Sustainability Analysis of Electric Cars Versus Conventional Cars

Logan, Julia, Collin, Marcio

ENVS 301: Tools for Sustainability

May 1st, 2017

Outline of Presentation

Background Information → Goal and Scope → Life Cycle Analysis → Cost-Benefit Analysis → Discussion of Results and Conclusions

Background Information

EVs started strong in the early 1900s for urban transit[25]

- With invention of the Model T, EV market destroyed
- Model T: $650 Electric Roadster: $1750

Interest reemerged in the ‘70s with rising oil prices

- Still had limited performance- 45 mph and 40 mile range

1990 Clean Air amendment and 1992 Energy Policy Act

Background Information-Rise of Electric Vehicles

- Prius released in 1997 in Japan as first mass produced hybrid vehicle
- Tesla Motors unveiled in 2006
  - $465 million loan from the Department of Energy in 2010
  - Paid back in full 9 years early
- Tesla's success sparked interest amongst the auto industry
- Recovery Act installs over 18,000 charging stations nationwide
- EV Everywhere Grand Challenge
- As of 2014, 23 EV models

Goals

Analyze the sustainability of driving electric vehicles (EV) versus conventional gas combustion vehicles (CV)

Compare and contrast manufacture, waste, emissions, fuel and other inputs/outputs over life cycle of each vehicle

Determine the consumer and societal costs and benefits and net present value of either product after specific time scale

Scope

- Focus on mid-sized sedans (typical four-person household vehicle)
- Use averages of gas consumption and electricity use
- 10 Year life span of a vehicle
- Champaign County energy/gasoline sources
- Assume car is charged/filled up and driven in Champaign/Urbana area
- Include non-market costs/benefits such as societal carbon cost and health costs of other emissions

Assumptions

- Ignore commonalities
  - Only compare Internal Combustion Engine (ICE) vs. Lithium-ion Battery (LiB)
  - Ignore common car components (internal seating, steering column, chassis, wheels, etc.)
- Use averages for electricity usage, fuel efficiency, energy inputs, social costs, health costs

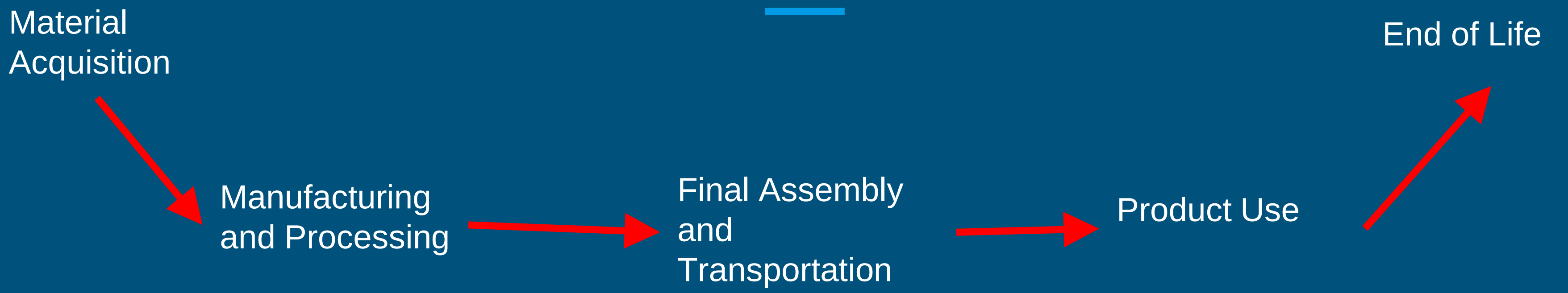
Indicators

Cost of Battery Production

Efficiency of Batteries

Availability of raw resources

Life Cycle Analysis



Scope and Functional Unit

- Scope
  - Focused on fuel acquisition, partial material acquisition, manufacturing, & product use
  - Focused on CO_2eq
- Kg CO_2 eq/mile

Other considerations:

