# A System Dynamics Approach on Green Car Diffusion Strategy and the Korean Case[1]

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## Abstract

The research is to identify important diffusion factors and their effects on green car diffusion process using system dynamics perspectives and a causal-loop analysis. First, we briefly investigate Korean government's effort to promote green car diffusion and the increase of green car in the country. And then, through a deep review on previous research, we have found the important factors of green car diffusion process. Price, driving range, network effect, recharge system, fuel cost had important facilitation on consumer attraction and green car diffusion. Based on the review, we have constructed a causal loop diagram explaining hybrid car diffusion process. We have found 3 important reinforcing loops in the causal loop diagram. Loop for learning & economies of scale(supply side), loop for network effect(consumer side), and loop for battery development(technology side) had most significant roles in the whole diffusion process. Through a deliberate analysis on the 3 causal loops, we have found meaningful results. First, there seems to exist a critical mass in the diffusion. Second, of the 3 loops, the battery technology had most significant role. Third, sales, not consumer installed base, must be a standard to decide whether the critical mass is achieved or not. Based on these findings, several meaningful implications are suggested for the government and corporations related to the green car industries.

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# I. Introduction

Environmentally friendly vehicles, Green vehicles, are now more widely used in the world. Many of automakers and governments are greatly concerned with development and diffusion of green vehicles. However, the diffusion and the market demand for green vehicles did not make notable progress and did not meet the expectations we had a decade ago. This research investigates the Korean government's policy and its support to promote green car diffusion. Also, a causal diagram of green car diffusion (especially for hybrid vehicle) is presented on the basis of in-depth review on recent researches in relevant areas.

The global competition among countries with advanced automotive technologies to develop environmentally friendly vehicle and dominate market share is getting fiercer. Boosted by the government subsidies, countless number of companies that are related to automotive manufacturing is banking on the development of environmentally friendly vehicles, and creates green vehicle market, and stabilizes diffusion of green vehicles. However, global demand for green vehicles is lower than the expectations. Furthermore, slow technological progress and high cost of batteries undermine automakers to generate profit as well as sales.

In the long-term, however, ever increasing petroleum price and tougher global environmental regulation will take the current automobile industry and relevant markets to the next level of green vehicle industry by replacing conventional internal combustion engine(ICE) to new green car including hybrid vehicles, electric vehicles and hydrogen fuel-cell vehicles. As the green vehicle industry has challenges and opportunities, governments and automakers and their suppliers need to make right choices in major policies. Even though full-fledged analysis was not completed, the attempts were made in Korea to conduct in-depth analysis with system dynamics in relevant fields including anticipation of demand for green vehicles and future energy and analysis of electricity market(Sang-man Kwan et al., 2002; Byung-ong Whang et al., 2010; Daechul Jang and Kyungbae Park, 2011). This paper will discuss polices of Korean government in development and diffusion of environmentally friendly vehicles. Also, this paper will look into previous researches of green vehicles and establish system dynamics causal loop diagram that could be widely used in the study of green vehicle diffusion on the basis of such researches. The established causal loop diagram will lay a

foundation for more accurate quantitative analysis in green vehicles diffusion and relevant policy establishment.

## II. Diffusion of Korean Green vehicles

### 1) Government subsidy and relevant budget

The Korean government has spent its budget to support the spread of various types of green cars. The support for green cars includes CNG bus, HEV, clean diesel and electric car. <Table 1> shows the Korean government's annual budget to support green cars.

Korean green vehicles are categorized into natural gas vehicles, hybrid vehicles, low emission diesel and electric vehicles. The Korean government started to execute full-fledged budget for environmentally friendly vehicles since 2004, and different amount of budget was estimated for each type of green vehicles, and different number and types of vehicles were sold in each year in accordance with allocated budget. <Table 1> shows specific numbers.

### 2) Increase in number of green vehicles sold and relevant government support

The overall government budget for direct subsidies for environmentally friendly vehicles has been phased out; however, the number of eco-friendly vehicles being sold is increasing. Even though the government reduced direct purchase subsidies for green vehicles, other incentives including tax breaks such as acquisition tax for environmentally friendly vehicles were provided since July 2009, and such tax credits boosted sales of hybrid vehicles. The sales of hybrid vehicles has remarkably increased among other green vehicles, and the number of hybrid vehicles sold represents consumers' interest and high marketability of hybrid vehicles. Another noticeable thing is subsidies for natural gas vehicles (buses) and increased number of sold vehicles. Unlike other countries, natural gas buses were successfully implemented in Korea owing to the government subsidies and establishment of infrastructures. It is also noticeable that the government subsidy for electric vehicles was started from 2011, and it attracts great attention on its market potential in the near future.

