As we approach a time where crude oil supplies are decreasing, and gasoline prices are increasing, the need for alternative energy sources is greater than ever. For some countries and regions with reserves and export energy, this issue could be less severe for the time being. But for others, those that depend almost entirely on external sources of energy, this could mark a new era with an utmost priority on alternative energy sources. With alternative energy sources, the way that energy is consumed must also change as different technologies are needed in order to translate the energy source into usable energy. In this essay, I will explore Taiwan as one of these places that rely on imported energy to thrive. I will discuss the feasibility of electrifying ground transport such as cars and motorcycles in Taiwan. I will first consider the technology of electric vehicles, and I will then look at the unique conditions in Taiwan to show the feasibility of electric vehicles.

Electric vehicles (EV) are not a new concept, but only more recently through their environmental benefits have they begun to receive more publicity. EVs are propelled by an electric motor powered by rechargeable battery packs. This gives electric vehicles a number of advantages over conventional gasoline-powered vehicles. One, they are more energy efficient, as electric motors convert 75% of the chemical energy from the batteries to power the wheels of the car, while internal combustion engines (ICEs), in gasoline-powered cars, only convert 20% of the energy in gasoline into power for the car since most of the energy is being released as heat in the combustion.1 Another reason why EVs can be so much more efficient than gasoline vehicles is EVs use regenerative braking. All of the energy in cars is lost while braking, but because electric cars use batteries to store its energy, it can regain some of the energy lost in braking using regenerative braking technology. The second advantage is that the electric vehicles themselves are more environmentally friendly as they emit no tailpipe pollutants. Although the power plants which produce the electricity may be producing pollutants, electricity could alternatively be produced from clean coal technology or renewable energy sources like solar,

hydro, or wind. Third, electric motors, compared to ICEs, provide quiet, smooth operation with stronger acceleration, and generally require less maintenance. Last, but perhaps most significantly, is that electric vehicles can reduce gasoline dependency. Electricity can be domestically produced anywhere, but significant amounts of crude oil can only be found in specific parts of the world, like the Middle East. This can make a huge difference for countries who want to reduce their energy dependence. With crude oil supplies declining and gas prices rising, it is more important than ever to focus on alternative sources of energy.

Although there are advantages to electric vehicles, there are also common disadvantages. One of the biggest disadvantages, particularly for consumers in the United States, is the driving range of EVs. On average, most EVs can only go about 80-200 miles before needing to recharge, while gasoline vehicles can often go over 250 miles before refueling. Second, the recharge time of battery packs is significant. Refilling the gas tank of a gasoline vehicle only takes a couple of minutes, but fully recharging a battery pack can take 4 to 8 hours, and even EVs which advertise a "quick charge" option to 80% capacity can take around 30 minutes. Third, battery packs are currently relatively expensive, as that is a large portion of the cost of EVs, and they only have a lifetime of around 10 years, so needing to replace the battery is an added expense. Fourth, the current infrastructure for EVs is not very widespread anywhere in the world, so consumers are hesitant to purchase EVs with nowhere to charge or quickly replace batteries.

Before I dive into the issue of the feasibility of electric vehicles in Taiwan, I want to first explain why I chose Taiwan for this research project. First, Taiwan is an island and it is small. For a country like the United States, it could be very difficult to embark on such an ambitious project to revamp ground transportation. With Taiwan's small size, the complete change of infrastructure would be more realistic to do in short period of time. On top of that, Taiwan has a very high population density. This means that there is a lot of traffic, and electric vehicles are more efficient than conventional gasoline cars for stop-and-go traffic because of regenerative braking. With Taiwan being so small, electric vehicles' shorter ranges are also not as big of an issue. Studying Taiwan for the feasibility of electric vehicles is also a good idea because conversion to EVs is quite realistic as they are relatively wealthy and already have the advanced technology to undergo such a project. There are also environmental benefits that make Taiwan an