- Lb CO_2 eq/mile
- Tonnes CO_2 eq/mile
- /km

Material Acquisition

Energy cost of extraction of materials

- EV materials more difficult to extract
- 0.003 kg CO_2 eq/mile for EV[55]
- Approximately 2.5% of total GWP impact[55]

Extraction of materials for engine/other different parts

- Difficulty in finding exact numbers, but the materials are more commonly available
- Assumption: impact of CV raw materials is much less

Manufacturing and Processing

- Emissions from EVs 15-68% higher than CV[15]
  - 15% for 84 miles/charge
  - 68% for 250 miles/charge
- Lithium (EV) and iron(conventional)
  - EV
    - Contributes 35-41% of GWP
    - 0.056 kg CO2eq/mile (entire EV, but again difference is mostly battery)[56,15]
  - CV

Final Assembly and Transportation

Assumed constant for EV and CV

Product Use - Lifespan

CV lifespan is 8-15 years or 150,000-300,000 miles[18]

EV battery[16]

- 5% reduction after 50,000 miles
- 10% reduction after 200,000 miles

Can essentially ignore lifespan within our scope of 10 years

Product Use - Emissions

EV emissions

Power plants ~35% efficient[19]

Power Transmission ~95% efficient[19]

Electric Vehicles ~ 74-94% efficient[20]

Power Plant-to-Movement efficiency of ~28%

Product Use - Emissions

CV emissions

- 0.36 kg CO_2 eq/mile
- 14-30% efficient[20]

Effects

- Power plants affect fewer people but more heavily
- CVs affect cities and therefore more people
  - Less smog than from power plants

Product Use - Emissions

Electricity Production for use in BEV

Average for US electricity production %

Three sources: two government, 1 journal article[5,57,58]

0.16 kg CO2 eq/mile driven

Average for Illinois

0.11 kg CO2 eq/mile driven

Nuclear

Key assumptions

Source	Percentage use avg in U
Coal	34.07%
Natural Gas	31.48%
Oil	0.76%
Nuclear	19.67%
Hydro	6.19%
Other renewables	6.76%

Fuel Production - Emissions

- Gasoline production for use in ICE vehicles
  - Refining
    - 0.063 kg CO2eq/mile
  - Transport
    - 0.0033 kg CO2eq/mile
  - Key assumptions
    - Refining: 0.13 g/MJ of oil
      - Issues with current analysis recognized but important, 3rd highest GHG portion of gasoline

Fuel Production - Emissions

Electric vehicles

Burning of the fuel is wrapped up in production of fuel

End of Life

5% of vehicle ends up in landfill[3]

Non recycling of heavy metals increases environmental impact

80% of a battery can be recycled[3]

- Increase lifespan of lithium resources

Ongoing work to increase the ability to recycle materials[15]

Overall Life Cycle Analysis

Final calculation

EV: 0.219 kg CO2 eq/mile

ICEV: 0.452 kg CO2 eq/mile

Difference: EVs produce just under half the emissions of an ICE

Other published LCAs

NREL - 1/3rd emissions for EV for low carbon grid, slightly less for fossil heavy[57]

Article in Journal of Industrial Ecology[59]

EVs produce 27-29% fewer emissions over ~124,000 mile life

Union of Concerned scientists: EVs less than half emissions of ICEV[15]

Takeaways of Life Cycle Analysis

Details matter

- Mix of electricity
  - Most emissions come from electricity for EV, so improving grid improves emissions
  - Ex: Illinois EVs due to nuclear energy produce about 37% of emissions compared to US avg (our analysis)
- More data and larger scope
  - Beyond our scope: refining processes, waste consequences
  - Very important: Health impacts
    - Cancerous, non-cancerous, tropospheric pollution impacts, urban density impacts

Cost Benefit Analysis

Cost Benefit Analysis

2015 Nissan Leaf (EV)
Vs.
2015 Toyota Camry (CV)

Consumer Benefits → $7,500 Federal Tax Credit for purchasing *new* EV[32]

Consumer Costs →

Year 0: Manufacturer's suggested retail price[48]

Yearly: Repair, Maintenance, Insurance, Fuel[34]