**<Table 1> Government subsidies for green vehicles and the number of vehicles sold**

(Unit: million KRW/vehicle)

| Categories | | ~'04 | '05 | '06 | '07 | '08 | '09 | '10 | '11 |
|---|---|---|---|---|---|---|---|---|---|
| Total | Budget | 112,374 | 48,792 | 49,821 | 44,316 | 78,131 | 67,553 | 41,733 | 49,515 |
| | Vehicle | 6,212 | 2,887 | 3,768 | 4,437 | 6,612 | 13,346 | 9,461 | 19,449 |
| Hybrid Vehicle | Budget | 1,374 | 8,736 | 10,276 | 8,298 | 14,525 | - | - | - |
| | Vehicle | 50 | 312 | 368 | 656 | 1,072 | 6,312 | 6,186 | 16,118 |
| Low Emission Diesel | Budget | - | 56 | 245 | 2,918 | 3,906 | 7,511 | - | - |
| | Vehicle | - | 8 | 35 | 489 | 1,419 | 2,921 | - | - |
| Natural Gas Vehicles | Budget | 111,000 | 40,000 | 39,300 | 33,100 | 59,700 | 60,042 | 41,733 | 40,356 |
| | Vehicle | 6,162 | 2,567 | 3,365 | 3,292 | 4,121 | 4,113 | 3,275 | 2,831 |
| Electric Vehicles | Budget | - | - | - | - | - | - | - | 9,159 |
| | Vehicle | - | - | - | - | - | - | - | 500 |

| Type of Green Vehicles | Hybrid Vehicle | Compact Low Emission Vehicles | Natural Gas Vehicles | Electric Vehicles | Total |
|---|---|---|---|---|---|
| Accumulated sales volume (~2011) | 31,074 | 4,872 | 29,726 | 500 | 66,172 |

* 2012 Parliamentary Inspection on the Ministry of Environment (Ministry of Environment, 2012)

## III. Major Factors to the Diffusion of Green Vehicles

### 1) Vehicle Price

Choy & Prizzia (2010) studied factors that are necessary to persuade consumers to adopt alternative fuel vehicles in Hawaii. As government's environment friendly policies impose penalties on pollutions and provide subsidies and tax breaks for purchasing hybrid vehicles, these government policies are directly linked to purchase intention of hybrid vehicles. Similarly to Choy & Prizzia, Stave (2002) studied promotion of public participation in an environment-related decision making process using system dynamics. According to his study,

few factors including price optimization were considered in transportation sector, and the price optimization is accompanied by additional policy cost. Carlsson & Stenman (2003) studied how the government subsidy affects introduction and promotion of electric vehicles. Unlike the findings of the two studies mentioned above, the government subsidy did not affect introduction and promotion of electric vehicles. Instead, fuel price and individual preference were more related to the sales of electric vehicles. In short, ultimate and sustainable social assistance rather than temporary subsidies need to be established in order to increase market penetration of green vehicles.

### 2) Driving Range using Battery or Eco-Friendly Fuel

Driving range of green vehicles that uses eco-friendly fuel including electricity (batteries) depends on technological development. Through the computer simulations Montazeri-GH & Asadi (2011) suggested methodological model that improves fuel efficiency and reduces pollutions without compromising performance of hybrid vehicles. Kadirov & Varey (2010) believed that automakers should improve the overall efficiency of green vehicles in order to boost sales. Kadirov & Varey suggested that environmental issues, increase in the price of natural resources, and regional conflicts have great influence on the improvement of green vehicles. Enhancing fuel efficiency would improve driving range, and that would save energy and resources and address environmental issues. Furthermore, driving ranges that were fueld by batteries and other eco-friendly fuels would have large influence on consumer's convenience.