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attractive place to switch to EVs. Pollution is very high in Taiwan with all the industry and transport emissions in such a densely populated area, so Taiwan could truly benefit from switching to transportation with lower emissions. Also, Taiwan already has a Sustainable Energy Policy which strives for goals that electric vehicles could help achieve. One of those goals is "Raise the fuel efficiency standard for private vehicles by 25% in 2015".\(^3\) This could be a very doable goal with EVs, as electric motors are already so much more efficient than internal combustion engines. On top of that, another one of their four policy principles is to decrease the dependence on fossil fuels and imported energy, which is impossible to do with gasoline, as crude oil is not being produced in Taiwan. With electricity, Taiwan could potentially produce energy through renewable energy sources. Their other three policy principles are: high efficiency of energy, high value-added for energy consumption, and low emissions, which can all also be achieved by going to electric vehicles. One final point, which is not very easy to determine quantitatively, is that if Taiwan is a pioneer in "green" transport with EVs, it could attract people as a tourist location, as they could claim to be the first to have fully electric, "green", ground transportation.

By discussing the energy used in ground transportation, I will also briefly explore the energy sources of Taiwan. Currently, 98% of Taiwan's energy depends on imports. The primary energy source of Taiwan is fossil fuels, with 59% of their energy generated from oil and natural gas.\(^4\) Below is a graph of the sources of Taiwan's energy usage from 1987 to 2008. KLOE stands for kiloliters of oil equivalent.

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By energy form in 2007, coal accounts for 32.13%, petroleum 51.13%, natural gas 8.38%, nuclear 7.97%, and renewable energy 0.3%.

In terms of energy consumption, here is a graph of the consumption by sector.\(^4\)
While industrial consumption is the largest with 51.81%, a majority of what Taiwan manufactures is then exported; while transportation, the second largest sector of energy consumption at 13.18%, is used directly for travel in Taiwan.

Taiwan has potential in generating electricity using renewable sources. In June 2007, Taiwan generated 2.782 million kilowatts through renewable sources, which accounts for 5.9% of the total generation capacity for Taiwan. This number will continue to grow as they are investing more money into research for sustainable energy development. Currently, they are "the second largest producer of solar cells in the world in terms of production volume". Because of that, they are already fifth place in the world in terms of the density of solar water heating system installation. Another example that shows the ambition of Taiwan to be more energy efficient is their achievement of replacing 690,000 LED traffic signals in September 2011, which made them the second country in the world to achieve an overall replacement of LED traffic signals.

Taiwan also already has the up-to-date technology to harness the renewable sources, as they are the eighth country in the world with the capability of manufacturing large scale 2MW wind turbines. Since Taiwan is pushing for their energy sources to be generated from renewable energy and reduce foreign energy dependency, it would make sense that they would want transportation, their second largest sector of energy consumption, to use that electricity if possible.

Now, I will compare the economic feasibility of an electric vehicle to that of a typical gasoline vehicle. I will make two comparisons, one for cars and another for scooters, as 68% of Taiwan's 22 million registered vehicles are scooters and motorcycles. To make the comparison, I am going to look at two aspects: the amortized upfront cost of the car, and the operational cost of the car to drive it. I will ignore other factors such as maintenance, though bear in mind that electric cars usually require significantly less maintenance than gasoline cars, and also that the electric car batteries usually need to be replaced around every 10 years. I will begin by determining the operating cost of a gasoline car.

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currently around $1.22/liter, or about $4.62/gallon. One of the current more popular models for gasoline cars is the Toyota Camry. The average price of a Toyota Camry is around $25,000, with a MPG (miles per gallon) rating of 25 City/35 Highway. The average is found to be about 28 mpg, so to find the operating cost, I will divide that by cost of gasoline per gallon, and so the operating cost of driving a Toyota Camry is about $0.17 per mile.

For an electric vehicle, I am going to choose one of the most popular fully-electric cars, the Nissan Leaf. The Nissan Leaf has a range of 100 miles/charge based upon US EPA LA4 City cycle using a 24 kWh lithium-ion battery. The Nissan Leaf costs $35,200 MSRP, but note that this is before any subsidies that Taiwan offers. Since the Leaf uses 24 kWh of electricity for 100 miles, we see that it needs 0.24 kWh per mile. For the price of electricity, Taiwan gets its electricity from the company Taipower, and below is a table of their electricity rates.

