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Abstract

The green innovation value-chain (GIVC) is a framework that compares the relative attractiveness of a green technology with conventional competitors(s) along stakeholder links representing the manufacturer, distributor, end-user, government, and the environment. Previous GIVC analyses have examined hybrid car and PV solar technologies, and conclude that each provides poor financial and environmental returns across the GIVC links in comparison with the most similar gasoline powered car and natural gas generated electricity respectively. The current research addresses the potential bias of using a single comparison point by including additional competing products/technologies that reflect actual marketplace or public policy advocated technology substitution. Although some of the new comparisons provide more encouraging green technology results than the earlier analyses, the overall conclusion remains that neither technology is likely to be attractive to stakeholders and widely displace the new comparison points. The market and public policy implications of the findings are then discussed.

Keywords: green innovation value chain; innovation diffusion; solar power; green vehicles; green subsidies.

1.0 Introduction

Widespread worries regarding rising energy prices, unstable energy supplies, anthropologic climate change, environmental degradation, and unsustainable development are spurring private and public sector investments in green technologies and products (Hardgadon and Kenney, 2012; Peattie and Peattie, 2009). Although public and private investors have spent billions to encourage the adoption of green technologies to replace dirtier conventional technologies, such investments do not always result in the desired level and type of substitution. In Germany for example, heavily subsidized renewable energy technologies are being used to replace relatively clean nuclear power, while at the same time the largest and growing share of German electricity is generated by relatively dirty coal-fired electricity generation plants (Burger, 2013; Friederici, 2013). Similarly, in the United States the most popular trade-in for buyers of the subsidized Chevrolet Volt extended range electric car (a.k.a. plug-in hybrid) is the also green Toyota Prius gas-electric hybrid, rather than more fuel thirsty vehicles (Weaver, 2012; Lienert, 2004).

The Green Innovation Value Chain (GIVC) is a recently introduced framework for analyzing the financial and environmental competitiveness of green technologies to determine their adoption prospects. GIVC analysis compares green technologies with conventional ‘brown’ technologies across each link of a chain that is comprised of manufacturers, distributors, end-users, government, and the environment to determine the green technology’s relative financial and environmental value within each link and across the entire value chain. The framework was first demonstrated with a comparison of hybrid cars and their conventional equivalents, where hybrids were found to be less profitable to car manufacturers and dealers, more costly to consumers, provided very expensive reductions in CO2 emissions, and a poor financial return for government funded hybrid subsidies (Olson, 2013). A second GIVC study compared photovoltaic (PV) solar generated electricity with natural gas generated electricity, and again found green technology financial deficits across all the chain links and a poor environmental return (Olson, 2014). Although the results of both GIVC demonstrations show substantial financial deficits that would need to be reduced in order to improve the likelihood of widespread adoption, each case limited the comparison to a single conventional competitor and hence may provide an incomplete picture of either green technology's current prospects. Thus the purpose of this research is to examine the sensitivity of the GIVC analysis to the use of alternative competitors that more fully reflect the technology substitutions hoped for by public policy makers and the actual technology substitutions occuring via customer choices in the market place.

2.0 Background

Although governments around the world have enacted policies to encourage green technology adoption, scholarly literature has also encouraged firms to 'green' their manufacturing, distribution, and products as a strategic path that will provide them and society with both environmental and economic benefits (e.g. Porter and van der Linde, 1995; Porter and Reinhardt, 2007; Unruh and Ettenson, 2010). Despite a great deal of public and private investment in green technologies, however, actual market place adoption has frequently been slower and/or more costly than planned (Olson, 2013). For example, U.S. President Obama used his 2011 State of the Union address to propose putting one million electric vehicles (EVs) on American roads by 2015 through the implementation of a variety of incentives and subsidies, but actual sales during the intervening period have fallen far behind the level necessary to achieve this goal (DOE, 2011; EDTA, 2013). In contrast, generous renewable energy subsidies has resulted in more solar panel installations than predicted by public policy experts in several major markets, resulting in unanticipated levels of subsidy expenditures and high electricity prices, which in turn have led to widespread solar subsidy cutbacks (Bryce, 2014; Olson, 2014). The slow pace of green technology adoption and/or cutbacks in public subsidies have also been at least partly responsible for many high profile bankruptcies among green technology firms including solar panel producers Solyndra, Evergreen, Spectrawatt and Solon, and electric car manufacturers Aptera, Bright, Coda, Fisker, and Think (Attkisson, 2012; Plumer, 2012; Solomon, 2011).

The financial losses suffered by public and private investors of under-performing and/or failing green technologies and firms was the impetus for development of the GIVC framework as a means of evaluating green technology competitiveness vs. the conventional competitors they might replace (Olson, 2013). GIVC analysis utilizes elements of traditional value-chain and lifecycle assessment (LCA) to determine the value that green products provide key stakeholders, who comprise each link of the chain (Olson, 2013, Olson, 2014). In so doing, GIVC analysis takes a broad perspective in evaluating adoption prospects by including all key stakeholders that are potential suppliers, buyers/users, and subsidizers of the green technology.

2.1 Combining Value-chain Analysis and Life cycle Assessment

Value-chain analysis traditionally focuses on the positive and negative financial implications that activities such as logistics, operations, and marketing/sales can have on the costs and pricing power of a firm’s product, but typically ignores important external stakeholders by limiting analysis to activities within a specific firm (Ginsberg and Bloom, 2003; Rehfeld, et al., 2007). In contrast, LCA utilizes a multi-stakeholder approach in the calculation of total emissions through each phase of the product’s life cycle from raw material extraction to final use and disposal, but typically ignores financial implications (Albino et al,. 2009, Hermann et al., 2006). GIVC combines the financial elements from value chain analysis with the environmental focus of traditional LCA across the key stakeholders that represent each link of the chain, which provides a more complete and diagnostic assessment of a green technology’s prospects for achieving widespread adoption (Olson, 2014).

