many companies will purchase the harvest for that year. After the lines are built, however, power lines leave a minimal impact. The farmer can grow crops in the field, while electricity continues to buzz through the overhead lines.

Furthermore, since the power lines run through many areas of national/state park territory, there is the issue of preservation and the protection of nature. Park Service organizations in particular oppose the proposed Susquehanna-Roseland route because of its infringement upon state parks. They claim the power lines are greedy ventures that would be detrimental to areas of nature and would obstruct the natural beauty for which NJ parks are known. The Park Service is also concerned that transmission lines would have an adverse effect on the careful balance of communities in the ecosystem and threaten endangered avian species that reside in state parks. Such opposition from the Park Service makes permits through state parks difficult and expensive to obtain.

Forests not owned by the Park Service or state are somewhat better than state park territory simply because Park Service organizations will not be as ardently protective of non-park forests. The biological impact and threat to indigenous species remains problematic, but the visual impact of transmission lines will be reduced because there are trees to obstruct the sight of wires. Because forestlands are mostly upland rights of way, which are lands not owned by any organizations or governments, permits for non-park forestland are easy to obtain.

In contrast, highways and barren lands present the perfect location for transmission lines simply because they are absent of sensitive wildlife and nature. Highways are pre-established sites of manmade infrastructure that are rarely home to diverse wildlife. The aesthetic impact of transmission lines along highways is minimal as well; few people will raise opposition to power lines along a view they see only in passing. Barren lands are similar: because they are remote and largely void of life, transmission lines will not inflict much damage upon the nonexistent wildlife. Although the aesthetic impact of power lines in barren lands may
be larger because there are no trees to conceal the wires and structures, the minimal biological impact of transmission lines along highways and in barren lands make the two regions favorable routes for PSE&G.

Of course, as with any project, money is also a factor. Yet unlike other for-profit projects, infrastructure is more of an investment so social impact should have a higher priority over cost. Nonetheless, some factors tend to drive up cost more so than others. For instance, building transmission lines through wetlands costs significantly more than regular construction because of its inaccessible location and the need to build stronger foundations. Additionally, many wetlands and forests reside in national and state parks that require permits to compensate for the intrusion into their lands. Not only that, but private landowners may seek compensation as well, especially farmers who cannot use their land while construction is taking place. Fortunately, these lands are easier to access due to the pre-existing roads, which offset the cost of compensation, making agricultural lands surprisingly cheaper to use.

In determining the best route for PSE&G, it is essential to minimize both resistance and cost. Reducing resistance will perpetuate PSE&G’s positive public image; reducing cost will maintain PSE&G’s budget. Through developing a mathematical model that analyzes the relative importance of a variety of factors, our group was able to select a solution that satisfies both the social concerns of the public and financial limitations of PSE&G.

2.3 The Proposed Routes:

During the planning of the Susquehanna-Roseland transmission line, three routes were set aside as possibilities. The first route, Alternative A, is by far the longest route, but is commendable because of how it avoids the Delaware Water Gap National Recreational Area. The second route, Alternative B, is favorable because it is the pre-existing route previously obtained by PSE&G. However, Alternative B also crosses directly through the Delaware Water Gap, directly intersecting the national park. The last possibility, Alternative C, is positive because it avoids all contact with national parks and is the shortest of the three routes. However, Alternative C does cross considerably more agricultural lands than the other two routes. Through the experimental analysis of this paper, we will evaluate the three routes in terms of social resistance and cost in order to determine the best transmission line route for PSE&G’s proposed Susquehanna-Roseland power line.

See Appendix 1, Fig. 1 for map

3. Experiment
3.1 Developing the Model

After carefully reading and analyzing of the concerns of numerous opposition groups to the Susquehanna-Roseland transmission lines, we developed a comprehensive list of the many issues facing PSE&G. Through meticulous research, we developed multipliers that described the relative importance of the concerns, in which greater values suggests more resistance or cost. We applied the multipliers to the many variables to create a formula to determine the most viable route for PSE&G.

3.1.1 Types of Land (Variables)

The possible routes for the Susquehanna-Roseland Power Line are comprised of numerous types of land, each with their own concerns and challenges. The multipliers and their application to the variable land types will demonstrate the social resistance and cost that each type of land poses to the transmission route.