<table>
<thead>
<tr>
<th>B. Meter Rate Lighting Service (110v, 220v, 220/380v)</th>
<th>Unit: NTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Regular Service (Non-TOU Rate)</td>
<td></td>
</tr>
<tr>
<td>Classification</td>
<td>Summer (Jun. 1 ~ Sep. 30)</td>
</tr>
<tr>
<td>Non-commercial</td>
<td></td>
</tr>
<tr>
<td>First 110 kWh per month</td>
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<td>Next 220 kWh per month</td>
<td>3.02</td>
</tr>
<tr>
<td>Next 170 kWh per month</td>
<td>4.05</td>
</tr>
<tr>
<td>Next 200 kWh per month</td>
<td>4.51</td>
</tr>
<tr>
<td>Over 700 kWh per month</td>
<td>5.10</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
</tr>
<tr>
<td>First 330 kWh per month</td>
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<td>Next 170 kWh per month</td>
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<tr>
<td>Next 200 kWh per month</td>
<td>4.51</td>
</tr>
<tr>
<td>Over 700 kWh per month</td>
<td>5.10</td>
</tr>
</tbody>
</table>

Table 1: Electricity Rates in Taiwan

11 http://www.nissanusa.com/leaf-electric-car/index#/leaf-electric-car/
For my calculation, I am going to just say that the cost of electricity is ~4 NT$ per kWh, since three-quarters of the year is the non-summer rates that are much lower, and it could vary by quite a bit depending on whether the car charges using commercial or residential electricity. On April 25, 2012, 4 New Taiwan Dollars converts to about U.S. $0.14. With electricity at $0.14 per kWh, if we multiply that by 0.24 kWh per mile that the Nissan Leaf requires, we see that the operating cost of the Nissan Leaf is about $0.03 per mile.

Looking purely at operational costs, the Nissan Leaf is clearly cheaper compared to the Toyota Camry, as the cost per mile is $0.03 compared $0.17, respectively. But as the cars themselves have a significant difference in the cost of the car up-front, as the Leaf requires the costlier battery, I will have to amortize the cost of each car per month to see which one comes out to be the more economical choice. Unfortunately, there is currently no easily accessible information on the average distance cars travel each day in Taiwan. In order to do this calculation, I am going to approximate that the average car in Taiwan travels 25 miles a day. The average daily travel distance in the U.S. is almost 40 miles per person per day, and since Taiwan is much smaller so people do not travel long distances and have shorter distance commutes, 25 miles a day would seem to be a safe guess. To start with, I will find the cost of the Toyota Camry amortized over its lifetime. For a lifetime, I am going to say 10 years for both cars, as that would probably be when the battery pack for the electric car would need to be replaced, and gasoline cars have a life expectancy more or less the same without high-cost maintenance. Amortizing the cost of $25,000 over 10 years for the Toyota Camry, at an 8% discount rate (may vary depending on loan), comes out to a monthly cost of $301.31. Now, adding the cost of driving 25 miles per day at a cost of $0.17 per mile, it comes out to an average cost of about $130 per month. Added together, the average monthly cost of a Toyota Camry is about $431.

Now doing the same for the Nissan Leaf, by amortizing the cost of $35,200 over 10 years at a discount rate of 8%, the amortized cost of a Nissan Leaf is $424.24 per month. Finding the cost of driving 25 miles per day at $0.03 per mile, the average monthly cost of operation comes out to be around $23 per month. Therefore, the average cost of buying and operating the Nissan Leaf is about $447 per month.

Leaf is about $447 per month.

Looking at these numbers, the Toyota Camry, with a monthly cost of around $431, looks to be slightly more economically feasible than the Nissan Leaf, which has a monthly cost of around $447. However if we were to include subsidies which Taiwan has begun to offer for electric vehicles as they push for sustainable energy, and the rising cost of gasoline due to limited resources, this cost may very well sway in favor of the Nissan Leaf. Further, the majority of the driving in Taiwan is city driving with heavy traffic, and electric cars have an advantage here because of regenerative braking, while Internal Combustion Engines are terribly inefficient in city driving. Beyond the cars themselves, there is also the important issue of oil dependence. Taiwan is completely at the mercy of the world prices of energy; particularly the rising prices of crude oil, and in turn, the rising prices of gasoline. With this serious implication of being oil dependent, switching over to electric vehicles offers significant potential and should be considered a top priority in striving for a plan for sustainable energy.

