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A SYSTEM DYNAMICS MODEL FOR SMALL HOUSEHOLD APPLIANCES' WASTE MANAGEMENT BY BAYESIAN NETWORK: A CASE OF TURKEY

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(TÜRKİYE'DEKİ KÜÇÜK EV ALETLERİNİN ATIK YÖNETİMİ İÇİN BAYES AĞIYLA BİR SİSTEM DİNAMİĞİ MODELİ)

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Aziz Kemal Konyalıoğlu

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LIST OF SYMBOLS

AB **:** Avrupa Birliği
ANN **:** Artificial Neural Network
App **:** Appendix
BN **:** Bayesian Network
CLSC **:** Closed Loop Supply Chain
EEE **:** Elektrikli ve Elektronik Ekipman
EU **:** European Union
SD : System Dynamics
WEEE **:** Waste of Electric and Electronic Equipments
MEUT **:** Ministry of Environment and Urbanization of Turkey

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ABSTRACT

Nowadays sustainability is one of the most important subjects in the developing world. Thanks to sustainability, waste management also gains more importance. Waste management is composed of many sub-areas in which liquid, gas or solid wastes are treated. The waste category that will be studied in this thesis is waste of electric and electronic equipment (WEEE) under solid wastes. Turkey is a country whose household appliances sector is outstandingly large. Furthermore, many small household appliances are thrown away or destroyed due to end of life or quality issues. Most of those wastes do not go through any treatment process even if Turkey has collection and recovery targets for all WEEE categories. As they are not properly treated, the process to destroy without reusing or recycling them causes environmental damage. The aim of this thesis is to put forward a system dynamics model for increasing recovery options of waste of small household appliances in electric and electronic sector, which is not treated in an environmentally friendly way. Besides, in this thesis, Bayesian network has been used for evaluating the probability of decision variable in order to understand proposed system dynamics model. The proposed model provides decrease in environmental damage. In this model, Anylogic program will be used for the simulation of the proposed system dynamics model. Different scenarios will be also conducted to give recommendations on how the whole system works in the case of Turkey by using Netica Bayesian Network program.

ÖZET

Günümüzde enerji kaynaklarının azalması ve üretim teknolojilerinin hızla gelişmesinden dolayı, sürdürülebilirlik kavramı oldukça önem kazanmıştır. Sürdürülebilirlik gerek ekonomik ya da sosyal gerekse de çevresel açıdan oldukça dikkat çekmektedir. Ekonomik, sosyal ya da çevresel açıdan ele alınan sürdürülebilirlik, her biri birbiriyle doğrudan bağlantılı bir kavram olarak öne çıkmakta olup, çevresel açıdan sürdürülebilirlik; ekonomik ve sosyal açıdan sürdürülebilirliği önemli derecede etkilemektedir. Üretim etkinlikleri gerçekleştikçe doğrudan tüketim de artmış bunun sonucunda insanların tercihleri ya da ürün ömrünün bitmesi nedeniyle "atık" kavramı ortaya çıkmıştır. Çevresel sürdürülebilirlik altında yer alan "atık yönetimi" kavramı gelişen dünyada tedarik zinciri yönetimi, üretim teknolojileri gibi alanların da çalışma konusu olmuştur. Atık yönetimi en başından itibaren katı, sıvı ya da gaz atıklar olmak üzere birçok alanda incelenmiştir. Bu çalışmada incelenen Elektrikli ve Elektronik Ekipmanların Atık yönetimi, katı atıklar kategorisindedir. Türkiye, elektrik ve elektronik sektöründe hızla gelişen bir ülkedir. Üretim, teknoloji ve bu alanların yönetimi geliştikçe, Türkiye'deki ev aletleri sektöründeki gelişmeler de ivme kazanmıştır. Fakat gerek ürün yaşam döngüsünün sona ermesi, gerekse de keyfi nedenlerden dolayı birçok ev aleti geri dönüşüm yapılmadan yakılmakta ya da çöpe gönderilmektedir. Geri dönüşüm yapılmamış ürünler sadece ekonomik olarak değil aynı zamanda çevresel olarak da birçok probleme neden olmaktadır. Türkiye, Elektrikli ve elektronik ekipmanların (EEE) geri dönüşümü için hedefleri olan bir ülkedir. Geri dönüşüm ya da yeniden kullanımın artışı Türkiye'nin ekonomisine katkı sağlayacak aynı zamanda da çevresel problemleri ortadan kaldırmaya yönelik sürecin kısalmasını sağlayacaktır. Diğer ülkeler ele alındığında, özellikle Avrupa Birliği ülkeleri elektrikli ve elektronik ekipmanların üretiminde çevreci yaklaşımları oldukça önemsemekte ve geri dönüşüme önem vermektedirler. Karbon emisyonunun azaltılması, geri dönüştürme tesislerini yaygınlaştırma gibi başarılı girişimlerde bulunanları destekleyerek; bu girişimleri ileriki zamanlarda

kanunlaştırmışlardır. Bu sadece ekonomik bir katkı sağlamak amaçlı değil aynı zamanda da çevre dostu tesislerle birlikte sosyal olarak da halkı bilinçlendirmişlerdir.