Social Costs →

Year 0: Indirect CO2 emissions from ICE/LiB manufacture[44,50]

Yearly: CO2 tailpipe emissions, CO emissions, NOx emissions, Indirect CO2 emissions (petroleum production), Indirect social health costs attributable to coal-based power generation[8,23,24,27-,33,37,40,41-43,45-48,50-52]

CBA: Calculations

	 2015 Nissan Leaf Electric Vehicle Automatic (A1)	 2015 Toyota Camry Gasoline Vehicle 2.5 L, 4 cyl, Automatic (S6)
Manufacturer's Suggested Retail Price	$32,065.00	$27,170.00
EPA Fuel Economy (1 gallon gasoline = 33.7 kWh)	114 MPGe (126 city/101 highway) (30 kWh/100mi)	28 combined city/highway (25 city/34 highway) (3.6 gal/100mi)
Annual Fuel Cost *Based on 45% highway, 55% city driving, 13,476 annual miles and current fuel prices in Champaign 61820	$500	$1,000
Cost to drive 25 Miles	$0.96	$2.19
Cost to Fill Tank		$42
Tank Size		17.0 gallons

Annual Consumer Electricity Cost[52]

Social Cost of Carbon (CO2)

- $35/ton[26,27,29,30]
- Tailpipe emissions Camry[42,46,53]
- Engine/battery manufacture[44,50,51]
- Petroleum production[45]

Social Cost of NOx, CO

- $11,000/ton and $490/ton[8]

Social Health Costs

- Ameren Electric Coal Power (valuation of death, hospitalization from

CBA: Emissions and Pollution Standards

40

Light-Duty Vehicles and Light-Duty Trucks: Tier 0, Tier 1, National Low Emission Vehicle (NLEV), and Clean Fuel Vehicle (CFV) Exhaust Emission Standards

	Vehicle Type	Emission Category	Vehicle Useful Life														
			5 Years / 50,000 Miles							10 Years / 100,000 Miles							
			THC [a, b, c] (g/mi)	NMHC [d] (g/mi)	NMOG (g/mi)	CO [c, e]	NOx (g/mi)	PM [f] (g/mi)	HCHO (g/mi)	THC [a, b] (g/mi)	NMHC [d] (g/mi)	NMOG (g/mi)	CO [g] (g/mi)	NOx (g/mi)	PM [f] (g/mi)	HCHO (g/mi)
	LDV [h, i, j]	Tier 0	0.41	0.34 [l]	-	3.4	1	0.20 [n]	-	-	-	-	-	-	-	-
		Tier 1	0.41 [k]	0.25	-	3.4	0.4 [m]	0.08	-	-	0.31	-	4.2	0.6 [o]	0.1	-

