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Modeling Robustness of Business Ecosystem of End of Life Vehicles Players

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Abstract. End of life vehicles (ELVs) recycling infrastructure is a business ecosystem of players that similar to a biological ecosystem, the sustainability of this structure depends on the interaction among players. For evaluation, the robustness of this ecosystem, not only economic sustainability of players but also the environmental and social impacts of their strategies should be considered. Moreover, this assessment should involve market forces, the impact of government policies and society needs as well as technology market. In this study, we introduced a framework for modelling robustness of the business ecosystem of automobile recycling players considering the response to dynamical effects, stability and learning outcomes. The descriptions of building blocks of the model are adapted for modelling the car passenger recycling infrastructure in US; however, the architecture of the model can be used in other regions or even in other industries.

Keyword: Business ecosystem, ELVs recycling infrastructure, Market forces, Government policy, Technology market, Robustness

1. Introduction

Currently, 95% of all the vehicles discarded in the U.S. enter the recovery infrastructure (Kumar& Sutherland, 2009). According to the EPA (US Environmental Protection Agency), 95% of all automobiles in US are plausible to be recycled. There are several players such as automakers, government, recycling enterprises and research centers involved in the automobile recycling chain. The players interdependency, the complex interaction among players, long-term outcome of decisions made by players on the recycling infrastructure, the impact of strategic changes of one entity on the other players and need to adaptation facing to external forces make this network of players as a business ecosystem. The robustness of this ecosystem to survive in response to environment changes requires a systematic approach to studying the behavior of players, planning future scenarios and monitoring the sustainability of players in coming alternatives. This paper proposes a framework for modeling the business ecosystem of automobile recycling in US. The main contributions of this study are listed below:

1. to introduce the recycling infrastructure of automobile as a business ecosystem with comparing the characteristics of the business ecosystem and the nature of recovery infrastructure
2. to propose a modeling approach in order to assess the robustness of this business ecosystem

This paper is structured as follows. Section two includes a brief literature review on automobile recycling in USA and related key studies. Section three introduces automobile recycling infrastructure as a business ecosystem of players. Section four describes the players and the interaction among them. Section five introduces essentials of the model. Finally, section six provides conclusive remarks and areas for further research.

2. Literature

In addition to different references used in this study, we focused on some key works which explained the different aspects of automobile recycling in USA. In the next parts, we described highlights in this literature and the existing gap in order to introduce the research question.

2.1. Automobile recycling in USA

After experiencing a period of crisis in the automobile industry in US, this industry will return to their high pre-crisis levels. Heymann (2012) believes that in the longer term, an even higher sales volume is plausible. The author mentions the growing population figures (another 50 million people by 2030) and the importance of cars for US consumers as the main drivers for this growth rate. Vehicles affect the environment over their entire life cycle. Some of these effects occur at the end of their lives such as hazardous substance emissions, and disposals (Kanari et al., 2003). Addressing the environmental issues for ELVs raises a number of serious challenges for the industry. In the USA, there is no explicit legislation regarding the management of ELVs. With respect to the broad landfill spaces with lower costs of waste disposal and lack of standard waste legislation for whole states, recycling industry has received much less interest (Konz, 2009). Automotive industry has an important role in the recycling industries in US and auto manufacturers participate in the programs for improvement recycling management process. For example, Ford has purchased more than 25 vehicle recycling operations in the US, with more expected and has an experimental dismantling center in Germany (Staudinger and Keoleian, 2001). In the absence of the identical legislation in auto recycling, automotive OEMs follow different strategies in a variety range from changes in design to issue a guideline or standards. Each of these strategies has also different impacts on the other players and even can change the economic sustainability (Kumar & Sutherland, 2008) of ELVs business. In USA, the infrastructure related to the recovery and recycling of ELVs is more or less profit driven. The players in this business such as dismantlers or shredders should be gainful to stay in this business (Kumar & Sutherland, 2008). All above mentioned reasons make the infrastructure of recycling ELVs in USA, an attractive area for assessing the business and economic issues, the games between players and the challenges facing the key decision makers.

2.2. Highlights in literature

The government policies regarding addressing different phases of ELVs recycling process especially those in improving recycling rate can affect new technologies, market share of automotive manufacturers, the profit of dismantlers and shredders and even the sustainability of the overall business. Hence, the first paper is a study by (Konz, 2009), which surveys the existing ELVs directives in US and European Union and propose a framework for the future direction of government policies considering the advantages and disadvantages of EU directives. The second study is a report of the Center for Sustainable Systems by (Staudinger & Keoleian, 2001) which provides an overview of current management of end-of-life vehicles (ELVs) in the United States. The subsequent three studies have been published as a report by Center for Technology, Policy & Industrial Development of Massachusetts Institute of Technology. The first work in this set, discusses the conflicts in meeting recycling objectives facing automakers relating to the other environmental aims such as increasingly stringent fuel economy, emissions, and safety standards. The next study by (Field et al., 1994) provides a systemic representation of the asset flows within the recycling infrastructure and uses it for analyzing potential policies directed toward increasing the recyclability of the automobile. The other study in this set addresses the economic challenges with respect to the material recycling of new design stream in US automotive market (Field et al., 1994). The next study is a master thesis in MIT university (Zamudio-Ramirez, 1994) which proposed a dynamic model for analyzing the interaction among parties in the recycling industry and evaluating the effect of policy changes in this context. The following research proposed a simulation model for material flows and economic exchanges within the US automotive material life cycle chain (Bandivadekar et al., 2004). Kumar & Sutherland (2008) with a survey in past research related to automotive recycling infrastructure; illuminate the limitations of existing works in order to ensure the sustainability of the recovery infrastructure. The last work by (Kumar & Sutherland, 2009) studies the profitability of the business entities in automotive recovery infrastructure in addition to assessing the technological strategy impact. Table 1 shows the highlights of these studies in details.

2.3. Limitations

Kumar & Sutherland (2008) highlighted the limitations related to works that have been done in the context of recovery infrastructure of ELVs. The first limitation is not considering the complex material flows and their economic impacts within the infrastructure. The authors emphasized that the composition of materials is an important factor in evaluating the profitability of different partners such as dismantlers and shredders. The second limitation is assuming the market factors as the exogenous variables in the developed models wherein some of these variables can be affected by changing the decision parameters. For example, when the US automotive industry is the main consumer of some special materials, any variations in using materials in design of future vehicles has an impact on the used materials price, therefor the price of such materials should be considered as endogens variable in related models. The other limitation is the effect of government policies on different players in recovery infrastructure of ELVs. The authors discussed that the sustainability of this infrastructure in the future can be influenced by the potential policies. And finally they mentioned that developing the variety of scenarios for examining the different impacts of key variables such as market share of new products, recycling technologies or government policies are needed.