<table>
<thead>
<tr>
<th>Types of Land (Variables)</th>
<th>Alt. A (miles)</th>
<th>Alt. B (miles)</th>
<th>Alt. C (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential (a)</td>
<td>0.938</td>
<td>1.25</td>
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<tr>
<td>Towns/Public Areas (b)</td>
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<td>0.53</td>
<td>0.56</td>
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<td>Agriculture (c)</td>
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<td>State/National Park (d)</td>
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</tr>
<tr>
<td>Wetlands (not including state park wetlands) (e)</td>
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<td>3.72</td>
<td>4.45</td>
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<td>Forests (f)</td>
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<td>Barren Lands (g)</td>
<td>0.28</td>
<td>0.21</td>
<td>0.67</td>
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<tr>
<td>Highways (h)</td>
<td>0.37</td>
<td>0.17</td>
<td>0.09</td>
</tr>
</tbody>
</table>
3.1.2 Social Impact

General Concerns (Multiplicative Factor)

General concerns are factors in the model that apply to multiple types of land and are not specific to one variable.

Health - 1.2

Transmission lines like the proposed Susquehanna-Roseland line are operated at extremely high voltages as large as 500 kV. The electric potential and current traveling through the wires generates both an electric and a magnetic field. Electric fields can be easily blocked by trees and buildings, but the powerful magnetic field can penetrate through many substances and has been linked to health defects and cancer in society. However, contrary to popular belief, most studies have produced little to no evidence of a correlation between magnetic fields and poor health. The magnetic fields that are generated by the transmission lines are in the Extremely Low Frequency range of the electromagnetic spectrum and lack sufficient energy to break molecular bonds. In addition, most everyday appliances have greater magnetic field strengths than transmission lines; the magnetic field strength of a microwave oven is as high as 236 milligauss while the magnetic field strength of a 345-kV power line is only 95.8 milligauss at the center line. The appliances we encounter on an everyday basis have a greater effect on our health than any power line could. Despite the reasoning, however, the perceived adverse health defects and its effects on PSE&G’s public opinion justify the 1.2 multiplicative factor of health.

This factor will be applied to residential areas, public areas, agricultural areas, national and state parks, wetlands, forests, and barren lands.

Sound - 1.1

Transmission lines emit a distinctive buzzing sound that can cause minor disturbances in residential and public areas. Rainfall can amplify the sound, making the presence of power lines even more unsettling to the public. Although such noises are not likely to be of impact in forests or wetlands, the buzzing of transmission lines presents a minor disturbance that can increase public opposition to the Susquehanna-Roseland Power Line. The minimal but nevertheless present and bothersome sound of power lines justifies the 1.1 multiplicative factor.

This factor will be applied to residential areas and public areas.

Specific Concerns:
Specific concerns are issues that can be directed toward just one type of land and can be applied to just one variable.

Residential Property Values - 3

Property values are arguably the most important public concern that could generate powerful opposition and seriously damage PSE&G’s public image. Studies have shown that property values can decline as much as 15-30% due to the negative public perception of transmission lines. Even if power lines are not linked to poor health, even if the aesthetic impact of the lines seems negligible in comparison to its power-carrying capacity, even if the distinctive buzzing sound can only be heard in the rain, the negative public opinion of transmission lines will almost always cause a plummet in property values wherever lines are constructed. Especially in the recovering New Jersey economy with the struggling housing market, any development that could lower house values will be
heavily protested by the public and could lead to a wide resentment of PSE&G. The massive impact of transmission lines on residential property values justifies the largest multiplicative factor of 3.

**Agriculture - 1.5**

Many times the transmission lines must pass through agricultural land. This can be a problem because there are many factors that affect the owners of the land. During construction, crops cannot be grown because of the machinery traveling through the fields. This is a major setback to the farmers as it destroys an entire year’s worth of harvests. In order to mitigate harm to crops, the construction must be done either very carefully or with strategic timing in order to not disturb the harvest. PSE&G would also need to compensate the farmer for any crops lost during the construction of the power lines, which could cost thousands of dollars. An aesthetic impact exists as well; the big metal towers are generally considered ugly and can cause a decline in agricultural land value. The inevitable discontent of farmers to power lines in their fields justifies the 1.5 multiplicative factor of agricultural lands.