2.2 Green Innovation Value Chain

The GIVC assumes that moving beyond niche market status requires the green technology to provide ‘win-win-win’ outcomes vs. conventional competitors across each separate chain link, which contrasts with the ‘lose-lose-lose’ outcomes for hybrid cars and PV solar found in earlier GIVC analyses (Olson, 2013; Olson, 2014). Both of these comparisons concluded that major improvements in green technology performance and/or relative cost were needed to widely replace the comparison conventional technology, and that current government supports were insufficient to overcome the deficits among the links while at the same time being overly generous relative to the economic value of the provided environmental benefits. In each of these cases, however, conclusions were based on a single conventional technology frame-of-comparison. Thus for hybrid cars, the comparison was with the most technically similar conventional version of the same/similar car (i.e. the Chevrolet Volt plug-in hybrid vs. the similarly sized and component sharing gasoline Chevrolet Cruze), while for PV solar the comparison was with natural gas generated electricity, the fastest growing source of carbon-based electricity in the U.S. Although both of these comparisons are reasonable, they do not necessarily reflect the desired or actual technology substitution effects of government policy makers and marketplace participants, and thus the conclusions offer an incomplete picture of each technology's current state of competitiveness. This is an important limitation, because the value of GIVC analysis to public and private technology evaluators is dependent on avoiding pro-green or anti-green biases in the selection of comparison points and assumptions (Olson, 2013, Olson, 2014). The sensitivity of the earlier GIVC analyses conclusions to public policy and market endorsed alternative frames-of-reference is examined in the following sections where coal and nuclear generated electricity are added to the earlier PV solar comparison, and the Chevrolet Silverado pickup and Toyota Prius are added to the earlier Chevrolet Volt comparison.

3.0 Chevrolet Volt GIVC case

Since the 1970s, various U.S. government policies and subsidies have attempted to encourage the adoption of greener vehicles and/or discourage the manufacture and sale of gas guzzling large cars and trucks (Olson and Thjomoe, 2010). These policies include increasing fuel economy standards (CAFE), tax-credits for hybrid and battery-powever electric vehicle purchasers, and the 2009 “Cash for Clunkers” program to encourage the scrapping of older thirsty vehicles by providing consumers with up to $4,500 for their old vehicle when they purchased a new fuel efficient vehicle (Olson, 2013; Shepardson, 2013). Despite these decades long efforts to encourage a consumer shift away from large thirsty vehicles, full-size pickups from either Ford or General Motors have continously been the top selling vehicle in the U.S. market since the mid-1980s, and during 2013 eight out of the top ten selling vehicles in the U.S. were large pickups, full-size cars, or SUVs (Gasnier, 1986; Mays, 2014). The difficulties in shifting U.S. car buyers out of their favored large trucks and cars is illustrated by fact that the

$7,500 federal EV tax credit provided to Chevrolet Volt buyers has its greatest impact on owners of the fuel efficient Toyota Prius hybrid, which has been the most popular Volt trade-in (Lienert, 2014; Weaver, 2012).

The earlier GIVC analysis compared all gasoline-electric hybrid cars sold in the U.S. market at the end of 2010 with their conventional equivalents, on relative profitability and emissions for the manufacturer, retailer (dealer), consumer, and the government (Olson, 2013). The Chevrolet Volt plug-in hybrid was found to offer the largest potential emission reduction among all the hybrids on the market, and for that reason is the focus of the current analysis utilizing the desired and actual technology substitution behavior of the marketplace. As noted in the detailed discussion that follows, the current comparison uses the assumptions and scenarios from the previous study to make two new comparisons that include: 1) the public policy desired substitution scenario of a Chevrolet Volt replacing the would-be purchase of a conventional Chevrolet Silverado pickup, and 2) the Toyota Prius to represent the most common Volt trade-in. Both scenarios are presented with updated volume, cost, and pricing data displayed in table 1 that reflect the influence of market changes since the late 2010 data collection of the previous study.

3.1 Volt Manufacturer Link

The GIVC manufacturer link reflects the added costs for the plug-in hybrid hardware development and manufacturing (i.e. batteries, electric motors, gearboxes, etc.), as well as the cost of developing the platform that houses the hardware (i.e. chassis, body, and conventional gasoline engine of the vehicle). Estimates for these costs are based on the earlier study that assumes a 3-year development period and a 6-year market life reflecting the 2010 U.S. annual sales rate, and a total development cost of $1.66 billion (Olson. 2013). Per unit development cost amortization are calculated by dividing the estimated 6-year sales volume into the estimated total development costs, while hybrid hardware manufacturing costs are calculated as the invoice price difference between the Volt and the Chevrolet Cruze. As with the earlier study, estimated costs and revenues are discounted by the manufacturer cost of capital (4.0% for Toyota and 5.1% for GM), and a cost of capital profit margin goal is assumed for each vehicle (Olson. 2013). Table 1 presents the data that is the basis for the current comparisons, which reflect changes since the original 2010 time-frame including: 1) the higher 2012 global sales rate used for development cost amortization, 2) $5,000 and $10,000 cuts in the Volt's retail price and manufacturing costs respectively announced by GM in 2013, and 3) higher 2013 average fuel prices (Bennett. 2013).