Based on the above mentioned limitations, we developed a framework for modeling the business ecosystem of automobile recycling with considering some of the key issues which have not been considered in previous studies. Before explaining the framework in details, definition of the business ecosystem and its application in this research is essential. In the next part, we clarify the concept of the business ecosystem in automobile recycling.

No	Papers/Research Works/Reports	Scope	Highlights
1	The End-of-Life Vehicle (ELV) Directive:	✓ European Union End-of-Life Vehicle	➢ In USA no national regulation exists for the disposal of automotive waste

No	Papers/Research Works/Reports	Scope	Highlights
	The Road to Responsible Disposal :(Konz, 2009)	Directive (success and criticism) ✓ United states End-of-Life Vehicle Directive(current situation and future challenges)	➢ Individual States are free to adopt inconsistent regulations, or forego regulation altogether ➢ Although the EU ELV Directive has a number of inadequacies, it can be considered as an initial model for uniform, federally mandated ELV legislation
2	Management of End-of Life Vehicles (ELVs) in the US:(Staudinger & Keoleian, 2001)	✓ Management of end-of-life vehicles (ELVs) in the United States including (Process, Environmental and Energy Burdens, Economic Assessment, Legislation/Policy, Key Players)	➢ 75% of the overall content of an original ELV reclaimed or Recycled ➢ Disposal of scrap tires, potential mercury releases during ELV processing, and disposal of ASR are three main challenges ➢ It is probable that the US would issue regulations restricting landfill disposal of ASR ➢ US manufacturers are setting internal guidelines based on the European targets for reducing the amount of ELV waste sent to landfill
3	The Recycling of Automobiles: Conflicting Environmental	✓ Assessing the economic and technological limitations of	➢ Limitation in technological feasibility of selecting materials for increasing recyclability rate

No	Papers/Research Works/Reports	Scope	Highlights
	Objectives In A Competitive Marketplace: (Field et al., 1994)	automobile recyclability ✓ Comparing the European, US and Japanese approaches for automobile recycling ✓ Automobile industry, its suppliers and consumers, and the government challenges with respect to automobile recycling	➢ Closed loop recycling is challengeable and costly ➢ Short of reorganizing and vertically integrating ➢ the entire process of recycling ➢ Actual willingness of all stakeholders for burden the associated costs ➢ Landfill use reduction and resource conservation conflict (the appropriate processes for reducing landfills may lead to an inefficient use of a scarce resource)
4	A Systems View of Recycling: (Field et al., 1994)	✓ Assessing the major actors in the recycling of the automobile ✓ Major interactions in the recycling infrastructure ✓ Impacts of Recycling Policy Options including (1) value of the old vehicle, (2) processing costs for existing or	➢ The value of the old vehicle is derived from the profitability of the rest of the infrastructure ➢ Reducing the processing costs of the existing processors require improvements in the technologies used in segmenting the automobile and segregating the available materials and parts ➢ for establishing new processors, it will be critical that the costs of the existing

No	Papers/Research Works/Reports	Scope	Highlights
		new recyclers, (3) value of recycled materials or parts, and (4) the cost of landfill	processes be reduced, or new processes be developed ➢ The maintenance of a strong market for recycled materials and parts will depend upon sustaining the value of these recovered resources ➢ the area of manipulating the cost of landfill can be considered as an area for implementing policy action
5	Recycling of US Automobile Materials: A Conundrum for Advanced Materials: (Field et al., 1994)	✓ 1970's automobile recycling problem, and its resolution ✓ The today automobile recycling problem in US from material point of view	➢ The importance of development in shredders technologies ➢ Pressures upon the automakers to reduce vehicle weight to achieve ever better fuel economy are likely to continue current material trends in the industry(materials with complex recycling process) ➢ Both suppliers and consumers, will be required to face and resolve ➢ The absence of the commitment, the automobile shredder's problems are going to get worse

No	Papers/Research Works/Reports	Scope	Highlights
6	Economics of automobile recycling: (Zamudio-Ramirez, 1996)	✓ An optimization model for assessing dismantling practices ✓ A dynamic model for studying the future situation of automobile recycling in US ✓ Analyzing the role of auto manufacturers	➢ Automobile manufacturers have good opportunities in order to apply certain strategies with participations of other partners in order to sustain the automobile recycling ➢ For applying some of these strategies such as DfD (Design for disassembly) self-maximizing profit goals are not good approaches.
7	A Model for Material Flows and Economic Exchanges Within the U.S. Automotive Life Cycle Chain : (Bandivadekar et al. 2004)	✓ Studying the effect of future changes in vehicle material composition on the automotive recycling infrastructure in US	➢ With significantly higher rates of dismantling and plastics recovery, the amount of ASR per vehicle will remain to increase ➢ The capital costs of the participants within the recycling infrastructure are not important when compared to material acquisition costs. ➢ The disposal costs are not a significant issue affecting the economics of shredding at present ➢ For increasing the economic sustainability of recycling infrastructure the dismantlers may have to

No	Papers/Research Works/Reports	Scope	Highlights
			attain much higher levels of dismantling than are currently employed
8	Sustainability of the automotive recycling infrastructure :review of current research and identification of future challenges:(Kumar & Sutherland, 2008)	✓ Studying the previous researches in relation to automotive recovery infrastructure ✓ Finding gaps in studies and future challenges	➢ Vehicle changes in design and government policy regulation raise challenges in automotive recovery infrastructure ➢ The models and studies are needed to address the interaction among stakeholders in the infrastructure ➢ Some issues such as energy consumption, using lightweight materials , applying new powertrain technologies should be considered in future studies in automotive recycling infrastructure
9	Development and assessment of strategies to ensure economic sustainability of the U.S. automotive recovery infrastructure:(Kumar & Sutherland, 2009)	✓ Studying the profitability of the business entities in automotive recovery infrastructure ✓ Assessing the technological strategy impact	➢ the economic benefits of achieving higher material recovery rates should be shared by all the stakeholders within the recovery infrastructure ➢ The future of the recovery infrastructure in terms of the amount of ASR is uncertain ➢ combination of technological

No	Papers/Research Works/Reports	Scope	Highlights
			innovation and government initiative or policy should be assessed for studying the dismantler's profit-enhancement tactics

Table 1: The highlights in literature review

3. Business ecosystem of the end of life vehicles players

Peltoniemi & Vuori (2004) believe that business ecosystem is a relatively new concept in the field of business research and by linking this concept to complexity; it is likely to provide new visions to changing business environments. In this part, first we review the value chain and its application in the business context and then explain the business ecosystem concept, its characteristics and justification for using this term for modeling the behaviors of the end of life vehicles players in this study. However, the concept of industrial ecosystem can be used in related to the recovery infrastructure of ELVs based on its features. Because the major objectives in industrial ecosystem analysis are to considering the principles of sustainable development into the industrial actions (Peltoniemi & Vuori, 2004) and efficient using of virgin materials and minimum use of them (Peltoniemi & Vuori, 2004) as well as reducing the waste (Korhonen et al., 2001) but with respect to this fact that automobile recycling in USA is profit driven, the concept of the business ecosystem is more appropriate for demonstrating the behaviors of agents in this environment.