**State/National Park Reserves - 3**

Possible transmission lines often run directly through State or National Parks, landmasses that are protected by the government to preserve nature and wildlife. State and National Parks are controversial lands for power lines, however, for a multitude of reasons. For one, many people do not want to disrupt wildlife and nature by running huge lines through the land. As one source put it, “when passing through a forest, a transmission line corridor appears as an ugly gash across the landscape. Such a scene detracts from the beauty of an otherwise natural view.”

Running machinery during construction through the ecosystem would kill many animals’ habitats and the towers and lines running through the land would conflict with wildlife as well.

In addition to disturbing nature, power lines would greatly disrupt the public. Many citizens enjoy going to the parks to enjoy nature. Besides being an eyesore, placing massive transmission lines amidst scenic views takes away from the experience of exploring nature. Preserving these lands is crucial to countless people from the environmentalists to the average citizens. Mainly because of the immense biological impact and inevitable uproar from the public and park service, all state and national park reserves were granted the weighty multiplicative factor of 2.5.

**Biological Impact: Wetlands - 2.5**

The intrusion of transmission lines into wetlands generates significant resistance in public opinion. Wetlands are marshy areas full of diverse flora and fauna that are protected by the state. The construction of power lines would be extremely detrimental to the wetlands’ tree canopy and inflict damage upon all the organisms that reside in the area. The absence of a tree canopy also removes the wetlands’ protection from the heat of the sun, causing temperature rises in the interior of the wetlands. Such heat influxes would disrupt the lifestyles of many organisms in the wetlands. Although the tree canopy may eventually grow back after many years, the destruction of the wetlands makes the biological impact of transmission lines in wetlands a legitimate concern. The opposition of naturalists and Park Service rangers, in conjunction with the pronounced biological impact, justifies the high resistance factor of 2.5 of wetlands.

**Biological Impact: Forests – 1.5**

Forests can be viewed as both positive and negative routes for transmission lines. A forest is a natural, peaceful place that many people would like to keep undisturbed. Running a power line would take the beauty away from a natural view, inflicting aesthetic damage upon a natural reserve.

More importantly, transmission lines would also damage the habitats and wildlife populations that reside in the forest. Running heavy equipment and machinery through the land disturbs the habitat and plowing down the vegetation can harm many animals’ ecosystems as well. Alarmed by the natural impact of power lines, environmentalists would be an unavoidable opposition group against transmission lines in forests. However, after the transmission line is completed, the woodland ecosystems should be restored. Vegetation can grow back to its original state and habitats can be developed again. The biological impact of transmission lines on forests is largely temporary, justifying the neutral multiplicative factor of 1.3.
Biological Impact: Barren Lands - 1

One of the least controversial places to run a transmission line is through barren land. This land is positive place to use because there are minimal conflicts with humans or wildlife in the area. No neighborhoods run through barren lands and unlike a forest, which is home to many plants and animals, little to no wildlife inhabit the area. Thus, running a power line through barren land will have a minimal biological impact, giving barren land the neutral multiplicative factor of 1.

Highways - 0.7

Highways are ideal locations for constructing transmission lines because they are typically straight, uninterrupted right-of-ways that are along pre-established sites of infrastructure. Aesthetic impact will be minimal, as few people are bothered by the sight of transmission lines along highways. Biological impact will be generally nonexistent because Health and sound concerns are also negligible as few people will be in contact with power lines on the highway for extended periods of times. Construction is also convenient, as the straight paths, previously cleared rights of way, and the limited social impact make highways desirable, warranting the highway multiplier of 0.7.