Table 2, section 1 presents the results of manufacturer link Volt comparison with the Prius, Silverado, and Cruze, with relative manufacturer profits for the Volt ranging from -$5,024 vs. the Prius to -$12,104 vs. the Silverado. The Volt vs. Cruze results change from -$10,177 in the earlier study, to the current -$5,838 for a 43% improvement, reflecting the Volt's improved sales rate and reduced manufacturing cost.

3.2 Volt Distributor Link

The GIVC distributor link reflects the relative inventory holding costs, retailer margins, and retail prices of the comparison vehicles, and uses the same values from the earlier GIVC analysis with the exception of using the Volt's recently lowered retail price (Olson 2013). Table 2, section 2 shows that the Volt improves retail profits by $219 vs. the Prius, and -$1,894 vs. the

Silverado. The earlier Cruze comparison shows the Volt offering retailers a $739 higher profit, which is reduced to $500 due to the 2013 reduction in the Volt's retail price.

3.3 Volt End-User Link

As with the earlier comparison, the GIVC end-user link calculations are based on a five year ownership period, and two annual driving rates: Scenario 1 uses 15,000 miles per year typical in the U.S., and scenario 2 uses 7,500 miles per year. Full retail price is assumed in the purchase, and the net present value (NPV) of the annual ownership costs utilizes a 7.5% discount rate and includes annual expenses for fuel and insurance, as well as the resale value at the end of the 5-year ownership period (see table 1). Fuel prices reflect the 2013 U.S. average of $3.50 per gallon for regular gasoline, $3.82 per gallon for the premium fuel required by the Volt, and $0.12 per kWh for recharging the Volt's batteries based on the EPA assumption that battery power is utilized for 50% of the annual mileage. To simplify the comparisons, resale value, insurance, and maintenance are assumed to be the same regardless of the annual mileage scenario.

The results from table 2, section 3, show that the Volt has a deficit of -$12,706 (7,500 annual miles) and -$11,233 (15,000 annual miles) respectively vs. the Prius, while saving the first owner $721 and $6,763 respectively vs. the Silverado. The earlier Volt comparison found a deficit of -$16,266 (7,500 annual miles) and -$15,826 (15,000 miles) vs. the Cruze, while the current results finds respective deficits of -$16,290 and -$15,874. As with the earlier comparison, these results confirm that Volt owners financially benefit from additional driving vs. all the comparison vehicles because more miles provide greater opportunity to take advantage of the Volt's lower fuel use.

3.4 Volt Government Link

The GIVC government link examines the attractiveness of green vehicle subsidies in compensating the manufacturer, distributor, and consumer links for their ‘green’ Volt sacrifices. Table 2, section 4 shows that the respective total link 7,500 and 15,000 mile deficits for the Volt are -$17,511 and -$16,038 vs. the Prius, and -$13,277 and -$7,235 respectively for the Silverado, before any federal aid to link members is considered. The earlier Cruze deficit vs. the Volt was -$25,472 (7,500) and -$25,035 (15,000), and currently -$21,628 and -$21,212 respectively. GM specifically received government grants and tax breaks totaling more than $300 million for the Volt project, and Volt retail customers can benefit from $7,500 in federal tax credits (Gantert 2011). When these federal benefits are included, the Volt deficits are -$8,417 and -$6,944 vs. the Prius, and -$2,712 at 7,500 miles per year vs. the Silverado. At 15,000 miles per year, the government benefits create a surplus of $3,330 across the Silverado chain. For the Cruze, the post-subsidy losses are -$12,534 and - $12,118 for the 7,500 and 15,000 miles scenarios respectively. Thus only in the high annual mileage Volt vs. Silverado scenario do government subsidies offset the Volt’s deficits across the manufacturer, distributor, and end-user links.

3.5 Volt Environment Link

GIVC analysis assumes that government support should be provided to green technologies that offer environmental benefits that are more valuable than predicted and/or foreseeable overall link losses (Olson. 2013). The GIVC environmental link utilizes LCA analysis covering each vehicle’s lifetime CO2 equivalent emissions that are based on emissions from vehicle manufacturing + driving + scrapping of the Volt vs. the comparison vehicles. The U.S. Department of Energy calculates that the hybrid’s lower fuel use and emissions are at least partially offset by higher manufacturing and scrapping emissions related to the energy intensive extra electric hardware and use of exotic materials (i.e. rare earths, aluminum, etc.) (Paster. 2007). Table 1 shows that when utilizing the same manufacturing and scrapping emissions from Olson, (2013), the Volt at 7,500 miles per year will generate 29 tons of CO2 equivalent emissions during the first 5 years, and 46 tons during its lifetime, vs. 29 and 51 for the Cruze, 30 and 46 for the Prius, and 56 and 99 for the Silverado respectively. At 15,000 miles per year, the Volt will generate 32 tons during the first 5 years, and 51 tons during its lifetime, while the comparable figures for the Cruze, Prius, and Silverado are 40 and 60, 38 and 53, and 77 and 118 respectively. Thus the Volt's CO2 equivalent emission reductions vs. the comparison vehicles range from 0 to 67 tons (see table 2, section 5), which are divided into the GIVC total deficits to calculate the cost per ton.