Küçük ev aletlerinin de EEE'nin bir alt başlığı olarak ele alınmaktadır. Türkiye, AB ülkeleriyle birlikte küçük ev aletlerinin üretiminin yüksek olduğu ülkelerden biridir. Fakat, üretimin fazlalığı, geri dönüştürme tesislerinin ve halk bilincinin eksikliği nedeniyle yaşam ömrü tükenmiş ya da eski küçük ev aletleri yeniden üretime dahil edilememekte, yeniden kullanılabilirlik aşaması doğrudan yok sayılmaktadır. Sistem dinamiği, genel olarak dinamik sistemlerin matematiksel model ya da simülasyonuyla ilgilenen bir disiplin olarak tanımlanabilir. Alt kullanım alanı olan, geri dönüşüm modellemesi ve simülasyonun önemli bir yer tutmakta olduğu ve iyi sonuçlar verdiği bilinmektedir. Bu çalışmada temel olarak Türkiye'deki küçük ev aletlerinin atık yönetiminin Bayes ağıyla sistem dinamiği kullanarak modellenmesi amaçlanmıştır. Hedeflenen modelin; kullanılmayan, keyfi olarak değiştirilen ya da yaşam ömrü bitmiş küçük ev aletlerinin ilk aşama olarak sistem dinamiğiyle bir geri dönüşüm mekanizması belirlenmiş, daha sonra Bayes ağı kullanılarak duyarlılık analizi yapılmıştır. Ayrıca çalışmada, Bayes ağı ve sistem dinamiği modeli; elektrik ve elektronik atıkların yönetilmesi ile ilgili öneriler vermek için önemli katkılar sağlamıştır.

1. INTRODUCTION

Waste management, which effects on sustainability in every aspect, is an important topic in the world. Sustainability means “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." according to Report of the World Commission on Environment and Development: Our Common Future (Brundtland, 1987).

Sustainability can be taken into consideration in three main areas which include economic, social and environmental dimensions (Dyllick and Hockerts, 2002). Waste management is particularly included in environmental and economic sustainability. For pursuing a “sustainable” policy, each waste management category has an important topic to investigate and one of them is Waste of electric and electronic equipment (WEEE). As the number of households using electric and electronic equipment increases and technological improvements go further year by year, management of WEEE becomes more important. This equipment can be classified into ten categories: large and small household appliances, IT and telecommunication equipment, consumer equipment, lighting devices and equipment, gas discharge lamps, electric and electronic tools, toys, entertainment and sport tool, medical equipment, monitoring and control devices/tools, and finally automats, on which Turkey has recycling and recovery targets according to the WEEE Regulation which was published in 2008 [1].

Furthermore, recovery and recycling targets are qualified based on the types of wastes which can be taken into consideration by collecting, economic and technical dimensions (Fischer, 2011).

[1] https://www.britannica.com/technology/waste-disposal-system.

Building a system for waste management is seen as one of the most crucial parts in terms of environmental waste management. A waste management system mainly describes the management of all tasks including responsibilities, routines, actions, measures and resources, which intend to manage wastes and abides by regulations. Besides, waste management is an important task in terms of economy and society. All countries, which are currently developing or developed, produce many types of wastes.

In Turkey, electric and electronic sector is sharply growing thanks to technological improvements and needs. Thus, environmental perspective is dependently changing since production and consumption of this equipment causes an increase in pollution and decrease in resources. To avoid these damages, Turkish government developed regulations to enable reuse or recycling of the electric and electronic equipment. One of the fields defined in the regulations is white good sector including small household appliances. There are humble eco-design efforts for small household appliances in Turkey however unless there is a strict waste management policy those efforts will not be sufficient. To have a holistic environmental sustainability, not only production process but also recovery processes for end-of-life products should be taken into consideration. This can be perceived as a whole system or process because in the whole system, each detail matters from suppliers to the recycling facility (Jie and Buekens, 2014).

The aim of the study is to propose an integrated system dynamics and Bayesian network model in order to evaluate small household appliances waste management by taking into account probabilistic Bayes nodes. First, the system dynamics model is used for minimizing wastes of small household appliances in Turkey and maximizing recovery applications instead of disposing them. The study will also help to understand how environmental sustainability concept works in Turkey. There exists a lot of studies about wastes of electric and electronic equipment in Turkey but there are not any studies especially focusing on waste management of small household appliances by using a system dynamic model.