3.1. Value chain

The concept of the value chain and its applications are not limited to a unique definition or a specific purpose. First time, this concept was described by Porter in 1985 in the context of competitive advantage (porter, 1996). Based on this description the value chain analysis is mainly used in strategic management and as a tool for strategic planning (Martin,1995).The applications of the value chain analysis are concerned with recognizing methods in which incomes or profits can be sustained over time (Dahlstrom, & Ekins,2005).

Focusing on the flow of revenue through the value chain, analysing the business scenarios, allowing the decision making at the extended enterprise and investigation of the strategic capacity issues made the value chain analysis as a practical tools for decision makers (Faße et al.,2009), (Buxton,2006). It facilitates identifying the parties involved in the problem, the interaction and relationship between parties and traces the money and information through the whole value chain as a result of different strategic planning scenarios. However, the concept of the value chain can cover the objectives of evaluating sustainability of ELVs recycling business, but in this problem, as we face with different players as an independent agent, the business ecosystem choice is more suitable. In the next part with defining the business ecosystem, we mention the reasons for this choice.

3.2. Business Ecosystem

With increasing the business complexity and interrelationship among enteritis, understanding how a decision made by an actor can impact on the other entities becomes a key challenge. And not taking into account of these interactions can lead to unanticipated and possibly undesirable outcomes (Heck & Vervest, (2007), (Peppard & Rylander, 2006), (Erhun & Keskinocak, 2003) cited by (Tian et al., 2008).

Tools which can help modeling the interactions in a network of entities and provide the analysing the impacts of each entity decision on the others in an organized way are crucial for improving business design (Tian et al., 2008). There are several approaches for defining a business ecosystem; in this section we review two of these approaches which are more related to the concept of ELVs recycling.

Based on a definition by (Moore,1998), Business ecosystem is an "extended system of mutually supportive organizations; communities of customers, suppliers, lead producers, and other stakeholders, financing, trade associations, standard bodies, labor unions, governmental and quasigovernmental institutions, and other interested parties. These communities come together in a partially intentional, highly self-organizing, and even somewhat accidental manner." This definition highlights the decentralised decision-making and self-organisation characteristics of business ecosystem (Peltoniemi & Vuori, 2004). Iansiti & Levien (2004) compare the business ecosystem with a biological ecosystem and point out that similar to a network of loosely interconnected participants in a biological ecosystem who depend each other for survival, the situation of each entity in a business network can impact the overall business ecosystem. Peltoniemi & Vuori (2004) according to (Iansiti & Levien 2004) have stated three success factors for a business ecosystem including productivity, robustness and the ability to create niches and opportunities for new entities. These three elements are appropriate for evaluating the infrastructure of ELVs recycling. Because like a business ecosystem this structure needs productivity in order to achieve the expected and desirable outcomes for players, sustainability or robustness to survive in response to environment changes and the ability for building more collaboration in a system of entities who seek values in ELVs recycling chain. Peltoniemi & Vuori (2004) have explained some special characteristics of the business ecosystem. We mentioned these features in Table 2 and for each one brought some justification to show that why the ELVs recycling can be considered as a business ecosystem.

	Characteristics	Definitions	In ELV case
1	Complexity	✓ Many relatively independent parts ✓ Highly interconnected and interactive ✓ Dynamics which arise from the interaction	➢ The independent players in infrastructure ➢ The interaction among dismantlers ➢ The interaction among automakers ➢ The interaction between government and the other players
2	Self-organizing	✓ There is no external or internal leader, who sets goals or controls the system ✓ The events occur spontaneously and due to local interactions ✓ Pattern and regularity emerge without the intervention of a central controller	➢ There is not any central agent in ELVs recovery infrastructure ➢ Players act individually, but affect each other
3	emergence	✓ The links between individual agent actions and the long-term systemic outcome are unpredictable	➢ The decision made by each players have some certain effects on material markets, car markets or second hand part markets ➢ As the effects can be evaluated by taking into account the interactional effects of players the outcomes of games are unpredictable
4	Co-evolution	✓ The evolutionary mutual changes of species (or organizations) that interact with each other ✓ Strategic changes of one company affect strongly to possibilities of other companies in its ecosystem	➢ Strategic decisions of auto makers can change the profitability of shredders and dismantlers

5	Adaptation	✓ The environment, the adaptive plan, and a measure of performance ✓ Adapts to the external constraints	➢ The government policies can change the design strategy of automakers, or the applied procedures of shredders or dismantlers ➢ The other players design certain strategies based on the regulations and directives of ELVs recovery and act the next action based on the performance measurement (fitness)

Table 2: The characteristics of the business ecosystem and ELV evidences

4. The business ecosystem configuration

4.1. Players and interactions

There are many different players in automobile recycling business ecosystem. However, some of these players are more influential and modeling the behaviors of these actors can illuminate the essential rules in this business network. Figure 1 shows the agents and their interactions in the business ecosystem of automobile recycling. The framework of the model should include the commercial rivals in different markets (material market, car market, used car market, sub-assembly parts market etc.), the behavior of main actors and the potential for monitoring the extracted values from interaction among players as well as considering technological innovations, government policies and social effects. A brief description of key agents and their role in the whole ecosystem has been explained in this part.

4.1.1. Material suppliers & The market of virgin materials

The automakers efforts in order to reduce vehicle weight and reduce emissions made fundamental changes in future direction of automotive industry (Kumar & Sutherland, 2008). The average new light-duty passenger vehicle sold in the U.S. weighs 1,730 (kg) in 2009. 80% of this weight is incorporated in its powertrain, chassis, and body (Cheah, 2010, p.33). The major materials found in an average automobile in the United States are shown in Figure 2. This figure shows the changes in material composition of Light Vehicle, Model Years1995, 2000, and 2009 according to (Davis et al, 2010). The automotive industry is the main consumer of materials such as lead and rubber and an important user of aluminium, zinc, and ferrous materials (Kumar & Sutherland, 2008). Therefore, it is obvious that the new trend in material consumption, in automotive industry, has impact on material markets and the supply of the main materials suppliers. Cheah (2010) provided the pros and cons of new trend in consumption of High-strength steel, Aluminum, magnesium, Glass-fiber reinforced polymer composite and Carbon-fiber reinforced polymer composite. The increasing costs of manufacturers can translate to increasing the price of cars and this issue can affect the used car and second hand part markets. Recycling of materials such as magnesium can lead to huge increase in the quantity of new scrap in scrap market as a short term effect and Additional magnesium-containing parts (old scrap) as a long term effect (Kamberovic, 2004). Hence the profitability of agents such as dismantlers and shredders can be affected by changing the amount of these materials. Glass-fiber reinforced polymer composite and Carbon-fiber reinforced polymer composite with difficulty in recycling can increase the costs of landfill disposal for shredders and non-ferrous processors.