8

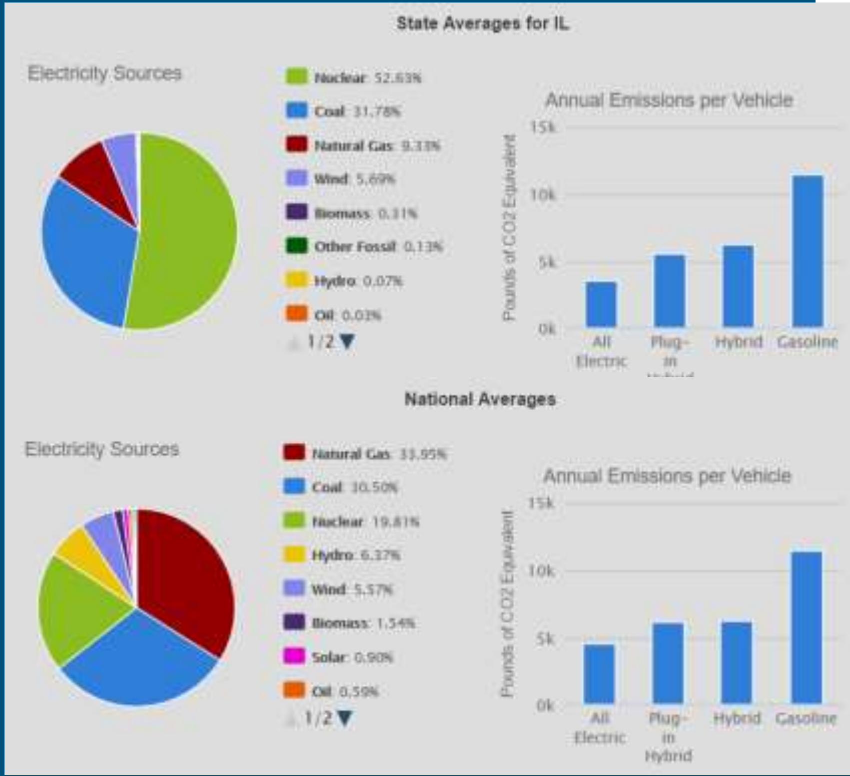
27

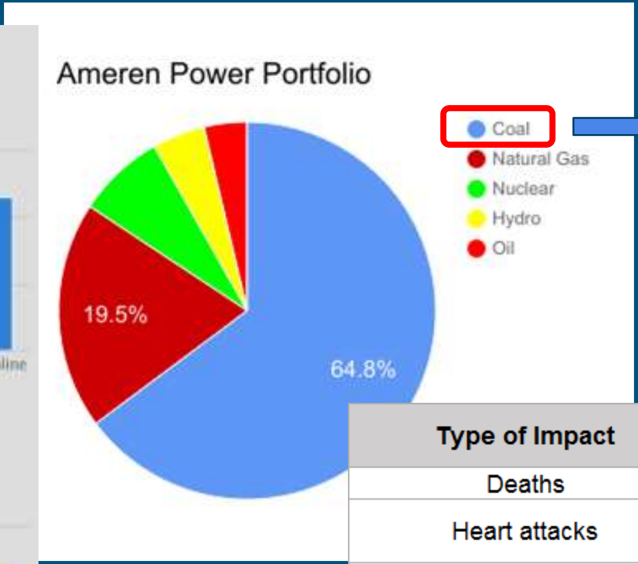
Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