As the second part, the study includes a Bayesian network evaluation. Using this Bayesian network model, the probability of recycling, expired products and related conditions of the closed loop supply chain of waste management of small household appliances changes according to stock variables and dynamics variables.

The original contribution of this thesis is to combine Bayesian networks and system dynamics as there is not any study gathering these two techniques in production area, especially in WEEE management field.

The study includes five main parts: introduction, literature review, modelling, which includes system dynamics and waste management of small household appliances' model, application of the model and network, and finally conclusion and future studies.

In the literature review part, waste and especially WEEE concept, green management, sustainability concept, system dynamics definition and Bayesian network information will be included to illuminate the main aim of the thesis. On the other hand, in this part, to give a general view, situation of waste management of electric and electronic equipment in Turkey will be investigated.

In the modelling part, the system dynamics model will be given to explain how the system dynamics concept has been applied to small household appliances' waste management in Turkey. Furthermore, the inputs shall be defined to understand how the whole built system works. To understand, the production process has been defined and the products were sent to the distributors. After sending distributors, the rates of all products have been put in the model. The possible and conducted sub-collection strategies to maximize recycled materials and to minimize incinerated or thrown away wastes have been put into model. Also, in the model, all components of recycling process have been taken into consideration to transfer to Bayesian network. Besides, one will be able to see that Bayesian Network has been applied to have a possibility decision tree in order to investigate the possible options of the system dynamics modelling.

In the analysing part, the outputs of the model have been discussed. The outputs of the system dynamics model have been also taken into account in the Bayesian network analyzing. The sensitivity analysis has been done in order to discuss the possibilities of variables that are taken place in the modelling.

In the conclusion part, the recommendations for the future studies and conclusion of the thesis will take place to emphasize the important points.

2. LITERATURE REVIEW

2.1.Waste Management and Sustainability Concept

Waste management can be defined as the waste materials which are aimed to process, collect, recycle or deposite[2] The amount of wastes has been increasing because of growing population and increasing needs for raw materials in a range including usual wastes and wastes of electric and electronic equipment (WEEE). (Takiguchi, 2016). WEEE can be defined as an electrically operated device that no longer satisfies the user or manufacturer for a specific purpose. (Sinha-Khetriwal et al, 2005). If WEEE is mismanaged; these wastes can clearly affect the environment and the human health. Environmental regulatory agencies; electronic equipment manufacturers, retailers and non-governmental organizations are quite concerned with the updated statistical data to which WEEE is produced, stored, recycled, or discarded (Jang, 2010). With the rapid development and use of electronic devices, the WEEE problem is growing rapidly in all countries. WEEE appear many times in developing or emerging countries which cannot have any important infrastructure to manage WEEE problems. (Safdar et al., 2015). On the other hand, in developed countries, for example in EU countries, it is expected that the EU will reduce its long-term differences in the level of recycling by linking its minimum recycling targets. In the last 15 years, the EU Member States have been able to change their perception of waste management. In the mid-1990s, EU member states have been able to gain more wastes and recycled them. They have made a very good start, although they need to do more (Fischer, 2011). In addition to developed countries, not only WEEE management or associated researches but also legal arrangements have sped

[2] https://www.britannica.com/technology/waste-disposal-system.

up in recent years with its conduction by Special Wastes Management Department at Waste Management Department in EU.

Salhofer et al. state that with the growing consumption rates, today "waste" is a very important topic to manage in a proper way. There are different types of waste which mainly divided by hazardous and not hazardous waste. A very big amount of the generated waste is now Waste Electrical and Electronical Equipment (WEEE) which is related to growing technology. WEEE has both hazardous, such as heavy metals, and not hazardous, even more valuable materials such as copper, materials inside. The increase of WEEE management strategies is triggered by producers' defined responsibilities and environment friendly production which is also named green manufacturing. In the middle of 2005, EU and RoHS directives (2002) were into force. Mainly the target was to collect 4 kg/cap/yr of WEEE but the recycling targets were different by their categories. In 2012, EU WEEE Directive was revised with respect to the growing consumption and waste generation rates (2016). Furthermore, According to Wäger, and Hischier, the revised directive firstly aims to decrease disposal rates while increasing the application of recovery options such as recycling, reuse and remanufacturing (2015). For older EU members the main target was easier to reach than a new member of EU. By 2019 there will be more strict numbers for collection such as 65% of the product which is at the market or 85% of generated WEEE. For these kind of reasons, countries started to seek for more efficient collection systems (Salhofer et al., 2016).