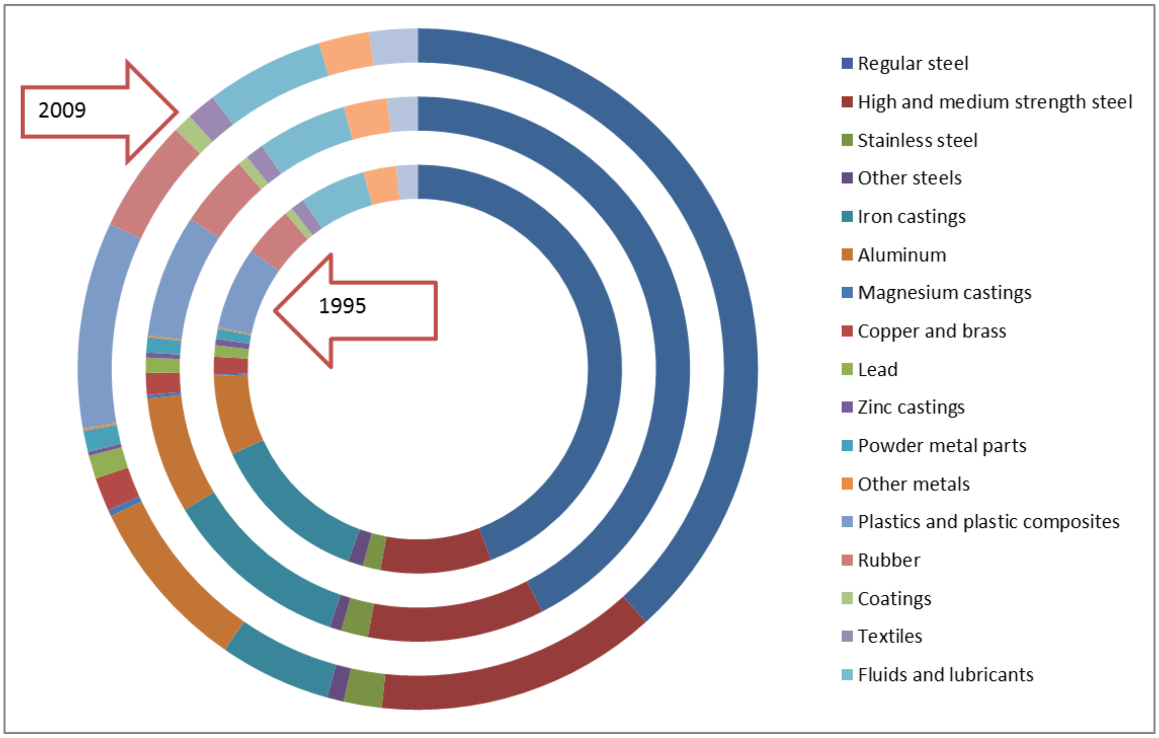
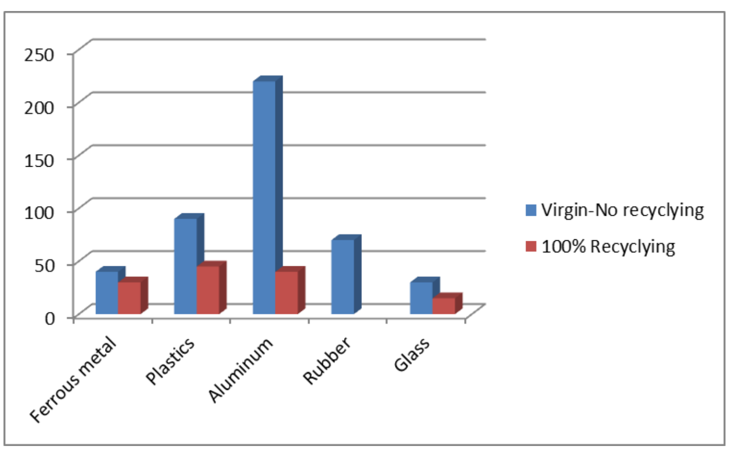


Figure 2: Material usage in Light Vehicles (1995-2000-2009) according to (Davis et al, 2010)



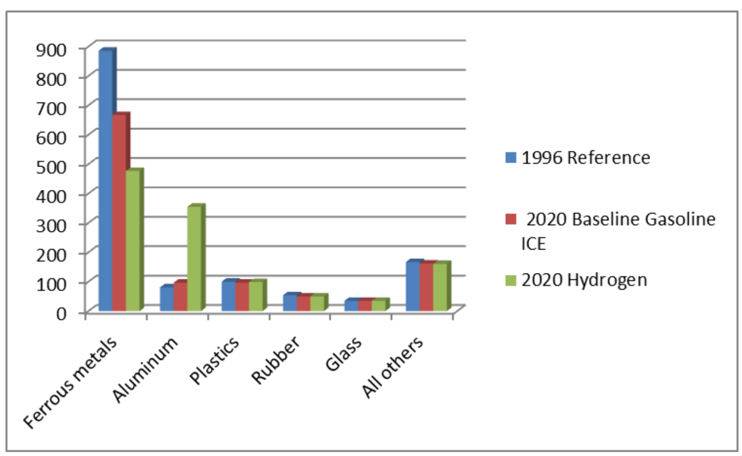


Figure 3: Energy Required to Produce Vehicle Materials, MJ per kg (a: Left) Selected Materials Usage in Three Vehicle Designs (b: Right) (Reference: Weiss et al., 2000)

4.1.2. Automakers & The market of vehicles

Gerrard & Kandlikar (2007) present an evaluation framework based on anticipated changes that could result from the ELV Directive. These changes relate to three areas: (a) vehicle design, (b) level of ELV recovery, and (c) information provision. The authors brought the evidences from different automakers in applying different strategies regarding ELVs recycling. Why the different automakers apply the variety of strategies and what are the advantages and disadvantages of different strategies are questions which should be addressed via an appropriate model in order to understand the behaviour of automakers. (Weiss et al., 2000) in their first report of studying the broad impacts of new fuel and vehicle technologies for road transportation, assessed the life cycle of new technologies and the impact on different stakeholders. They considered a family car similar to a Toyota Camry, as a "1996 reference", passenger car vehicle that is likely to evolve by 2020 without radical new technologies or major cost increases, but responsive to calls government or market for improved fuel economy and advanced 2020 technologies all include advanced technologies in the propulsion systems, and make extensive use of lightweight materials and reduction of other driving resistances, aerodynamic drag and rolling resistance. The authors believe that Successful development of new technologies requires acceptance by all major stakeholder groups including private-sector fuel and vehicle suppliers, government bodies at many levels, and ultimate customers for the products and services. Hence, the economic, environmental, and other characteristics of each technology must be assessed for their potential impacts on each of the stakeholder groups (Weiss et al., 2000). According to this study, Energy Required to Produce Vehicle Materials, MJ per kg and Selected Materials Usage in Three Vehicle Designs have been shown in Figure 3 (a,b). In addition, to change in material usage by automakers, and the weight reduction strategies, the design for disassembly is also an important factor. The energy consumed and the environmental impact should also be considered in analysis of the business ecosystem. As discussed above, the different types of vehicles proposed to market based on new technologies and their demand and price should be considered in modeling the business ecosystem.