CBA: Social Costs of Electricity Generation

33





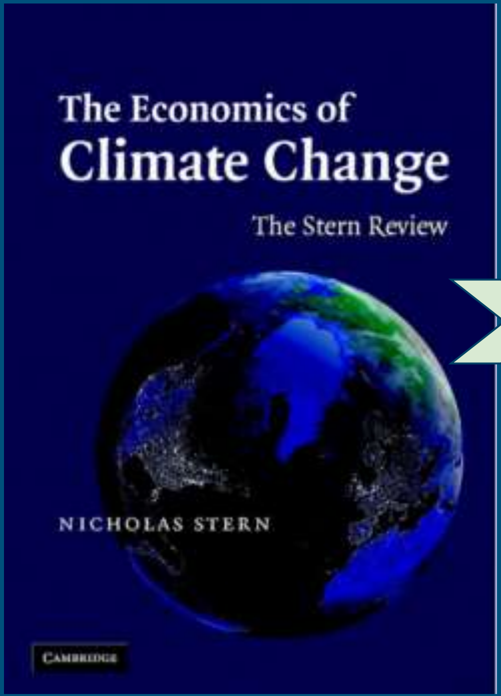
31

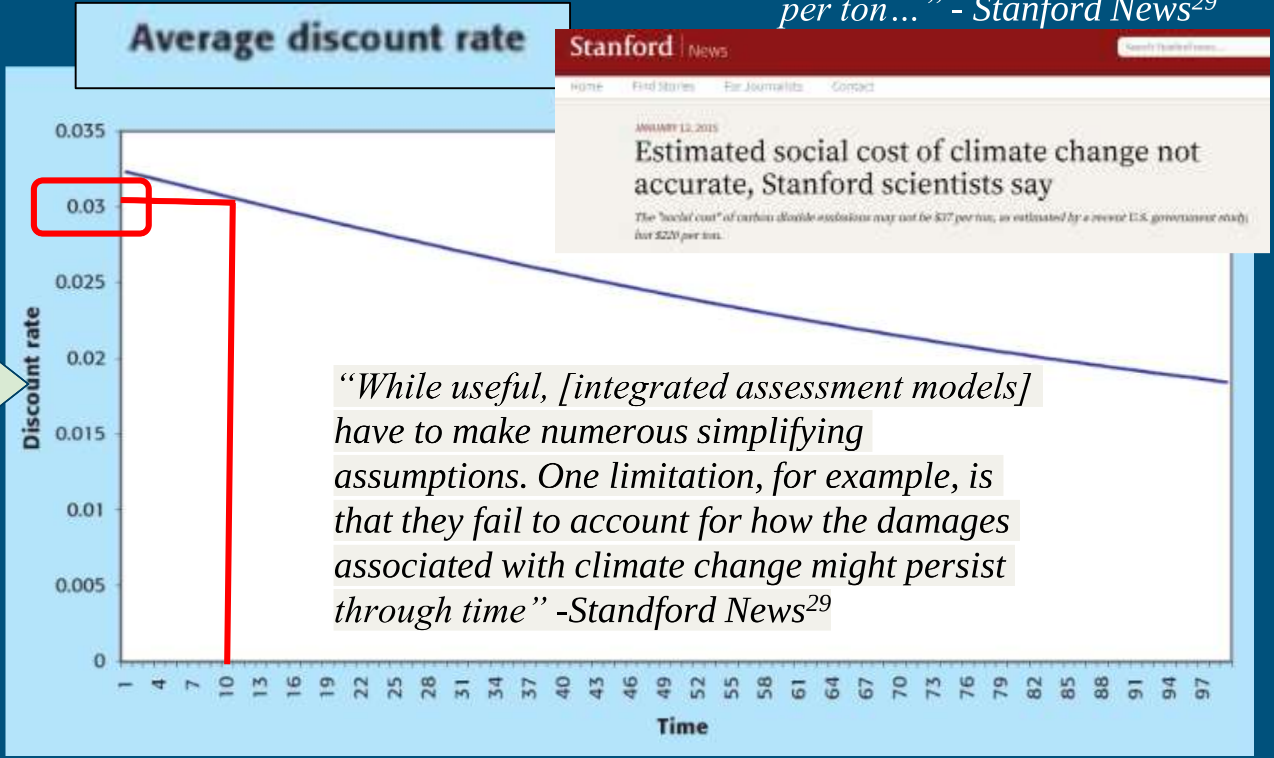
Type of Impact	Annual Incidence	Valuation
Deaths	407	$3.0 billion
Heart attacks	628	$68.7 million
Asthma attacks	6,896	$0.36 million
Chronic bronchitis	250	$111.0 million
Asthma ER visits	440	$0.16 million

CBA: Selecting Discount Rate

"The "social cost" of carbon dioxide emissions may not be $37 per ton, as estimated by a recent U.S. government study, but $220 per ton…" - Stanford News[29]

30





"While useful, [integrated assessment models] have to make numerous simplifying assumptions. One limitation, for example, is that they fail to account for how the damages associated with climate change might persist through time" -Standford News[29]

CBA: Toyota Camry (CV) (3% discount rate)

Costs											
Year	0	1	2	3	4	5	6	7	8	9	10
Manufacturer's Suggested Retail Price	-$27,170.00										
Repair		-$134.20	-$134.20	-$134.20	-$134.20	-$134.20	-$134.20	-$134.20	-$134.20	-$134.20	-$134.20
Maintenance		-$601.60	-$601.60	-$601.60	-$601.60	-$601.60	-$601.60	-$601.60	-$601.60	-$601.60	-$601.60
Insurance		-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60	-$1,184.60
Fuel		-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00	-$1,000.00
Carbon Dioxide Tailpipe Emissions		-$172.36	-$172.36	-$172.36	-$172.36	-$172.36	-$172.36	-$172.36	-$172.36	-$172.36	-$172.36
Carbon Monoxide Emissions		-$24.75	-$24.75	-$24.75	-$24.75	-$24.75	-$30.57	-$30.57	-$30.57	-$30.57	-$30.57
Nox Emissions		-$65.36	-$65.36	-$65.36	-$65.36	-$65.36	-$98.04	-$98.04	-$98.04	-$98.04	-$98.04
Indirect CO2 emissions (petroleum production)		-$11.60	-$11.60	-$11.60	-$11.60	-$11.60	-$11.60	-$11.60	-$11.60	-$11.60	-$11.60
Indirect CO2 emissions (combustion engine manufacture)	$0.00										
Indirect Social Health Costs Attributable to Coal Generation for Power		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Benefits											
Year	0	1	2	3	4	5	6	7	8	9	10
Federal Tax Credit	$0.00										