As I mentioned, I will now compare the costs for a gasoline-powered scooter and an electric scooter. One of the most popular scooters in the world is actually produced in Taiwan, and that is the Symba produced by Sym (Sanyang Industry Co.). The Symba has a 101-cc engine which produces 6.7 horsepower. It can get 100 mpg, and has a cost of $2,598. With the same calculations for the cost of the Toyota Camry, the operating cost of the Sym Symba is $0.05 per mile. As there is no data on the lifespan of a motorcycle or scooter as it can be so variable depending on how well one cares for it, I will say that the cost of the scooter will be amortized for 5 years, as that will probably be about how long it could last before people resell or require major maintenance. Amortizing the cost of $2,598 for 5 years at a discount rate 8%, the cost per month of paying off that loan is $52.33. Adding that to the operating cost multiplied by the estimated 25 miles per day, the total cost of the Sym Symba is around $90 per month.

Next, I will do the same for an electric scooter. Sym also manufactures an electric scooter called the E-Woo that is currently in production and for sale in Taiwan. The E-Woo utilizes a detachable lithium-ion battery with a voltage of 48V and a capability of 15 Ah, and it has a top speed of 50km per hour. The advantage of the battery being easily detachable is that the battery

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15 http://tw.sym-global.com/product/items_subcat_spec.php?CA=4&sub_CA=64
can be easily charged in a standard electric outlet, which eliminates the need for a personal charging station. Given these specs, to convert into kWh, I will multiply the voltage by the capability to get Wh, and divide by 1000 to get kWh, and this gives a number of 0.96 kWh. This means that fully charging the E-Woo requires using 0.96 kWh of electricity. On a full charge, the E-Woo has a range of about 50 Km, or about 31 miles. Calculating the operating costs the same way as for the Nissan Leaf, the E-Woo costs $0.0043 per mile. The E-Woo, using the current exchange rate on May 3rd, 2012 for NT$66,500, costs $2275.45. Amortizing that cost over 5 years at a discount rate of 8% gives a cost per month of $45.83. Adding the operating cost per month to the amortized cost, the Sym E-Woo costs a total of about $49 per month. Below is a table with the cost comparison of all four vehicles.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Purchase Cost</th>
<th>Operating Cost</th>
<th>Amortized Cost per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota Camry</td>
<td>$25,000</td>
<td>$0.17</td>
<td>$431</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>$35,200</td>
<td>$0.03</td>
<td>$447</td>
</tr>
<tr>
<td>Sym Symba</td>
<td>$2,598</td>
<td>$0.05</td>
<td>$90</td>
</tr>
<tr>
<td>Sym E-Woo</td>
<td>$2,275.45</td>
<td>$0.0043</td>
<td>$49</td>
</tr>
</tbody>
</table>

Table 2: Cost Comparison

Economically, the E-Woo wins over the Symba with a cost of $49 per month versus $90 per month. Even with similar costs for the scooters themselves, the operating cost of the E-Woo clearly wins out over the already impressive 100 mpg Symba, with each mile for the E-Woo costing less than half a cent compared to the five cents per mile of the Symba. Another advantage for Taiwan is "[In 2009], companies in Taiwan made 278,000 e-scooters, or 38.6% of the world's total production, ARTC said in a statement on its website". With so many electric scooters already manufactured in Taiwan, there is no need to import the vehicles.

On top of that, Taiwan has been offering substantial subsidies for electric scooters. With the government's plan to push electric vehicles, they are offering subsidies of $246 to $339 for

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17 Only place with this type of info is Taiwan Yahoo: http://tw.knowledge.yahoo.com/question/question?qid=1612041400332
buyers of electric scooters. Since most scooters already only cost between $2000-3000, this is quite a significant discount. Despite electric scooters' advantage economically, there is, however, still the lack of infrastructure which dissuades consumers. The Taiwanese government is aware of this issue, and already has a plan in place to set up 3,000 battery exchange stations by 2014. If they are able to do that, eco-tourists from all over the world may want to come witness this transformation in Taiwan.