### 3) Network Effect

Network effect is an external effect that occurs when a certain behavior of economic actor has positive or negative effect to the third party without going through the process of price determination including supply-demand process. Oliver & Lee (2010) studied purchase intention of hybrid vehicles in U.S. and Korea. Oliver & Lee pointed out that communication is a factor that should be considered to improve consumer's perception in social value of hybrid vehicles and create positive image of owing hybrid vehicles, and to revitalize hybrid market in U.S. and Korea. Collecting information about consumer's perception in green

vehicle is essential activity that is required at this point. Harich (2010) studied resistance (acceptance) to sustainability regarding environmental issues. Harich suggested that appropriate actions to address environmental issue along with technological progress (technological solution) make positive changes and that eventually create virtuous cycle for sustainability. Therefore, once positive network effect is established, it would facilitates sales boost and market penetration of green vehicles, and word-of-mouth marketing is widely used to achieve such positive network effect.

**4) Recharging System**

Recharging system is a fuel supply system of environmentally friendly vehicles including electric vehicles; the charging system of electric vehicles is closely related to social infrastructures. Noh & Kim (2008) suggested that PHEV (Plug-in Hybrid Vehicle) needs to promote its economic benefits of recharging system. When gas price increases, PHEVs that has longer electric driving range are preferred, and PHEVs with a large battery capacity that have many advantages including driving range could be considered as positive factor for PHEVs price. Noh & Kim (2008) added that electricity price fluctuation, however, would cause differences in economic benefits among PHEVs segments. Fiorello et al. (2010) noted that GDP has much influence on investment in infrastructures which also affects establishment of charging station network. The network of recharging station, similar to fuel price, affects purchase of green vehicles.

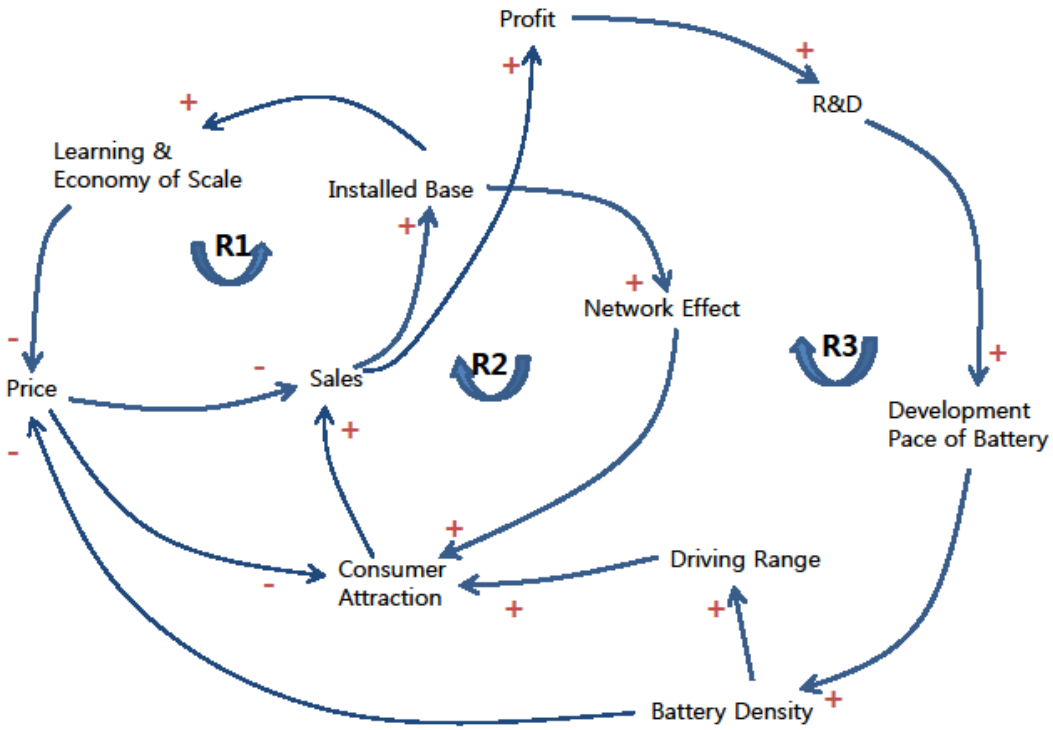
**5) Fuel Price**

Fuel price has a direct influence on automakers as well as consumer's choice. Kadirov & Varey (2010) studied automakers' goals and customer's perspectives. GE's goals include guarantee of safety, high quality, and fuel-efficiency and reduce international energy consumption and pollutant generation, whereas Toyota has goals of reduce, recycle and reuse. The automakers' goals represent the future outlook of the automobile industry. Mazraati & Shelbi (2011) proved the influence of fuel price with quantitative figures. The study demonstrated that the amount of fuel saved by Alternative Fuel Vehicle (AFV) gradually increased as the sales of AFV increased.