Net Present Value											
Year	0	1	2	3	4	5	6	7	8	9	10
Yearly NPV	-$27,170.00	-$3,101.43	-$3,011.09	-$2,923.39	-$2,838.25	-$2,755.58	-$2,707.56	-$2,628.70	-$2,552.14	-$2,477.80	-$2,405.63
Cumulative NPV	-$27,170.00	-$30,271.43	-$33,282.52	-$36,205.91	-$39,044.16	-$41,799.74	-$44,507.30	-$47,136.00	-$49,688.14	-$52,165.94	**-$54,571.57**

CBA: Nissan Leaf (EV) (3% discount rate)

Costs

Year	0	1	2	3	4	5	6	7	8	9	10
Manufacturer's Suggested Retail Price	-$32,065.00										
Repair		-$154.60	-$154.60	-$154.60	-$154.60	-$154.60	-$154.60	-$154.60	-$154.60	-$154.60	-$154.60
Maintenance		-$577.60	-$577.60	-$577.60	-$577.60	-$577.60	-$577.60	-$577.60	-$577.60	-$577.60	-$577.60
Insurance		-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80	-$1,218.80
Fuel		-$366.03	-$366.03	-$366.03	-$366.03	-$366.03	-$366.03	-$366.03	-$366.03	-$366.03	-$366.03
Carbon Dioxide Tailpipe Emissions		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Carbon Monoxide Emissions		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Nox Emissions		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Indirect CO2 emissions (electricity production)		-$89.75	-$89.75	-$89.75	-$89.75	-$89.75	-$89.75	-$89.75	-$89.75	-$89.75	-$89.75
Indirect CO2 Emissions (lithium-ion battery manufacture)	-$118.10										
Indirect Social Health Costs Attributable to Coal Generation for Power		-$422.75	-$422.75	-$422.75	-$422.75	-$422.75	-$422.75	-$422.75	-$422.75	-$422.75	-$422.75

Benefits

Year	0	1	2	3	4	5	6	7	8	9	10
Federal Tax Credit	$7,500.00										

Net Present Value

Year	0	1	2	3	4	5	6	7	8	9	10
Yearly NPV	-$24,683.10	-$2,747.12	-$2,667.10	-$2,589.42	-$2,514.00	-$2,440.78	-$2,369.69	-$2,300.67	-$2,233.66	-$2,168.60	-$2,105.44
Cumulative NPV	-$24,683.10	-$27,430.21	-$30,097.32	-$32,686.74	-$35,200.74	-$37,641.51	-$40,011.20	-$42,311.87	-$44,545.53	-$46,714.12	**-$48,819.56**

CBA: Net Present Value Comparisons

Toyota Camry

Net Present Value											
Year	0	1	2	3	4	5	6	7	8	9	10
Yearly NPV	-$27,170.00	-$3,101.43	-$3,011.09	-$2,923.39	-$2,838.25	-$2,755.58	-$2,707.56	-$2,628.70	-$2,552.14	-$2,477.80	-$2,405.63
Cumulative NPV	-$27,170.00	-$30,271.43	-$33,282.52	-$36,205.91	-$39,044.16	-$41,799.74	-$44,507.30	-$47,136.00	-$49,688.14	-$52,165.94	**-$54,571.57**