As shown in table 2, section 6, the Volt's cost per CO2 equivalent ton reduced for the first 5 years of ownership is $17,511 vs. the Prius at 7,500 miles per year, and $2,673 at 15,000 miles per year, and $492 and $161 respectively vs. the Silverado. Due to the lack of CO2 reduction vs. the Cruze, the cost per ton is infinity at 7,500 miles per year in both the previous and current analysis, and $3,129 and $2,652 respectively at 15,000 miles per year. Vehicle lifetime figures are infinity at 7,500 miles per year vs. the Prius, and -$11 per ton vs. the Silverado, while at 15,000 miles per year the cost is $7,967 vs. the Prius and -$138 vs. the Silverado. The Cruze lifetime comparison was $5,692 (7,500) and $2,811 (15,000) in the previous study, and $4,877 and $2,397 respectively in the current analysis. These cost figures per CO2 equivalent ton reduced via Volt adoption are then compared to previous economic analyses of the social, economic, and environmental benefits from a one-ton reduction in CO2 emissions, which are typically valued at less than $50 per ton (Tol. 2007). This means that only the lifetime comparison between the Volt and the Silverado provides a total GIVC cost that is lower than $50 per ton value of the emission reduction benefits. In all other scenarios the Volt offers a poor environmental return compared to the more similarly sized Prius or Cruze or the original owner of the large Silverado.

3.6 Volt Link Summary

The Volt's current GIVC deficits do not provide support for government and manufacturer link Volt investments unless future projections show a high likelihood that technology advances can quickly and dramatically reduce or eliminate the deficits, OR that major portions of large-vehicle buyers will start adopting the Volt. For example, recent studies predict that higher volume production may reduce the price of hybrid batteries and other components as much as 60% by 2020 (Mosquet et al., 2011). Yet even is such reductions would occur they could not completely close the cost gap with conventional cars, because of the need for both gasoline and electric powertrains, and this system redundancy essentially doubles the price of a car's most expensive component (Richard, 2009). Furthermore the Volt's disappointing sales and overall negative GIVC results suggests that current government supports are inadequate for achieving the sales volume necessary to reduce costs, but overly generous given the poor environmental returns on taxpayer money, particularly when the subsidies are most persuasive in attracting buyers of relatively clean cars such as the Prius.

4.0 PV Solar Green Innovation Value Chain

Due to its low cost and wide availability, coal is the world's most popular fuel for generating electricity, but also the dirtiest fossil fuel source in terms of greenhouse gas emissions (EIA, 2012; WCA, 2013). In contrast, nuclear generated electricity is among the cleanest, but fears about nuclear accidents caused by human-error (e.g. Chernobyl) or acts of nature (e.g. Fukushima Dai-Ichi) has resulted in the closure of many older nuclear plants and the postponement or cancellation of new plant construction in many developed countries (Douglas, 2013; Brown, 2013). This is illustrated by recent trends that find newly installed renewable energy sources in the U.S., Japan, and Germany largely taking the place of nuclear power, while coal's share remains dominant (Friederici, 2013; Roney, 2013). Thus in Germany, while solar generated electricity grew by 44.5% in 2012 vs. 2011 and accounted for 5.7% of total German electricity generation, coal generated electricity also grew by 8.1%, and accounted for 52% of total production, while nuclear power's share shrank by 8.4% (Burger, 2013). In the U.S., nuclear's share has dropped 4% since 2011 due to increasing regulations and fuel prices that raise building and operating costs in the face of competition from natural gas and subsidized renewables (Brown, 2013).

The earlier GIVC analysis compared PV solar with natural gas generated electricity, the fastest growing carbon-fueled source of electricity in the U.S. (EIA, 2012; Smil, 2012), and concluded that PV solar offered poor financial and environmental returns (Olson, 2014). The current GIVC analysis of PV solar will use the same assumptions and source materials as the earlier analysis (see table 3), but adds coal and nuclear power as PV solar competitors due to widespread public policies designed to encourage their replacement by renewable sources.

4.1 PV Solar Manufacturer Link

The manufacturer link of the PV solar GIVC chain is based on the profitability of solar panel manufacturing vs. the manufacturing of steam turbines that are used by natural gas, coal, and nuclear power plants to generate electricity. Due to heavy losses and numerous recent bankruptcies among solar panel producers, the earlier analysis estimates 0% profit margins for solar panel manufactures, and 15% margins for turbine generator manufacturing (Hinton, 2011; Konrad, 2012; Olson, 2014). The earlier analysis also assumed a 30-year plant life and 24% utilization rate based on U.S. data from the Energy Information Agency, and the current analysis makes a simplifying assumption that coal and nuclear power plant turbines will provide similar margins and lifespans (EIA, 2012). As table 4, section 1 shows, these assumptions yield an identical profit of $0.47 per MWh for coal, nuclear, and natural gas turbine manufacturing vs. the $0.00 per MWh estimate for PV solar panel manufacturers.

4.2 PV Solar Distributor Link

The PV solar power distributor link is comprised of electric utility companies that operate power plants to generate electricity for retail sale. The distributor link profitability shown in table 4, section 2, is calculated by the following formula: Profit = (revenue from power sales – (cost of power generation + cost of backup power)). The cost of power generation utilizes EIA estimates for the levelized cost of generating one MWh of electricity that includes the costs of building, operating and maintaining a power plant during a 30-year life. The EIA predicts a cost of $63.10 per MWh using natural gas, $50.00 per MWh for both nuclear and coal, and $152.70 for PV solar (EIA, 2012). The PV solar estimate also includes a $4 per MWh cost of backup conventional power to provide customers with a reliable power source when the sun is not shining (St. John, 2012). In the U.S. the average power company customer pays $98.26 per MWh (EIA, 2010), and together with the additional $0.35 per MWh coming from higher fees for green power (see note 5 in table 3) means each MWh of PV solar generated electricity is sold at a loss averaging $58.09. In contrast, natural gas generated electricity earns a profit of $35.16 per

MWh, while nuclear and coal earn $48.26 per MWh. This means the total financial deficits range from -$93.25 to -$106.35 per MWh for PV solar in the distributor link (see table 4, section 2).