Least Social Resistance

<table>
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<th>Concerns</th>
<th>Multipliers</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>a   Residential</td>
<td>Health, Aesthetics, Sound, Res. Property Values</td>
<td>1.2 * 1.2 * 1.1 * 3</td>
<td>4.752a</td>
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<td>b   Towns and public</td>
<td>Health, Aesthetics, Sound</td>
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<td>1.584b</td>
</tr>
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<td>c   Agriculture</td>
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<td>d   State/Nat Park</td>
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<tr>
<td>e   Wetlands</td>
<td>Aesthetics, Biological Impact</td>
<td>1.2 * 2.5</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>(Wetlands)</th>
<th>Multipliers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>Forests</td>
<td>1.2 * 1.5</td>
<td>1.8f</td>
</tr>
<tr>
<td>g</td>
<td>Barren Lands</td>
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<td>1.2g</td>
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<tr>
<td>h</td>
<td>Highways</td>
<td>0.7</td>
<td>0.7h</td>
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</table>

Total = 4.752a + 1.584b + 1.8c + 3.6d + 3e + 1.8f + 1.2g + 0.7h

Permit and Construction Costs:

Residential Areas

Permit - 1

While running a transmission line through residential areas requires only public approval, obtaining consent is still difficult and costly because public support is very difficult to obtain. The residents of that community are not very willing to give up their land to run the transmission line through, even if it only takes a small portion of land. Public outrage sets the project back, which costs time, and the longer the delay, the higher the cost. Citizens may also file a lawsuit against the companies, which costs more money. Many people want a form of compensation for the power line but the companies cannot simply pay off a person to run a line through their backyard- that would give the company a bad image and set a bad precedent as well. Regardless, the company spends a lot of money with the public opinion when running lines through or near the residential communities.

Construction Costs - 8

The construction of a transmission line near a residential area is relatively cheap compared to the other areas. Although a factor of 8 may seem like a lot, it is actually a relatively low factor. The reason that the construction factor is so much larger than the permit factor is that construction costs can reach tens of millions of dollars due to all the material, labor, and transportation costs, while permits are just a one time fee. In residential areas there are generally a lot of roads around the area PSE&G are placing the lines, so it is easy to get the heavy machinery and
equipment in place. There is no money or time wasted placing temporary roads down to get the equipment to the site. The lands around these communities are also generally cleared, so that cuts out the cost in clearing trees and other vegetation.

**Public Areas**

**Permit - 1**

Permit costs for public areas are relatively low because only the approval of the municipal is required to obtain right-of-way. Although some people might have health and sound concerns regarding the power lines, convincing the public of the necessity of the transmission lines is typically not too difficult. Public areas are already urbanized and developed; the presence of transmission lines will not taint any scenic views or sights. The only significant cost associated with power lines in public areas is the delay in construction that might delay profits. For this reason, the permit costs of public areas are granted a multiplicative value of 1.

**Construction - 8**

Building transmission lines in public areas is inexpensive in comparison with some of the other places transmission lines must be built. The area generally has many roads leading to the job site so it does not cost extra money in transporting the materials and equipment there. It is easy to drive the equipment right there and there is no need to either fly in materials or lay temporary roads which cost extra time and money. The construction in public areas is easier than other areas because it is generally already well kept and near public roads. For these reasons, construction in public areas is granted the base multiplicative value of 8.

**Agricultural Areas**

**Permit - 2**

Obtaining approval for power lines through agricultural lands is not expensive, but certainly pricier than approval for residential areas or highways. In addition to the base costs of obtaining the farmer or municipal approval, PSE&G will also need to purchase the farmer’s crops if construction will halt the harvest season. The costs of purchasing crops will likely cost tens of thousands of dollars, which is reasonable considering the million-dollar costs for constructing through national parks. The reasonable permit and approval costs warrant the multiplicative factor of 2.

**Construction - 10**

The construction costs through agricultural lands include the basic wire, structure, and labor fees associated with typical transmission lines. There is an added cost of finding methods to transport equipment and materials to construction sites because of the vast farmlands through which workers must trek. For the extra cost of transporting machinery, construction costs of transmission lines in agricultural lands are granted the multiplicative factor of 10, slightly greater than the factor for residential lands.

**State/National Park Reserves**

**Permit - 10**

Usually, it is near impossible to get a permit to build through a national park in the first place. However, as this line was proven to be necessary by PJM, the national park service grudgingly relented, but at a price. This permit is the costliest out of all the others because PSE&G must compensate for a number of factors. First off, the construction process would without doubt disturb fragile wildlife and possibly ruin parts of the land. Moreover, unlike with other non-state/national park owned forest and wetlands, there is the issue of tourism. National parks are valued for their pristine nature, so awkward man-made structures hanging over the horizon may ruin the experience for hikers and tourists alike. Park service opposition is typically so vehement that obtaining permits can cost millions of dollars, thus justifying the extremely high permit multiplicative factor of 10.