Nissan Leaf

Net Present Value											
Year	0	1	2	3	4	5	6	7	8	9	10
Yearly NPV	-$24,683.10	-$2,747.12	-$2,667.10	-$2,589.42	-$2,514.00	-$2,440.78	-$2,369.69	-$2,300.67	-$2,233.66	-$2,168.60	-$2,105.44
Cumulative NPV	-$24,683.10	-$27,430.21	-$30,097.32	-$32,686.74	-$35,200.74	-$37,641.51	-$40,011.20	-$42,311.87	-$44,545.53	-$46,714.12	**-$48,819.56**

Net Present Value (No Tax Credit)											
Year	0	1	2	3	4	5	6	7	8	9	10
Yearly NPV	-$32,183.10	-$2,747.12	-$2,667.10	-$2,589.42	-$2,514.00	-$2,440.78	-$2,369.69	-$2,300.67	-$2,233.66	-$2,168.60	-$2,105.44
Cumulative NPV	-$32,183.10	-$34,930.21	-$37,597.32	-$40,186.74	-$42,700.74	-$45,141.51	-$47,511.20	-$49,811.87	-$52,045.53	-$54,214.12	**-$56,319.56**

Results

LCA

EVs produce ½ the total emissions of CVs

Likely to improve as technology improves

CBA

Leaf is $5700 cheaper over 10 years

Without tax credit, Leaf is $1700 more expensive over 10 years

Conclusions

Expect Electric Vehicles to surpass Conventional Vehicles in all regards

- Appreciably the same already
- Rising costs of carbon and emissions
- Improving technologies
- Support our indicators
  - Cost, efficiency, and availability