4.1.3. Aging agent

The retirement rate of vehicles depends on several factors. These factors are included: Income per capita, vehicle fuel consumption, driving licenced, population, car average age, service price, fuel price, GDP, car import and export rate. Some of important factors have been shown in Figure 1. Zamudio-Ramirez (1994) also considered this agent in his system dynamic model.

4.1.4. Dismantlers, Shredders & Non-ferrous processors

Based on (Staudinger & Keoleian, 2001) there are two types of dismantlers; High-value parts dismantlers and Salvage/scrap yards. The first type dismantler removes high value parts for resale and sends what remains as hulk to a shredder. The second type dismantler stores ELV and removes the parts gradually. The number of dismantlers in North America is over 12,000. Following the dismantling process, the remaining of ELV is sent to a shredder. The materials separated into two main groups; ferrous metal and non-ferrous materials. At shredder facilities, hulks are inspected prior to shredding to ensure that potentially hazardous components such as batteries, gas tanks, and fluids have been removed. Hulks (and other collected materials) are then shredded into fist-sized pieces using large hammer mills. There are nearly 200 shredder facilities in US. The separated non-ferrous metal fraction (containing aluminum, brass, bronze, copper, lead, magnesium, nickel, stainless steel, and zinc) is typically sent to another, specialized facility to separate the stream into its individual metals by a variety of means. Aluminum and stainless steel are separated by both "light-media" and "heavy-media" plants. In performing these separations, a significant amount of contaminants (non-metals) are removed. This waste, referred to as "heavy ASR," is sent for landfill disposal (Staudinger & Keoleian, 2001, p.16-19).

The variables that affect the extracted value for dismantler include supply of subassembly parts, the supply of hulk and the environment impact of the process and energy consumed by dismantler during the process of dismantling. However, the existing recycling infrastructure of ELV in US is profit driver (Kumar & Sutherland, 2008) but considering the environmental impact and energy consumed by dismantlers with respect to the future directives are important. In order to evaluate the sustainability of this infrastructure, in addition to assess the economic sustainability, we need to consider the environmental impact and energy consumed by players. For shredders and non-ferrous processors, the supply of scrap, the ASR, as well as environmental impact and energy consumed are considered.

4.1.5. Landfill

Non-recoverable waste material is sent to landfills for disposal. According to (Staudinger & Keoleian, 2001, p.20), Auto Shredder Residue (ASR) consisting of remaining non-metallic materials – plastics, glass, rubber, foam, carpeting, textiles, etc. is usually sent to landfill. Except in California, ASR is considered a non-hazardous solid waste and thus, can (and is) disposed of in regular municipal or industrial solid waste landfills. The unit cost of landfill (disposal fee) in US depends on the regions and states in US. Every year in the United States about 3 million tons of ASR is landfilled (Jody et al. 1994).

4.1.6. Government & Society

The effect of government policies on recycling business ecosystem is essential. The government implications can be classified in four categories. The directives related to export and import and tax policy can affect the market of virgin materials as well as car markets. In addition it can influence on retirement rate of vehicles.

The future changes in ELV directives in US including the change in recovery rate, disposal policies and ELVs responsibilities and related charged fees have impacts on automakers, dismantlers, shredders and non-ferrous processors. Partnership for a New Generation of Vehicles (PNGV) for a reduction of 40% in vehicle weight within ten years (Kumar & Sutherland, 2008) and the Corporate Average Fuel Economy (CAFE) in order to improve the average fuel economy of cars and light trucks (trucks, vans and sport utility vehicles) sold in the US :(Kumar & Sutherland, 2008) are the other policies established by US government which can affect automakers strategy in design and subsequently the vehicle and material market. Government as a key player affecting the macro-economic factors such as GDP can also influence the business ecosystem of recycling players.

Society with environment friendly needs, as well as pressures by certain communities, can change the design behavior of automakers, the initiatives and policies of government and subsequently the other agents in the business ecosystem.

4.1.7. The market of subassembly parts & scrap

According to (Zamudio-Ramirez, 1996) affiliated dismantlers in North America use special information system for suggested price of parts number of parts in stock and other useful information with respect to used parts market in region. The author believes that the interaction of information, supply and demand forms the pricing dynamics of used parts. The change in material usage by automotive industry may change the demand of materials (virgin and scrap) and since the recycling system has a surplus supply in this condition, the price of relevant scrap can be reduced in market. (Zamudio-Ramirez, 1996) has highlighted this issue with an example of steel scrap price in the case of increasing the usage of plastic.

4.1.8. Technology & Labor market

Technology market is a significant agent in the business ecosystem of recycling. The new technologies in different stages of recycling can improve the sustainability of the recycling infrastructure. In automotive industry, the new technologies can change the trend of material usage, DfD level as well as environmental impact and energy consumed by automakers. For dismantler, the innovation in information system used by dismantler and automation can affect the profit level. Level of innovation in scrap recycling, separation and sorting techniques, and the amount of produced ASR can change the profit of shredders. For non-ferrous processor, the innovation in plastic and tire recycling and the amount of produced ASR can affect the profit level. Moreover, these levels of innovation can change the environmental impact and energy consumed by these players. The marginal cost of dismantler in comparison to market cost of labor is important. Because in some cases removing the parts and selling them in second hand part market considering the labor cost are not profitable and attractive for dismantler. The change in labor market can affect the economic sustainability of dismantlers. On the other side, the change in design for disassembly level can change the operation costs of dismantler and subsequently the demand for labor cost (Zamudio-Ramirez, 1996). Hence, the interaction among labor market, dismantlers and automakers DfD has impact on business ecosystem.

5. Modeling Robustness of business ecosystem

In this part, we present the introduced framework for modeling robustness of business ecosystem of ELV players. For this framework, we applied the concept of ecosystem robustness. According to (Wilmers, 2007) there are some properties which can be used to understand the resistance or vulnerability of ecosystems. The dynamical effects on persistence, the effects of clusters and networks of species on stability and biodiversity implications of species in response to climate changes and human activities can be considered to evaluate robustness of ecosystems. Hence we used three essential elements for modeling business ecosystem of ELV players including the response to dynamical effects, the stability of ecosystem, performance evaluation and learning effects. These elements will be discussed in details in the next sections.