**Construction - 40**

National parks also have wetlands and other unstable lands that make construction more expensive and more time-consuming. Furthermore, as the purpose of national parks is preserving the purity of nature, there is usually no clear access to the construction sites. Sometimes, helicopters may be needed to airdrop material into the sites, which are extremely costly and slow. Other times, a temporary road may be needed instead; utility companies have been known to use these thick, dense mat-like structures as roads. By binding
these mats together, a temporary path can be forged straight to the destination, even across swamps and wetlands. The only downside is that these roads need to be torn up afterwards, and any trees and plants must be replanted.

**Wetlands Permit - 2**

The costs of constructing transmission lines through wetlands are significant as well. The inevitable opposition of the Park Service to the power lines will make for costly, timely negotiations for permits to the land. Environmentalists will likely have massive protests due to the biological and aesthetic impacts that the power lines will have on the wetlands. However, because the wetlands are not state or national parks, efforts to obtain approval will be targeted toward the corresponding municipal instead of the Park Service. Municipal and public approval are significantly easier to gain than Park Service approval, meaning that negotiation and permit costs will be substantially less with a multiplicative factor of 2.

**Construction - 40**

The costs of constructing through wetlands are extremely high due to the marshy setting and soft soil. Because heavy machinery cannot be driven across the soft ground, massive mats are required to form temporary roads. The mats are typically plastic, 5 feet by 8 feet and 6 inches thick. Up to $30 million can be spent on solely building temporary roads to transport machinery.¹⁷ As the mats are laid out, PSE&G must also hire companies to clear the trees and vegetation to make way for the transmission line and equipment. When the right of way is finally established and the temporary road is built, extra concrete must be inserted deep into the soil to serve as a foundation for the transmission structures. As the transmission line continues to be built through the wetlands, more and more temporary roads and concrete foundations are needed. The cost of constructing through wetlands is substantially greater than the generic cost of constructing through residential or public areas, warranting the high multiplicative value of 40.

**Forest Permit - 1**

The costs of obtaining permits for constructing transmission lines through non-park forests should be relatively minimal, as only approval from the corresponding municipal is needed. Public opposition should not be too high; the only likely concerns involve biological and aesthetic impact. However, such concerns should be overcome through public meetings and negotiations that stress the necessity of the Susquehanna-Roseland power lines. The only substantial financial concern would be the profits lost from delay while waiting for municipal approval. Because of the relatively minimal costs of obtaining approval for constructing in non-park forests, forests are granted the neutral multiplicative factor of 1.

**Construction - 20**

Building transmission lines through a forest or wooded area is very costly in construction due to many factors. The first difficulty is getting the equipment to the job site; often times the forests are away from most roads and are not easily accessible. In order to accommodate for this there are a couple different options. One is to place mats down as temporary roads in order to drive the equipment in and out of the job site. This option is also costly and takes more time. Another option is to fly pieces of the towers and other necessary parts in via helicopter. This option is also costly and takes more time.

Another problem with running transmission lines through a forest area is the trees and vegetation must be cleared to make a path.¹⁷ Most companies, like PSE&G, will hire a company who specializes in clearing land to do the job for them. Another costly part of this is that the land must be continually maintained so that the vegetation does not grow too close to the electric lines. Another issue with clearing so many trees is since it is harmful to the environment most companies will agree to plant more trees than they destroyed in the process of building their project. There are many expensive procedures PSE&G and similar companies must go through in the construction of transmission lines through a forest or wooded area.
Barren Land

Permit - 1

The costs of obtaining approval for transmission lines through barren lands are relatively minimal. PSE&G will need to appeal to the municipal as with residential and public areas, but opposition should be relatively minimal as the only concern would be with the aesthetics of the barren land. The basic delay and time costs that may result from appealing to the general public warrant the basic multiplicative factor of 1 for permit costs in barren land.