4.3 PV Solar End-User Link

The customer link utilizes the U.S. national average of $1.75 cents per kilowatt-hour (kWh) price premium charged to U.S. electricity customers that are offered the opportunity to buy green power generated from renewable sources (Environmental Leader, 2010). Solar's higher costs to the GIVC customer link are presented in table 4, section 3, and assumes the solar power buyer paying the $17.50 per MWh average 'green power' program price premium.

4.4 PV Solar Government Link

The government link addresses the degree to which government support offsets the PV solar financial deficits vs. alternatives, which range from -$111.22 to -$124.32 per MWh from the manufacturer, distributor, and customer links (see table 4, section 4). Solar power receives a wide variety of supports from governments around the world, which includes research grants, tax credits, feed-in tariff subsidies, and renewable energy mandates for electric utilities (Olson, 2014). In the U.S. such subsidies are valued by the EIA at $24.34 per MWh generated, which are many multiples higher than the $0.25, $1.59, and $0.44 per MWh subsidies received by natural gas, nuclear, and coal respectively, and are therefore insufficient to overcome the PV solar financial deficits of the other links. Thus the PV solar deficits remain -$87.13 to -$101.57 per MWh even after government subsidies are included.

4.5 PV Solar Environment Link

As with the Volt case, the economic argument for the government support of the PV solar industry is dependent on the environment link analysis showing greenhouse gas reduction benefit valuations that are high enough to overcome the financial deficits required to achieve them across the other GIVC links. As with the earlier GIVC analysis of PV solar, the current analysis relies on previous LCA studies that have calculated the greenhouse gas emissions and other pollutants associated with all phases of the construction, operation, and decommissioning of PV solar, natural gas, nuclear, and coal electricity generating capacity (Olson, 2014). The resulting LCA estimates vary due to differing assumptions regarding power plant efficiency levels, expected plant lifespan, local weather conditions (i.e. sunny hours per day), and needs for power grid investments (i.e. connecting power plant to grid). Hence table 3 shows that LCA estimates for PV solar range from .03 to .22 CO2 equivalent tons per MWh, .39 to .44 for natural gas, .1 to .13 for nuclear, and .77 to 1.17 for coal (Lenzen, 2008; Sovacool, 2008). Table 4, section 5 shows the PV solar-induced CO2 equivalent ton reduction per MWh, and section 6 the estimated cost per ton to achieve the reduction, using scenarios that utilize the LCA mid-points estimates, best solar vs. worst alternative estimate, and worst solar vs. best alternative. The subsidy-free cost per CO2 ton reduction range from $115 to $1,247, although only the best solar vs. worst nuclear provides a CO2 reduction in the nuclear comparison, which are all higher than the estimated $50 per ton benefit from the reduction (Tol, 2007).

4.6 PV Solar Link Summary

These uneconomic environmental benefits might be justified if significant improvements in the relative efficiency and cost of PV solar are anticipated. Although solar panel prices have dropped dramatically in recent years due to growing economies of scale and technology improvements, future progress is predicted to slow due to the lack of industry profitability (Styles, 2011). Experimental solar panels are also being tested that double the energy conversion rates of current panels, but competition from efficiency improvements to conventional power plants may mean cost gaps remain large (Smil, 2012). Furthermore, until cost effective systems are developed for the storage of excess power generation during the sunniest hours, solar power is unlikely to reach complete parity with carbon-based or nuclear generated electricity due to the need for system redundancy in the form of conventional power plant backups for periods when the sun doesn’t shine (Bryce, 2014; St. John, 2012). Perhaps the biggest threat to PV solar competitiveness comes from hydraulic fracturing (a.k.a. fracking) technology that has unleashed vast new natural gas supplies that have reduced the U.S. price of natural gas from $15 per thousand cubic feet in 2005 to less than $2 in 2012, with dramatic negative impact on most PV solar financial projections (Brady, 2012; Smil, 2012).

5.0 Discussion

There may be strong pressure to be ‘politically correct’ and create pro-green scenarios that show only the best possible financial and environmental results when using the GIVC framework to evaluate green technology adoption prospects (Olson, 2013). Thus public policy makers that intend to use GIVC analysis to determine the most effective means of achieving environmental goals should choose scenario parameters that reflect the actual marketplace to avoid pro-green (or anti-green) biases. Perhaps the most important GIVC parameter is the choice of competitor(s) that provides the needed comparison point for the green technology under review, and previously published GIVC studies of hybrid cars and PV solar provided only a single comparison point for each technology (Olson, 2013; Olson, 2014). The danger of such single comparisons is that they may not provide sufficient context to determine if GIVC based conclusions are biased even when reasonable justification is provided for the comparison. Furthermore, the use of single comparison points in GIVC analysis may not reflect the hoped for technological substitutions of public policy makers or the actual technological substitutions taking place in the competitive marketplace.