5.1. Essentials of the model

As we need to assess the complex dynamic behavior of recycling infrastructure, it is needed to change unit of analysis from firm to group of firms in this business context. The model should reflect interactions among so many players and demonstrate strategic effects of changes in the structure of automobile recycling business ecosystem. Moreover, the model should have the capability to cover wide range of possible future scenarios and their effects on business ecosystem. Kumar & Sutherland (2008) also explained the importance of developing future scenarios include the variables such as market shares of new vehicles, recycling/recovery technologies, and government policies directed at improving recovery rates in studying the dynamics of automobile recycling infrastructure. Morecroft (2007) explained in his book the advantages of scenario planning. He believed that scenario planning provides the ability to make the organization a skill full observer of business environment. The author also emphasized that the models that fit the requirements of executives and scenario planners should have the ability to simulate different thinking about future business options. These models should also be understood by the scenario planners to be communicated effectively to corporate executives and business managers (Morecroft, 2007, p.263). Based on the above descriptions, the essentials of the model have been illustrated in Figure 4. This model has three main parts. The first part aims to address how business ecosystem response to dynamical changes. Hence we need to build a set of appropriate scenarios. Based on market variables, future policies of government, technological changes and the shift in strategies practiced by players, the future scenarios will be designed. The second part of the model is modeling the stability of key players. It means that we need a set of appropriate models for explaining and analysing the behavior of each agent. Modular design of this architecture makes this flexibility for extending the model in next versions. The game theory is an appropriate approach in order to model the stability of ecosystem. And finally based on the reaction of players in different scenarios the extracted value will be monitored. This monitoring approach can reflect the sustainability of business ecosystem in different possible scenarios and the positional shifts of players. In this part, the network outcomes for players and network implications including learning diffusion can be assessed. It should be noted that fuzzy rule base approach can be utilized for performance evaluation of key players.