Construction - 10

Barren lands are relatively easy to construct through in a transmission line project. There is no heavy vegetation that must be cleared, so that saves a lot of time and money. It is also easier because since those things are not in the way the equipment is very easy to get to the job site. There is plenty of room to work in so the transmission line can be constructed quickly and efficiently. With the few obstacles in the way barren lands are optimal for construction of transmission lines and can be done quickly and less expensive than many other options.

Highways

Permit - 1

Obtaining approval for transmission line construction along highways is typically pretty cheap. PSE&G will need to gain the approval of the road’s coordinating Department of Transportation by providing plans for development and how the transmission lines may impact the roadways. Because power lines are not likely to have any effect on highways or transportation, the permits will only be costly in the sense that approval will take time and procedures, and time is money. For these reasons, highway permit costs are given the base multiplicative value of 1.

Construction - 10

Compared to other choices such as wetlands and forests, constructing transmission lines along a highway is relatively cheap (although still very expensive altogether). This is because when the highways were initially built, the workers had to clear out all the trees and obstacles and evaluate the land for stability. PSE&G could simply build the highway alongside this already cleared path to save a significant portion of money.

<table>
<thead>
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<th>Variable</th>
<th>Land Type</th>
<th>Permit Mult.</th>
<th>Con. Mult.</th>
<th>Total</th>
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<tbody>
<tr>
<td>a</td>
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<td>8</td>
<td>9a</td>
</tr>
<tr>
<td>b</td>
<td>Public</td>
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<td>8</td>
<td>9b</td>
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<td>12c</td>
</tr>
<tr>
<td>d</td>
<td>State/Nat’l Park</td>
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<td>40</td>
<td>50d</td>
</tr>
<tr>
<td>e</td>
<td>Wetlands</td>
<td>2</td>
<td>40</td>
<td>42e</td>
</tr>
<tr>
<td>f</td>
<td>Forests</td>
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<td>20</td>
<td>21f</td>
</tr>
<tr>
<td>g</td>
<td>Barren Lands</td>
<td>1</td>
<td>10</td>
<td>11g</td>
</tr>
<tr>
<td>h</td>
<td>Highways</td>
<td>1</td>
<td>10</td>
<td>11h</td>
</tr>
</tbody>
</table>

Total = 9a + b + 12c + 40d + 42e+ 21f + 11g +11h

4. Results

The multipliers and equations generated by the factors that influence resistance against the power lines shed new light upon the true impact of certain factors. For example, wetlands and residential areas both have heavy opposition against power lines, but residential areas are a greater source of heavy-impact concerns and thus have a resistance coefficient factor of 4.752, a value significantly larger than the wetlands, which have a resistance coefficient factor of 1.092. Such coefficient values thus show that, in terms of societal opposition, it would be better to travel through three times as many miles of wetlands as residential neighborhoods. This observation makes sense, especially considering that the residents are directly affected by transmission lines in residential neighborhoods and will generate the most resistance.
Social Impact

For chart, see Figure 2 Appendix 1

Graph 1 analysis:

After plugging the miles of the alternative routes into the total resistance equation (Eq. 1.1), we found that Alternative C, by only a slight amount, would generate the least resistance from the many opposing parties.

Although Alternative A was successful in avoiding residential neighborhoods, the wetlands and forests it routed to avoid the residential neighborhoods actually stacked up more resistance against the power lines.

Costs

For Table, See Figure 3 Appendix 2
Graph 2 Analysis:
Route A costs the most because it has a little bit of everything and it has the most total road; Route B saves money by going through few forests while Route C saves money because it does not go through any state or national parks.

Final Analysis

Final Comparison:
Route A has both the highest social impact and cost. This shows that Route A is not a viable route and is not a good option. Route B and Route C however have very close social impacts and costs as well, so it is much more difficult to distinguish between which is the better route. Route B is the route that PSE&G already has a line built in, so it is a much better option. Seeing as the pre-existing route must be taken down regardless of the chosen route, there is no significant benefit to choosing Route C instead.

5. Discussion/Analysis
Alternative A is a poor option for two main reasons. First, it is the longest route of the three meaning it will require the most equipment, materials, and money. Second, it will likely generate extensive opposition from the public because of the many miles of forestland it will infiltrate. The social and financial barriers are both greatest for Alternative A, which makes it the least favorable route for the Susquehanna-Roseland transmission line.