The desirability of additional comparison points in GIVC analysis is addressed by the current research, and with a single exception their inclusion failed to achieve an attractive GIVC result for either the Chevrolet Volt or PV solar. Only the Volt comparison with the Chevrolet Silverado using the lifetime GIVC scenario yielded a cost of $50 or less per CO2 ton reduction, while comparisons with the Prius proved to be even less attractive than the earlier GIVC comparison using the Chevrolet Cruze. The PV solar comparison with nuclear power resulted in much poorer financial and environmental GIVC results than the earlier natural gas comparison, while the comparison with coal was somewhat better, but still well above the $50 per CO2 ton target. These results would suggest that the prospects are very limited for either the Chevrolet Volt extended range electric vehicle or PV solar generated electricity to widely replace any major conventional competitor among each link of the GIVC unless there are dramatic improvements in relative efficiency and cost that would make them more attractive to private investors and customers.

5.1 Market and Public Policy Implications for the Plug-In Hybrid Cars

The comparison between the Chevrolet Silverado pickup and Volt extended range electric vehicle comes closest to providing a compelling case for green vehicle government subsidies and private investment. Even without the considering the value of government subsidies, the GIVC consumer link analysis shows that Volt buyers will experience lower ownership costs than Silverado buyers due to the large fuel savings provided by the Volt. Despite the favorable ownership costs, the sales figures in table 1 show the Silverado outselling the Volt by a 29 to 1 ratio despite the government subsidies for plug-in hybrid buyers. In fact, during 2013, full-size pickups from Ford, GM, and Dodge were the 1st, 2nd, and 5th best selling vehicles in the U.S. with over 1.8 million total units sold, which was almost 36 times the 48,951 total U.S. plug-in hybrid sales, of which the Volt captured a 47% share. This would suggest that buyers of the most popular type of vehicle in the U.S. market do not view relatively small cars such as the Volt as an adequate substitute. Furthermore, the current analysis shows that large trucks such as the Silverado provide far higher profits to auto manufacturers and dealers than plug-in hybrids such as the Volt, giving neither link incentive to develop and promote such vehicles. This is particularly true for General Motors, whose previous generation Silverado (and other GM models sharing the same platform) was offered in a hybrid version that was unsuccessful in the marketplace and highly unprofitable, and as a consequence is not offered in the latest generation Silverado introduced in 2013 (Ewing, 2012; Olson, 2013). These marketplace results suggest that current government subsidies are insufficient to overcome U.S. consumer preferences for larger vehicles, even in cases where the current analysis suggests they are adequate for overcoming the overall GIVC financial deficits in the large vehicle (Silverado) vs. plug-in hybrid (Volt) comparison. The Silverado vs. Volt scenario is also the only comparison that provides a reasonable cost for each CO2 equivalent ton reduction, but this occurs only when considering the entire vehicle life. Yet the first owner receives the bulk of current U.S. subsidies, where the cost per CO2 ton values are approximately 3 to 10 times higher than the value of the environmental benefits. Since recent US vehicle sales mix results suggest current subsidy levels are not successful in convincing large vehicle owners to buy a plug-in hybrid such as the Volt instead, the relatively low sales volume of the Volt and other plug-in hybrids also means the more encouraging lifetime emission reduction benefits are likely to be rare.

On the other hand, current subsidies may be more influential in persuading Prius owners to buy a Volt, since the model is the most popular trade-in among Volt buyers. Yet the Volt-Prius comparison poses a very different policy challenge relative to the Silverado comparison, because the Volt's only GIVC advantage vs. the Prius comes from its slightly higher dealer profit, which is overwhelmed by its financial deficits in the manufacturer and consumer links, providing little incentive for either link to widely adopt the plug-in hybrid vehicle technology. The consumer link deficits are caused primarily by the Volt's substantially higher retail price, and its relatively small operating cost advantages over the very fuel efficient Prius. This small fuel efficiency advantage also poses a problem with regards to the cost of emission reductions, since the Volt is only slightly cleaner at best, making cost per ton reduced a minimum of 53 times higher than the financial value of environmental benefits. Thus public and private investments receive a very poor environmental return when they prove most persuasive in convincing already green car users to buy only a slightly greener car. Such poor environmental returns will likely become more common due to the toughening fuel economy and emission standards for conventional vehicles that have been enacted in many major auto markets, because more efficient conventional vehicles will decrease the potential emission reduction advantages of electric and partial electric vehicles such as the Volt (Olson, 2013).

5.1 Market and Public Policy Implications for Renewable Energy

Approximately 90% of U.S. government renewable energy supports focus on the commercialization of existing technology, while only the small remainder funds R&D that might reduce the costs and/or improve the efficiency of solar power and other renewables to make them more competitive with conventional alternatives (Victor and Yanosek, 2011). The current GIVC results strongly suggest that these public and private efforts to encourage the replacement of nuclear and/or carbon-based power with current PV solar technology will not provide economically justified environmental returns. The GIVC comparison between PV solar and coal, the dirtiest and most plentiful source of electricity globally, finds costs that are more than twice as high as the value of the environmental benefits. The PV solar vs. nuclear power comparison finds that costs are almost 25 times higher than the environmental benefits provided in the best possible PV solar scenario, while the remaining two scenarios showed that nuclear power is both cleaner and less expensive than PV solar. The current results are also not supportive of energy related public policies that restrict the use of hydraulic fracturing (a.k.a. fracking) to recover additional supplies of natural gas, and/or the development of new nuclear power plants, which are both much cleaner than coal (BBC, 2013; Burger, 2013; Mcallister, 2013). These policies together with the current high costs, limited efficiency, and low reliability of many renewable energy sources have ironically resulted in greater private investment in relatively cheap, but dirty coal for electricity production in technologically advanced and wealthy markets such as Germany and Japan (Friederici, 2013).