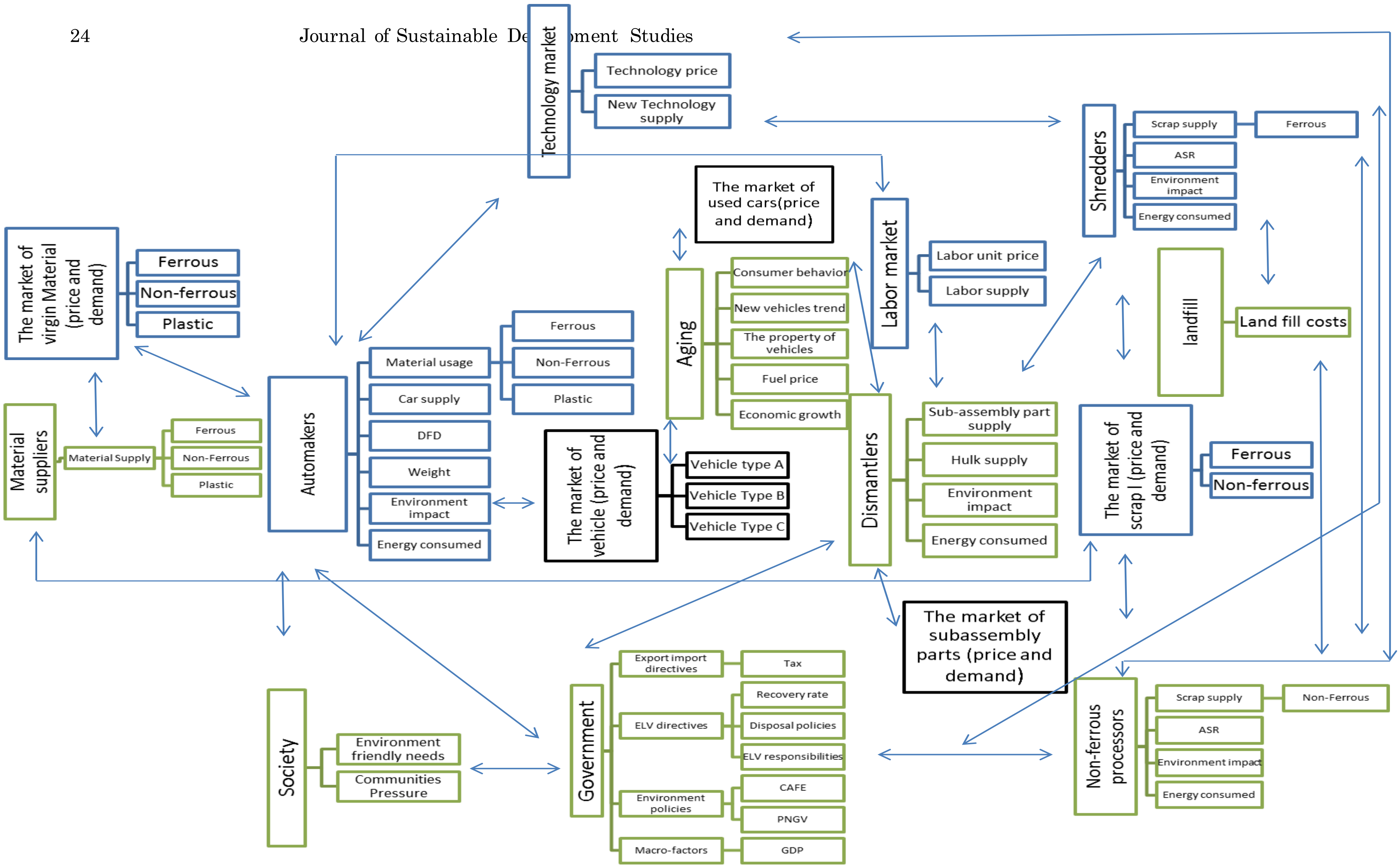


Figure 1: Key agents in automobile recycling infrastructure and interaction

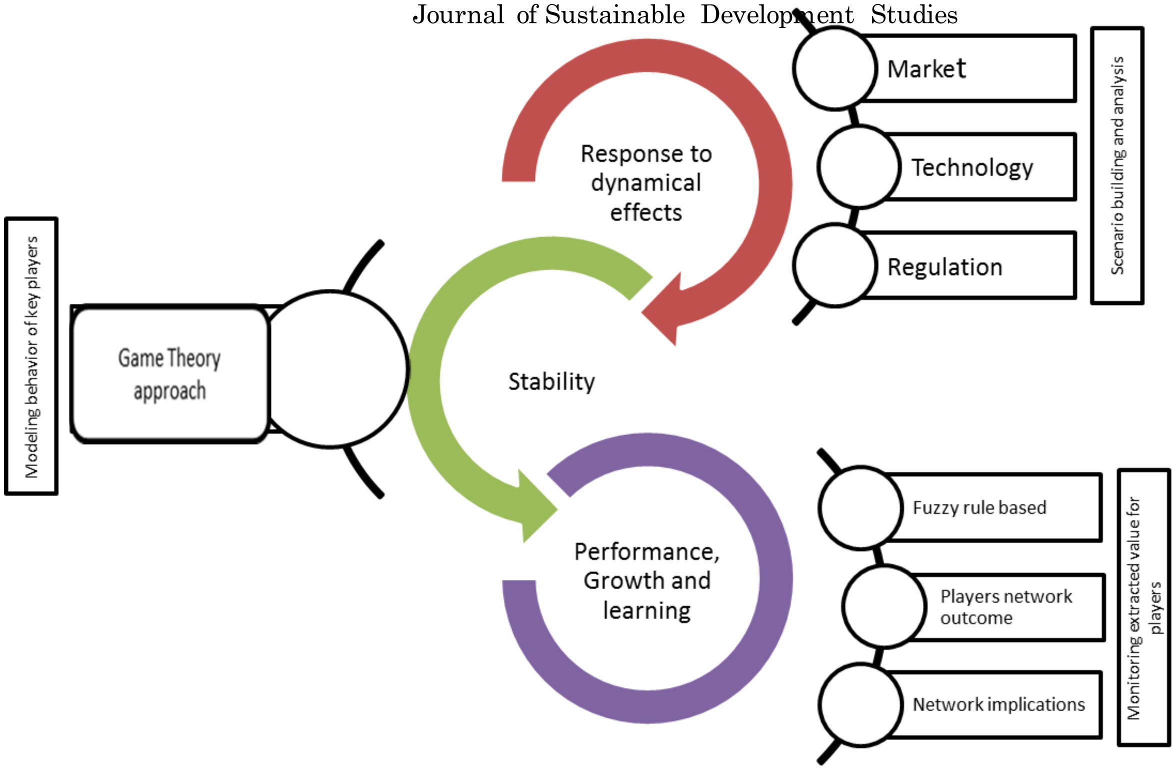


Figure 4: Essential of the modelling robustness of business ecosystem of ELV players

5.2. Response to dynamical effects

Accoding to section 4, technology changes, uncertainty in regulations and maerket variables are important parameters, which can affect the susttanability of ELV players. In order to assess the effect of these factors, we need a framework to build and analyze the scenarios.

5.2.1. Scenario building and analysis

First step to build the scenarios is identifying the appropriate attributes. According to conducted literature, the main attributes for building the future scenarios are shown in Table 3. All possible scenarios can be generated from a combination of factors' future trends. For better illustration of different attributes combination for generation the scenarios, an example has been shown in Table 4. In technology part, we considered recycling technology including plastic recycling and separation techniques as well as automobile technology including diesel, hybrid and electric cars. We also considered two types of material composition including aluminum intensive and composite intensive. Regarding the market variables, we considered three trends for market share of different types of automobile technologies. And finally for considering the regulation attributes, we selected recycling rate and banning hazardous substances. For simplifications, we used level 1, 2 or 3 to show different future trends. For example, level 1 for plastic recycling can be explained by small progress in plastic recycling technology. Level 2 can be defined as considerable progress in plastic recycling technology. Hence, scenario 1 demonstrates a scenario with small progress in plastic recycling, small progress in separation technique, an aluminum intensive car with Diesel technology and low market share and recycling rate and banning hazardous substance has been set at level 1.

Two clustering methods including (Fuzzy C-means clustering (FCM) method and SOM (self-organizing map) can be utilized for ranking the scenarios by calculating the degree of possibility, priority and pairwise compatibility for each final scenario. Pishvaee et al. (2008) also used fuzzy clustering-based method for scenario analysis of an Asian pharmaceutical company.

Scenario attributes	
Recycling technologies	Plastic recovery
	Separation technologies
Material composition	Ferrous Usage
	Non-Ferrous Usage
	Plastic Usage
	Other-Unrecyclable
New technologies	hybrid vehicles
	fuel cell technologies

	Biofuel
	Composite-Intensive Vehicles
	Aluminium-intensive
	Electric vehicles
Market share	Low
	Medium
	High
Geographic Regions	Regulations
	Transportation costs
	Land fill costs
Policies	Recycling rate
	Banning hazardous materials
	Information and manuals

Table 3: The attributes for building scenarios

	Recyclying Technology				Material composition		Automobile Technology			Market Share			Recyclying Rate			Banning Hazardous Material		
	Plastic Recyclying		Sepeartion		Aluminium Intensive	Composite Intensive	Diesel	Hybrid	Electric	Low	Medium	High	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Scenarios	Level 1	Level 2	Level 1	Level 2														
1																		
2																		
3																		
4																		
5																		

Table 4: An example of scenarios generated from attributes

5.3. Stability of ecosystem

In order to assess the stability of ecosystem, we need to study the behavior of players. Considering the interdependency of firms involved in the business ecosystem, the possibility of conflicting interest, the game theory approach would be the appropriate framework for modeling.

5.3.1. Game theory approach

Cooperative games and non-cooperative games are two approaches, which can be utilized in this context. A cooperative game is a game where groups of players may impose cooperative behaviour; hence the game is a competition between combinations of players, rather than between individual players (Driessen, 1988). This approach can be used in order to evaluate the value splitting among players in different network structure. A non-cooperative game is a game in which players make decisions individually. This approach can be used in order to focus on behavior of some players (for example, manufacturers and regulation bodies, or manufacturers and competitors) however, in order to present the network value, this approach has some limitations. In conventional game theory, there are three assumptions: (1) rational behavior of all the agents, (2) complete sharing of empirical information, (3) all the agents have common knowledge of these assumptions (Barari et al., 2012). As in the real world, considering these assumptions is difficult or even impossible, applying evolutionary game theory can bring the most advantages for modeling the behaviors of players. In Evolutionary game theory instead of directly calculating properties of a game, populations of players using different strategies are simulated and, a process similar to natural selection is used to determine how the population evolves. Varying degrees of complexity are required to represent populations in multi-agent games with differing strategy spaces. Zhu & Dou (2007) used evolutionary game theory in order to investigate the games between governments and core enterprises in greening supply chains. (Barari et al., 2012) applied evolutionary game for analyzing the game between the producer and the retailer to adjudicate their strategies to trigger green practices with the focus on maximizing economic profits.

Geçkil & Anderson (2009) also used game theory approach for analysing the game among government and automakers in for regulations regarding CAFÉ (corporate average fuel economy) standards in US. Table 5 illustrates different approaches in game theory, and potential application in the context of business ecosystem of ELV players.