According to the mathematical model, Alternative C is technically the best route because it has the least social resistance and cost. The feature that makes Alternative C unique is how it avoids all national and state parks, greatly reducing permit and construction costs. Route C is also the shortest of the three, meaning material, equipment, and labor costs should be the lowest.

However, Alternative B is the best option overall because it runs along a pre-existing transmission line route. Social resistance should be lower than the resistance predicted for Alternative C. Permit costs should also be cheaper because municipalities and the Park Service are more likely to approve a right-of-way along a previously constructed route. Construction costs could be slightly lowered as well since forest and wetlands will not need to be as extensively cleared. Ultimately, PSE&G made the right choice in designating Alternative B as the route of the Susquehanna-Roseland transmission line.

6. Conclusion
6.1 Verdict
The results of the analysis interestingly debunked the common myth that to minimize social impact, a company must suffer an increase in cost. Alternative A would face extensive public resistance while simultaneously costing millions
more in permit and construction expenditures. In contrast, Alternatives B and C both managed to minimize social impact in addition to expenses. Even better, Alternative B runs along a pre-existing route, further reducing social resistance and cost. For this reason, PSE&G should opt for Alternative B as the Susquehanna-Roseland transmission line route.

6.2 Future Plans

In the future of routing transmission lines it is imperative to strike a balance between social impact and cost. Because power lines are designed to last for decades and even centuries, the approval of the public is necessary to protect PSE&G’s image and maintain a stable customer base. For this reason, it would be in the best interest of PSE&G to invest in a slightly more costly route in the interest of public approval.

However, there are certain areas that PSE&G should make an effort to avoid because of their negative impact on both public relations and budget. State and National Parks, especially those with wetland reserves, will generate great environmentalist opposition and social resistance. The public can paint PSE&G’s intrusion into natural reserves as blind acts of greed, selfishly invading the homes of native animals in the interest of money. As a result of societal disapproval, permit costs will be exorbitant in an effort to discourage transmission line routing in a protected park. Construction costs will be enormous as well: utility mats and concrete foundations will make power line construction in protected wetlands many times more expensive than construction through residential or public areas. Even if PSE&G must route through additional miles, it should make all efforts possible to avoid State and National parks.

On the other hand, there are some areas that PSE&G should aim to utilize in its routes. Highways, for example, will generate minimal social resistance and also have low permit and construction costs. Because highways represent pre-established forms of infrastructure, it is unlikely that the public will object to another form of infrastructure. The visual impact is minimal as well; most people view highways as simply a method of transportation, not a scenic or natural retreat. Cost-wise, construction along highways is relatively cheap as the land is already well maintained and straight, easily accessed by the heavy machinery. Permit expenses are minimal as well: PSE&G only requires approval from the Department of Transportation, which is typically a quick, painless process. Because of the low social and financial costs, highways should be the most favorable lands for transmission line routes.

All types of lands have their own advantages and disadvantages, either in appeasing the public or maintaining the budget. When planning future transmission routes, PSE&G must strive to balance the public approval with financial costs. However, when it comes down to the final decision, PSE&G should keep in mind that transmission lines are a social investment, which justifies reasonable excess expenditures.

7. Acknowledgements

Special thanks to all the people who made this experience possible for us: Garan Gunn and Jason Kalwa, our patient and supportive mentors at PSE&G; Brian Belding, our wonderful project advisor; Stoyan Lazarov, Josh Binder, and Adrien Perkins, for aiding us through the process; all the GSET counselors for their kindness and support; Jean Patrick Antoine, GSET assistant program director; Jean Ilene Rosen, Ed.D, GSET program director; the Governor’s School Board of Overseers; Bill Mackey from PSE&G; Thomas Patterson, from Licensing and Permitting at PSE&G; Rutgers University; the State of New Jersey; Morgan Stanley; Lockheed Martin; South Jersey Industries, Inc.; Public Service Energy and Gas (PSE&G);

8. Works Cited


17. Mackey, Bill. Interview by NJGSET. 17 July 2012.
9. Appendix 1

Figure 1
Map of Possible Susquehanna-Roseland Transmission Line Routes

### Figure 2

**Social Resistance**

<table>
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<th>Type of Land</th>
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Total Costs

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Permit Costs: A 99.603
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