6.0 Conclusion

As noted in tables 1 and 3, the respective market share of the Chevrolet Volt and PV solar is currently very low despite a wide variety of private investments and government subsidies and supports designed to encourage the widespread adoption of green vehicles and renewable energy. The current analysis of both green products supports the ‘wisdom’ of the marketplace in not widely adopting these technologies as neither provides a good financial or environmental return across the GIVC links compared to a variety of conventional competitors. The current comparisons also supports the importance of applying GIVC analysis to other green products that have achieved smaller than hoped market success to determine where the problem(s) are before committing major investments as a shareholder, manager, consumer, or government policy maker.

Government mandates may be one public policy alternative to the variety of green subsidies that are the primary focus of the current government link analyses. In fact both the Chevrolet Volt and PV solar industry exist largely due to mandates that have forced GIVC stakeholder links to adopt a specified quantity of renewable energy and zero-emission vehicles despite their general financial unattractiveness (Atiyeh, 2013; Bryce, 2012). Although green mandates are popular with policy makers because they are a less expensive substitute to taxpayer financed subsidies, they cannot by themselves erase a green technology’s unattractive tradeoffs, and they may have unintended negative effects. For example, renewable energy mandates can result in the loss of farmland and wildlife habitat due to the large footprints of PV solar power plants (and other renewable technologies such as wind), while the resulting unreliability and higher price of renewably generated electricity may decrease the potential operating cost advantages of electric vehicles such as the Volt (Bryce, 2012; Miller, 2013).

Rather than using subsidies and mandates to speed the commercialization of currently uncompetitive green technologies such as plug-in hybrids and PV solar, a more cost effective policy might focus government support on the R&D that could close the financial and technical gaps that these and other green technologies have with conventional competitors (Hargadon and Kenney, 2012; Lomborg, 2011; Victor and Yanosek, 2011). Both PV solar and the plug-in hybrid technology of the Volt would greatly benefit from the development of economical energy storage systems that might eliminate the expensive and emission emitting system redundancies both technologies currently require to provide reliable service. If the competitive gaps highlighted by GIVC analysis can be reduced or eliminated, the necessity of providing expensive subsidies for the widespread commercialization of green technologies will also be greatly reduced when the marketplace finds it easy to be green.

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Table 1

Chevrolet Volt versus Alternatives

section		Volt	Prius	Silverado	Cruze
1	2012 Global Sales	31,400	389,932	683,849	784,014
	2013 U.S. Sales Index	100	624	2,958	1,128
2	U.S. Retail Price	$34,145	$22,000	$44,690	$19,680
	U.S. Invoice Price	$32,745	$20,900	$41,338	$18,873
	Dealer Profit %	4.1%	5.0%	7.5%	4.1%
	EPA Mixed MPG	149.0	49.7	16.7	33.0
	Fuel Requirement	premium	regular	regular	regular
3	Fuel Price (2013 US. Avg)	$3.82	$3.50	$3.50	$3.50
4	Annual Insurance	$1,158	$1,409	$1,263	$1,124
	5 year Resale Value	$24,106	$14,058	$17,921	$12,261
	Vehicle Weight (lbs)	3,781	3,011	5,027	3,042
5	Development Cost per unit	$8,835	$711	$406	$354
	Manufacturing Cost per unit	$26,271	$18,365	$30,461	$15,750
	Profit Goal per unit	$1,672	$833	$2,400	$964
	Manufacturer Profit per unit	-$4,033	$991	$8,071	$1,805
6	Holding Cost per Unit	$224	$143	$282	$129
	Dealer Profit per unit	$1,176	$957	$3,070	$676
7	CO2 tons 1st owner 7,500 miles per year	29	30	56	29
	CO2 tons lifetime 7,500 miles per year	46	46	99	51
	CO2 tons 1st owner 15,000 miles per year	32	38	77	40
	CO2 tons lifetime 15,000 miles per year	51	53	118	61

Section Notes: (1): global and U.S. sales data from the Gasnier (2013) – Silverado data includes identical GMC Sierra sales. (2): Price, profit margin, fuel economy and fuel type data from Yahoo.auto.com (2013), EPA mixed fuel economy based on 55% city and 45% highway driving. (3) fuel price data from EIA: http://www.eia.gov/petroleum/gasdiesel/. (4) insurance, resale, weight data from Yahoo.auto.com. (5) development cost, manufacturing cost, profit goal, unit profit from Olson (2013) with updates from Bennett (2013). (6) holding cost and dealer profits from Olson (2013). (7) CO2 emissions from Olson (2013) and based on EPA estimates (Paster 2007).