Game theory approaches		*Studies in green context*	*Application in modeling business ecosystem of ELV players*
Non cooperative game (one stage or extensive form)	Nash equilibrium	CAFÉ Standards and Competing Automakers (Geçkil & Anderson, 2009)	The game between automakers and government regarding ELV regulations
	Evolutionary equilibrium	Green supply chain contracts(Zhang, & Liu, 2012)	The game between automakers in order to apply design for the end of life practices
		Governments and Core Enterprises in Greening Supply Chains (Zhu & Dou, 2007)	The game between dismantlers/shredders/non-ferrous processors for setting the price
		Coordination mechanism in three-level green supply chain under non-cooperative game (Barari et al., 2012)	
Cooperative game (one stage or extensive form)	Coalition game		Coalition game among automakers, research centers and recycling bodies
Economic game (one stage or	Oligopolistic game (Cournot,	Price Competition and Product	The game between automakers in order to

extensive form)	stackelberg and Bertrand game)	Differentiation When Consumers Care for the Environment Conrad, 2005)	apply design for the end of life practices The game between dismantlers/shredders/non-ferrous processors for setting the price
		Environmental quality competition and eco-labeling (Amacher et al.,2004)	
		The greening of the market (Kuhn,200)	

Table 5: The game theory approaches in green context and potential application in the context of business ecosystem of ELV players

5.4. Performance Evaluation, Learning and growth

Considering the availability of data, the uncertainty of the problem and existence of data based on common sense, experience and intuitions, fuzzy rule based approach also can be a useful tool for modeling. Moreover, learning, evolution and growth are the other properties of a business ecosystem which play key role in its robustness.

5.4.1. Fuzzy rule based approach

Yuan (2009) explains the advantages of fuzzy logic in comparison to simulation, stochastic and probabilistic methods. With considering the complexity or costly of applying mathematical and stochastic models for small or medium size firms, probabilistic models requirement and the problem of accommodating dynamic business conditions with the assumption of these models, the author addresses the need for a practical and simplified method which minimize these complexities. In the context of economic, environmental and social analysis of key players in automobile infrastructure, we have the same problems in applying the probabilistic and stochastic models. The size of players, the uncertainties in input variables and the lack of data availability are the reasons for utilizing fuzzy based approach in analyzing the key player's sustainability.

Certain sub models for calculation of sustainability of players can be developed. Each model has three parts for evaluation of economic, environmental and social sustainability of key players such as dismantlers, shredders, nonferrous processors and auto manufacturers. Figure 6 illustrates a preliminary application of Fuzzy rule based in order to assess the sustainability of dismantlers. For economic performance, we used three layers Mamdani's model. First layer is included fixed cost, volume, variable cost and revenue. For operation cost, we considered separation technology, information technology, type of car, labor skills and labor price. For transportation cost, we considered distance and unit price of hulk transportation. For revenue, we considered the revenue of parts and hulks. The environmental performance can be evaluated considering technology, type of car, labor skill and the distance for hulk transportation. For social performance, we considered employment rate, the health and risk for labor and health and risk for local residences. And finally the sustainability index can be obtained. This framework only used as an example, the detailed application, parameters, rules and numerical examples are performed by authors and will be published as further studies .

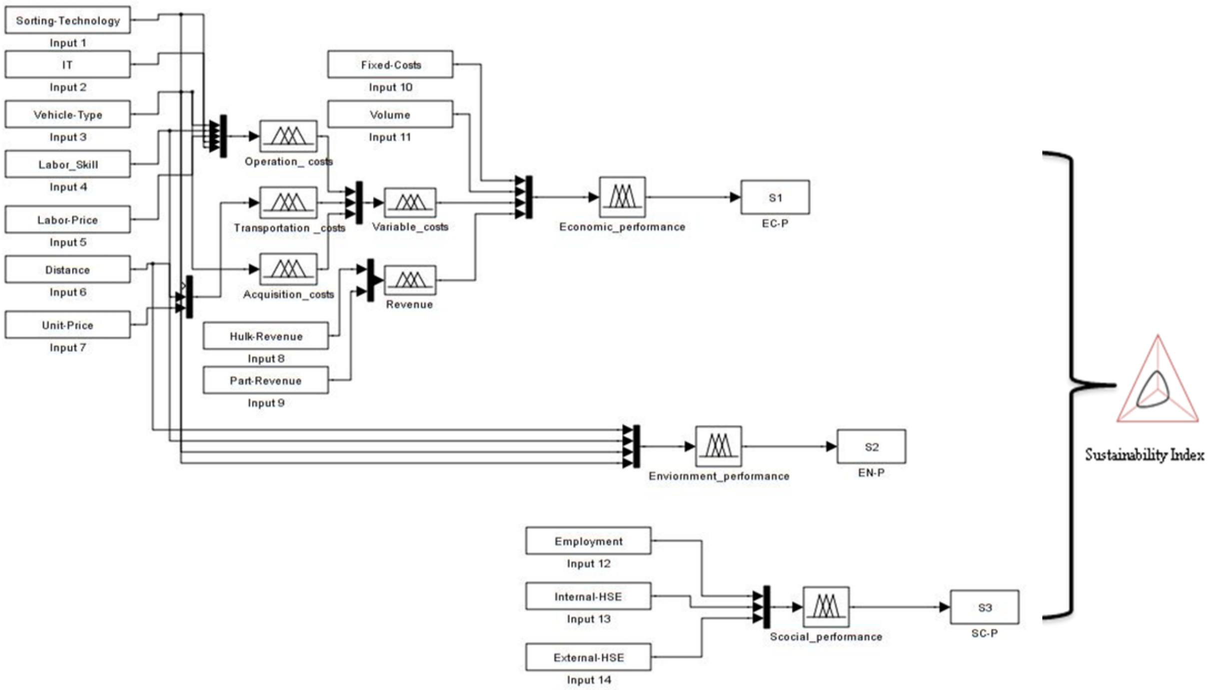


Figure 6: Application of Fuzzy rule based model for evaluation of sustainability of dismantlers

5.4.2. Players network outcomes & Network implication

Social network analysis literature is full of different measures and functions which can be used in order to study business ecosystem of players. However, some of these measures can provide highlights with respect to functionality and efficiency of network. According to (Jackson, 2008) There are two challenges in modeling networks from a strategic point of view. Explicitly model the costs and benefits that arise from various networks and how the individual incentives translate into network outcomes. In addition since the sharing information and opinions formation are important characteristics of social networks, how the structure of the network can affects learning and information diffusion are needed to be considered in social network analysis. The dynamic characteristic of network of ELV players needs to be considered in order to evaluate the synergy in stakeholder's network. The utility of player or pay-off player represents the net benefit that a player receives in a particular network. The costs and benefits of interaction and different types of allocation rule (player based or linked based) are discussed in this part (Jackson, 2008). Influence and learning effect are the other issues in the modeling business ecosystem. The first one determines which players have the most influence over the opinions (Jackson, 2008) and the learning determines how quickly players learn and how the information can be aggregated in the network (Jackson, 2008). As the communities and media are important stakeholders, these measures can determine most influential players and the structure which lead to a convergence of opinions more quickly.

6. Summary

An essential part of modeling and analysis of ELV recycling infrastructure is to capture the dynamic interactions among entities in this network of players. Considering the concept of business ecosystem, we proposed a framework to integrate modeling and analysis of the complex interaction among players in automobile recycling infrastructure. More work is required to develop an integrated model in order to consider a variety of factors which have been explained in this study. This study provided a research agenda for the modeling business ecosystem of ELV players.

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