How to encourage the change

- Inequalities of LCA and CBA

Sources

1) "How Clean Is Your Electric Vehicle?" *Union of Concerned Scientists*. Union of Concerned Scientists, n.d. Web. 24 Apr. 2017.
2) Johnson, Tamra. "New Study Reveals When, Where and How Much Motorists Drive." *AAA NewsRoom*. AAA NewsRoom, 25 May 2016. Web. 24 Apr. 2017.
3) Boren, Sven, and Henrik Ny. "A Strategic Sustainability Analysis of Electric Vehicles in EU Today and Towards 2050." *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering* 10.3 (2016): n. pag. *Waset.org*. Web. 24 Apr. 2017.
4) "Global Gender and Environment Outlook 2016." *Clean Energy Ministerial* (2016): n. pag.*Iea.org*. International Energy Agency, 2016. Web. 24 Apr. 2017.
5) Greenstone, Michael, and Adam Looney. "A Strategy for America's Energy Future: Illuminating Energy's Full Costs." *The Hamilton Project* (2011): n. pag.*Hamiltonproject.org*. Brookings, 2011. Web. 24 Apr. 2017.
6) "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *What Is U.S. Electricity Generation by Energy Source? - FAQ - U.S. Energy Information Administration (EIA)*. U.S. Energy Information Administration, 18 Apr. 2017. Web. 24 Apr. 2017.
7) Valentine, Katie. "Here's What Gas Would Have To Cost To Account For Health And Environmental Impacts." *ThinkProgress*. ThinkProgress, 05 Mar. 2015. Web. 24 Apr. 2017.
8) Shindell, Drew T. "The Social Cost of Atmospheric Release." *SpringerLink*. Springer Netherlands, 25 Feb. 2015. Web. 24 Apr. 2017.
9) Josephs, Leslie. "Charging a Tesla Goes from Free to Dirt Cheap Now That There's a Supercharger Station Fee." *Quartz*. Quartz, 13 Jan. 2017. Web. 24 Apr. 2017.
10) Healey, James R. "Average New Car Price Zips 2.6% to $33,560." *USA Today*. Gannett Satellite Information Network, 04 May 2015. Web. 24 Apr. 2017.
11) Frankel, Matthew. "10 Incredible Financial Statistics That Sum up the Average American."*USA Today*. Gannett Satellite Information Network, 04 Apr. 2017. Web. 24 Apr. 2017.
12) Migliozzi, Blacki, David Ingold, and Adam Pearce. "Scientific Proof That Americans Are Truck Addicts: The Story of the Pickup's Prodigal Return." *Bloomberg.com*. Bloomberg, 15 Jan. 2015. Web. 24 Apr. 2017.
13) "Greenhouse Gas Emissions from a Typical Passenger Vehicle." *Questions and Answers*(2014): n. pag. *Epa.gov*. United States Environmental Protection Agency, May 2014. Web. 24 Apr. 2017.
14) "Table 4-23: Average Fuel Efficiency of U.S. Light Duty Vehicles." *Bureau of Transportation Statistics*. U.S. Department of Transportation, 2015. Web. 24 Apr. 2017
15) Nealer, Rachael, David Reichmuth, and Don Anair. "Cleaner Cars From Cradle To Grave (2015)". *Union of Concerned Scientists*. N.p., 2015. Web. 25 Apr. 2017.
16) Lambert, Fred. "Tesla Battery Data Shows Path To Over 500,000 Miles On A Single Pack". *Electrek*. N.p., 2016. Web. 25 Apr. 2017.
17) Maverick, J.B. "What Types of Raw Materials Would Be Used by an Auto Manufacturer?"*Investopedia*. Investopedia, 23 June 2015. Web. 24 Apr. 2017.
18) Boyle, Tim. "What's The Life Expectancy Of My Car?". *msnbc.com*. N.p., 2017. Web. 25 Apr. 2017.
19) Wirfs-Brock, Jordan, Jordan Wirfs-Brock, and More Jordan. "Lost In Transmission: How Much Electricity Disappears Between A Power Plant And Your Plug?". *Inside Energy*. N.p., 2015. Web. 25 Apr. 2017.
20) "Where The Energy Goes: Gasoline Vehicles". *Fueleconomy.gov*. N.p., 2017. Web. 25 Apr. 2017.
21) "82. THE COST COMPONENTS OF A LITHIUM ION BATTERY - Qnovo". *Qnovo*. N.p., 2016. Web. 25 Apr. 2017. CBA
22) "Plugshare". *Plugshare.com*. N.p., 2017. Web. 26 Apr. 2017.
23) Weaving, John H. *Internal Combustion Engineering*. London: Elsevier Applied Science, 1990. Print.
24) *Proceedings of the 2009 Spring Technical Conference of the ASME Internal Combustion Engine Division: Presented at 2009 ASME Internal Combustion Engine Division Spring Technical Conference, May 3-6, 2009, Milwaukee, Wisconsin USA*. New York, NY: ASME, 2009. Print.
25) "The History Of The Electric Car". *Energy.gov*. N.p., 2014. Web. 29 Apr. 2017.
26) Nordhaus, William D. "Revisiting the Social Cost of Carbon." *Proceedings of the National Academy of Sciences* 114.7 (2017): 1518-523. Web.
27) Wihbey, John. "Understanding the Social Cost of Carbon." *Yale Climate Connections*. Yale University, 06 Jan. 2017. Web. 29 Apr. 2017.
28) "Sources of Greenhouse Gas Emissions." *EPA*. Environmental Protection Agency, 14 Apr. 2017. Web. 29 Apr. 2017.
29) University, Stanford. "Estimated Social Cost of Climate Change Not Accurate, Stanford Scientists Say." *Stanford News*. Stanford University, 08 Apr. 2016. Web. 29 Apr. 2017.
30) Stern, N. H. *Economics of Climate Change: The Stern Review*. New York: Cambridge UP, 2007. Print.
31) "Ameren." *Ameren - SourceWatch*. Sourcewatch, 21 Aug. 2014. Web. 29 Apr. 2017.
32) "Benefits and Considerations of Electricity as a Vehicle Fuel." *Alternative Fuels Data Center: Benefits and Considerations of Electricity as a Vehicle Fuel*. U.S. Department of Energy, 10 Apr. 2017. Web. 29 Apr. 2017.
33) "Emissions from Hybrid and Plug-In Electric Vehicles." *Alternative Fuels Data Center: Emissions from Hybrid and Plug-In Electric Vehicles*. U.S. Department of Energy, 03 Apr. 2017. Web. 29 Apr. 2017.