## IV. Causal Loop Diagram for Green Car Diffusion

<Figure 1> shows causal loop diagram that generally includes key factors in sales and spread of environment friendly cars (especially for hybrid vehicles). Here, we ignore recharge system and fuel price for simplicity of the analysis.

**<Figur 1> causal loop diagram that explains how hybrid cars are spread**




### 1) Determination of consumer attraction

According to the causal loop diagram above, it simply shows that sales are determined by consumer attraction, and consumer attraction is determined by the price of environmentally-

friendly (hybrid) cars, network effect, and driving range. This is due to the fact that when factors are excessively included, an analysis of causal loop diagram may become unnecessarily complicated and thus interfere with finding a key feedback loop.

**2) Loop1: Production sector → learning effect and economies of scale**

When the sales of green vehicles increase, a certain part of the profit is invested to increase installed base and because of the increased installed base, not only auto manufacturers but also part companies and businesses in the related industry enter into producing parts and an industry related to eco-friendly business based on the increased market attraction. This creates economies of scale attributable to competition or learning effect and in turn lowers the price of eco-friendly cars, which will be transferred to consumer contact point and lowers the cost to increase consumer attraction. In conclusion, Loop1 is a reinforcing loop that appears between car manufactuing and consumer sector via effects of learning and economies of scale. Once the sales of hybrid cars are on the right track through this process, it is shown that the spread may increase rapidly due to effects of economies of scale. On the other hand, if the sales are not on the right track, inefficiency of production sector and cost increase would lower consumer attraction and thus the sales of hybrid cars may decline before they go up sufficiently.

**3) Loop2: Consumer sector → network effect**

In the event the sales of green cars increase, infrastructure for sales, maintenance, and complementary facility of cars increases due to expanded investment in installed base. This creates word-of-mouth buzz between consumers and it may either improve or lower potential consumer attraction by changing consumer recognition. In case negative events or problems or negative word of mouth due to negative purchase experience occur, this may impact Loop2 negatively in general. Eventually, this may offset virtuous cycle created in Loop1 (learning, economies of scale and production sector). As a result, Loop2 shows causal relationship of social network effect among consumers.

**4) Loop3: technological advancement → battery density and battery driving range**

Present battery performance is determined by research and development, which is affected by previous sales and their profit, and the speed of technological advancement due to R&D. The battery performance is generally calculated by life, safety grade and cost. Consumer's perceived battery density is calculated by life, safety grade and battery driving range. This study chose battery density as the key variable representing battery performance (assuming battery life and safety grade are consistent). As for consumers, it is more proper to say consumer's purchasing will is affected by increased driving range due to increased battery performance and consequential increased mileage and lowered total car price due to battery price drop rather than actual battery performance. Increased consumer attraction will once again increase sales and businesses will gain more profit. Thus, more investment in technological development in batteries is feasible. Consequently, Loop3 shows causal relationship between solving technical problems and consumer attraction.

## V. Analysis of Causal Loop Diagram and Policy Implications

### 1) Three major reinforcing loops and their features

Each of Loop1 (learning effect and economies of scale), Loop2 (network effect), and Loop3 (technological investment and advancement) shows reinforcing effect due to actions and causal relationship taking place in manufacturing sector, consumer sector, and technological sector. The fact that the three loops are reinforcing loops makes it possible to predict that a certain level of critical mass or tipping point may exist in the spread of green cars, hybrid cars in particular. In around reaching critical mass, the system's behavior changes dramatically. When critical mass is reached, the system spreads rapidly with its own driving force; however, the system gradually declines and disappears when it fails to reach critical mass.

### 2) Existence of critical mass and its policy implications

In Korea, natural gas buses successfully spread and completely replaced diesel buses thanks to the government's active policy support and infrastructure-building. On the other hand, in

Canada, it seemed that the diffusion was taking place successfully in its early stage due to government's support and subsidies, however, after the support ended, the spreading force began to fade and vanished from the market. In particular, the biggest problem auto companies are facing is that it is hard to find critical mass beforehand. According to Dong-Hwan Kim (2004), the situation may differ case by case, however, generally, experts predict the level is about 20% of the total population. Therefore, it is important for auto companies to take note of the fact that whether the spread of hybrid cars reached 20% of the total market and if the level has been reached, radical spread may take place. Therefore, car manufacturers should continue with technological investment and development of new line-ups in preparation of that.