Table 2

Chevrolet Volt GIVC Results

section		Volt vs. Prius	Volt vs. Silverado	Volt vs. Cruze	Volt vs. Cruze 2010
1	Relative Mfg. Profit per unit	-$5,024	-$12,104	-$5,838	-$10,177
2	Relative Dealer Profit per unit	$219	-$1,894	$500	$739
3	Relative 1st Owner Profit 7,500 miles per year	-$12,706	$721	-$16,290	-$16,266
3	Relative 1st Owner Profit 15,000 miles per year	-$11,233	$6,763	-$15,874	-$15,829
4	Overall Results 7,500 miles per year	-$17,511	-$13,277	-$21,628	-$25,472
	Overall Results w./govt. aid 7,500 miles per year	-$8,417	-$2,712	-$12,534	-$15,972
	Overall Results 15,000 miles per year	-$16,038	-$7,235	-$21,212	-$25,035
	Overall Results w./govt. aid 15,000 miles per year	-$6,944	$3,330	-$12,118	-$15,535
5	CO2 tons 1st owner 7,500 miles per year	-1	-27	0	0
	CO2 tons lifetime 7,500 miles per year	0	-53	-5	-5
	CO2 tons 1st owner 15,000 miles per year	-6	-45	-8	-8
	CO2 tons lifetime 15,000 miles per year	-2	-67	-10	-10
6	Cost per CO2 ton 1st owner 7,500 miles per year	$17,511	$492	infinity	infinity
	Cost per CO2 ton lifetime 7,500 miles per year	infinity	-$11	$4,877	$5,692
	Cost per CO2 ton 1st owner 15,000 miles per year	$2,673	$161	$2,652	$3,129
	Cost per CO2 ton lifetime 15,000 miles per year	$7,967	-$138	$2,397	$2,811

Notes: Negative column values indicate Volt deficit vs. alternative. (Section 1): manufacturer profit = (Volt – alternative) from section 5 in table 1. (Section 2) distributor profit = (Volt – alternative) from section 6 in table 1. (Section 3) owner profit = (Volt – alternative) and based on discounted cost of car purchase, fuel use, insurance costs, and resale value at end of 5 years at either 7,500 or 15,000 miles per year and assuming achievement of EPA fuel economy and based on Olson (2013). (Section 4) overall results are sum of sections 1 to 3, overall results after govt. supports include GM and electric vehicle federal government subsidies from Gantert (2011). (Section 5) emission results = (Volt – alternative) from section 7 in table 1. (Section 6) Cost per CO2 equivalent ton reduction = ((1/section 5 value)*section 4 value without govt. supports).

Table 3

PV Solar versus Alternatives

section		PV Solar	Nuclear	Coal	Natural Gas
1	2010 Global Share of Electricity Production	0.81%	13%	40%	22%
	2011 U.S. Share of Electricty Production	1.00%	19%	42%	25%
	2040 U.S. Share of Electricty Production	1.80%	17%	35%	30%
2	Manufacturer Profit Margins	0.0%	15.0%	15.0%	15.0%
3	U.S. Retail Price per MWh	$98.61	$98.61	$98.61	$98.61
	Cost of power generation per MWh	$152.70	$50.00	$50.00	$63.10
	Cost of backup power per MWh	$4.00			
4	Distributor profit per MWh	-$58.09	$48.61	$48.61	$35.51
5	Green program fee per MWh	$17.50	$0.00	$0.00	$0.00
6	Govt. support value per MWh	$24.34	$1.59	$0.44	$0.25
7	CO2 equivalent emission tons per MWh best case	0.030	0.100	0.770	0.390
	CO2 equivalent emission tons per MWh mid-point case	0.125	0.115	0.944	0.415
	CO2 equivalent emission tons per MWh worst case	0.220	0.130	1.117	0.440

Section Notes: (1): source data is from the EIA (2010,2012). (2): manufacturer profit margin from Olson (2014). (3) retail price and cost of power generation from EIA 2012, backup power cost estimate from St. John (2012). (4) distributor profit based on formula: U.S. retail price - (cost of power generation + cost of backup power). (5) source for green power subscription fee based on Environmental Leader (2010). (6) govt. subsidy source: EIA (2012). (7) sources for CO2 emissions are LCA studies by Lenzen (2008) and Sovacool (2008).

Table 4

PV Solar GIVC Results

section		PV vs Nuclear	PV vs Coal	PV vs N. Gas
1	Relative Manufacturer Profit per MWh	-$0.47	-$0.47	-$0.47
2	Relative Distributor Profit per MWh	-$106.70	-$106.70	-$93.60
3	Relative Customer Profit per MWh	-$17.50	-$17.50	-$17.50
4	Overall Results per MWh	-$124.67	-$124.67	-$111.57
	Overall Results per MWh after Govt. Supports	-$101.92	-$100.77	-$87.48
5	Relative CO2 Equivalent tons per MWh best to worst	0.100	1.087	0.410
	Relative CO2 Equivalent tons per MWh mid-point to mid-point	-0.010	0.819	0.290
	Relative CO2 Equivalent tons per MWh worst to best	-0.120	0.550	0.170
6	Cost per CO2 Equivalent ton per MWh best to worst	$1,246.70	$114.69	$272.12
	Cost per CO2 Equivalent ton per MWh mid-point to mid-point	-$12,467.00	$152.32	$384.72
	Cost per CO2 Equivalent ton per MWh worst to best	-$1,038.92	$226.67	$656.29

Notes: Unless otherwise indicated the source data is from the EIA (2010,2012). Negative column values indicate PV solar deficit vs. alternative. Column values based on (PV solar column figure – alternative from table 3. (Section 1): manufacturer profit uses EIA based assumptions from Olson (2014) with 30 year plant life and 24% utilization rate and profit margins from table 3. (Section 2) figures from table 3 used in formula: U.S. retail price - (cost of power generation + cost of backup power). (Section 3) cost of green power subscription fee from table 3. (Section 4) overall results are sum of sections 1 to 3, overall results after govt. supports include government supports from table 3. (Section 5) best solar vs. worst alternative from table 3, mid-point solar vs. mid-point alternative from table 3, worst solar vs. best alternative from table 3. (Section 6) Cost per CO2 equivalent ton reduction = ((1/section 5 value)*section 4 value without govt. supports).