3) **Essential role of technological development of batteries: the most important reinforcing loop and limiting factor**

Among the three reinforcing loops, the impact of the technological sector is expected to be the greatest. Unlike other two reinforcing loops, technological advancement of battery influences reinforcing loop effect due to increased driving range and reinforcing loop effect due to price fall. That explains why it is considered as the loop with the biggest impact in the causal loop diagram. In general, network effect in consumer sector is regarded as most important in the penetration process of hybrid cars, but technological development in battery sector is identified as the biggest factor underneath. Still, among many experts, battery is taken as the biggest bottleneck factor in development and performance improvement of electric vehicle.

4) **Importance of sales: the key variable in diffusion, which is included in all reinforcing loops**

Sales are the only variables that are included in all three reinforcing loops. Via formation of installed base, sales are both involved in economies of scale and network effect of consumer sector. In addition, by contributing to profit, they also contribute to technological advancement and development. Installed base, on the other hand, contribute to learning, economies of scale and network effect but not directly to battery technology sector by itself.

When combined with the critical mass effect expected in the diffusion of hybrid cars discussed above, this has clear implications. In other words, it is likely that what defines critical mass or self-sustaining power may not be installed base but sales.

## VI. Conclusion

According to analysis result, first, it is identified that critical mass may exist in the diffusion process of hybrid cars. Although there may be some differences among different situations, but generally, according to Kim(2004), once about 20% level of critical mass has been reached, diffusion and hybrid cars may take place dramatically to settle down successfully.

Second, battery technology is regarded as the most important loop and limiting factor. Technological advancement of batteries influences increase of driving range and price fall of hybrid cars at the same time and consequently it determines comparative advantage of hybrid cars in comparison to internal combustion engine vehicles. Relative attractiveness of hybrid cars, which has been improved by advancement of battery technology, triggers network effect in consumer sector to surpass critical mass. Since this will in turn lead to a successful diffusion, advancement of battery technology is considered to be a hidden fundamental factor for success of hybrid cars.

Third, reaching critical mass should be determined by sales not by installed base, which are accumulated sales. That is because sales, not installed base, create profit necessary for advancement of battery technology. With that in mind, sales stagnation of hybrid cars worldwide should be considered seriously. If this trend continues more than three to five years, even if installed base increases gradually, diffusion failure of hybrid cars may be possible.

The government and businesses related to automobile industry may be provided with some implications from such findings. Rather than providing subsidies directly to consumers, it may be more effective for the government and businesses to invest limited resources effectively in a concentrated manner in development of battery technology. As for providing

subsidies, taking Korea as example, in the process of hybrid car penetration, tax reduction was more effective than providing direct subsidies, which is also less burdensome for the government's budget. Furthermore, businesses should take note of the fact that critical mass exists in the penetration process of hybrid cars. Businesses should examine closely whether critical mass level has been reached, and since the growth may take place radically once critical mass is reached, businesses can avoid becoming a failure in this fast-changing market environment only if they put constant effort into investing in related technology and development of new line-ups. Lastly, the recent stagnation in hybrid car sales shows possibility of complete diffusion so businesses should continue with parallel effort and flexible approach for other options such as more improvement in internal combustion and development of next generation green compact cars. In particular, this is especially important if the stagnation continues for more than three to five years. Therefore, motor makers may have multi-track plan or strategy in this regard (PHEV, pure electric vehicle, Fuel cell car, and so on).

In the future studies, based on causal loop diagram suggested in this study, more enhanced, quantitative analysis diagrams may be developed to perform analyses. It is expected that quantitative analysis diagram will enable researchers to draw more sophisticated analysis results and draw deeper policy and strategic implications. Furthermore, in order to avoid complication of analysis, this diagram, which concentrated on hybrid cars, did not consider recharge system and fuel cost, the two other important factors that can contribute to diffusion of green cars. It would be more desirable if future studies for pure electric vehicle and hydrogen fueled cell vehicle would develop research diagram that include these factors. Especially, study on the effects of fuel price changes would be a quite interesting topic and expected to be conducted independently in the future.

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