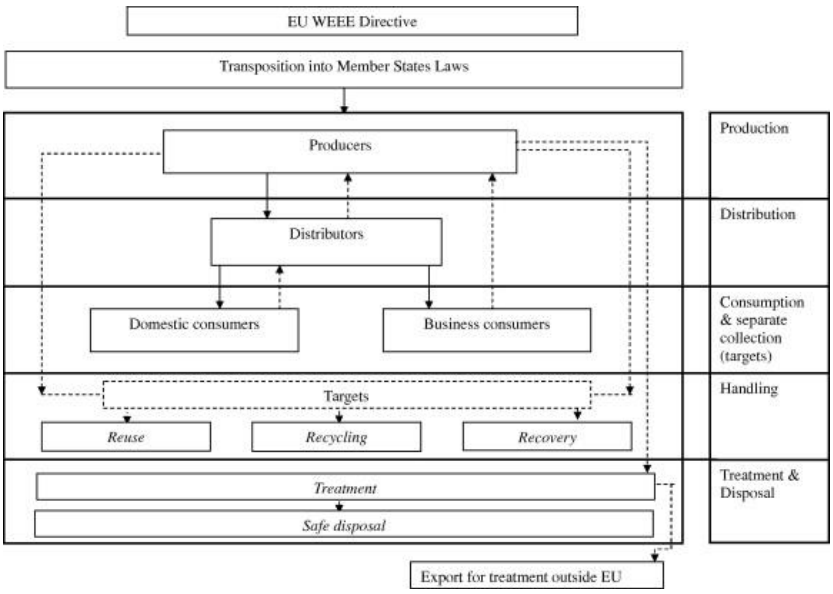

Figure 2.1: EU WEEE Directive Summary as a Flowchart of the System (Ongondo et al.,2011)

EU WEEE directive does not only give the target points but also draws a map for every kind of actors who are already included in the waste management system. Figure 2.1 shows the directive’s flowchart for WEEE management. (Ongondo et al., 2011)
Besides, according to Fischer, many countries in EU have nationally been successful to recycle e-waste before taking initiatives on behalf of EU. Estonia and Hungary have tried to landfill all municipal wastes in a short time ago (2011). Table 2.1 given below shows the percentage of e-waste recycling in EU countries until 2015.

Table 2.1: Percentage of recycling of e-waste in EU (Eurostat, 2016)

Geo\Time	2008	2009	2010	2011	2012	2013	2014	2015
EU (28 countries)	:	:	27,8	28,7	28,8	29,6	32,2	35,6
Belgium	28,3	30,8	30,4	31,9	32	31,7	28,4	30,9
Bulgaria	:	:	40,8	49,4	62,4	60,2	68,3	96,5
Czech Republic	:	:	22,7	26	27,1	28,5	29,3	37,9
Denmark	:	39	41	50,1	46,5	37,6	42,3	43
Germany	:	38,1	37,8	34,4	34,8	35,6	36,9	33,9
Estonia	:	22,4	30,3	36,9	35,9	27,8	30,4	33,3
Ireland	:	:	30,9	32,5	36,1	38,6	43,1	46,1
Greece	21,6	29	19,4	19	18,6	22,1	29	32,7
Spain	:	12,6	14,7	16,7	19	26,1	26,2	35,6
France	:	19,2	21,8	22,6	22,6	23,6	26,3	32,2
Croatia	:	:	:	:	:	:	35,7	58,3
Italy	:	:	27,8	29,8	27,7	26,3	27,3	32,1
Cyprus	:	10,9	11,5	11,5	12,2	12,1	17	:
Latvia	:	:	14,5	19,9	26,5	27,8	26,4	23,1
Lithuania	15,2	10,5	16,6	28,2	41,1	43,8	64,6	45,9
Luxembourg	36,6	38	33	30,6	27,6	29,3	35,4	42,5
Hungary	28,3	29,5	26	25,3	30,8	40	47,7	50,7
Malta	:	12,1	13,1	9,7	9,9	11	11,5	:
Netherlands	22,5	22	27,8	33	33,2	31,3	38,1	39,4
Austria	46	36,1	35,7	37,1	38,2	37,6	39,1	40,7
Poland	:	13,9	17,7	23,9	30,4	28,1	27,4	33,1
Portugal	21,8	24	22,8	30,5	24,9	32,3	38,2	42,7
Romania	:	17	12	10,3	14,5	21	21,3	:
Slovenia	:	17,6	22	26,4	26,9	16,7	27,5	47,7
Slovakia	31,8	34,2	34,9	39,6	42,6	41,7	44,1	40,3
Finland	37,9	29,9	28,7	31	32,8	36,3	42,4	43,2
Sweden	62,4	52,2	55,3	64,9	62,6	64,9	52,7	51,6
United Kingdom	:	:	26,9	23,9	22,5	22,8	29,6	36,6
Iceland	:	:	:	:	:	:	:	:
Liechtenstein	:	:	:	:	:	:	117,8	127,1
Norway	35,4	46,9	45,3	48,4	46,4	46,5	47,5	50,4

To have a perspective, Figure 2.2 shows the WEEE treatment system and the actors who are responsible at different stages such as collection, disassembling, selling, etc. in Germany.

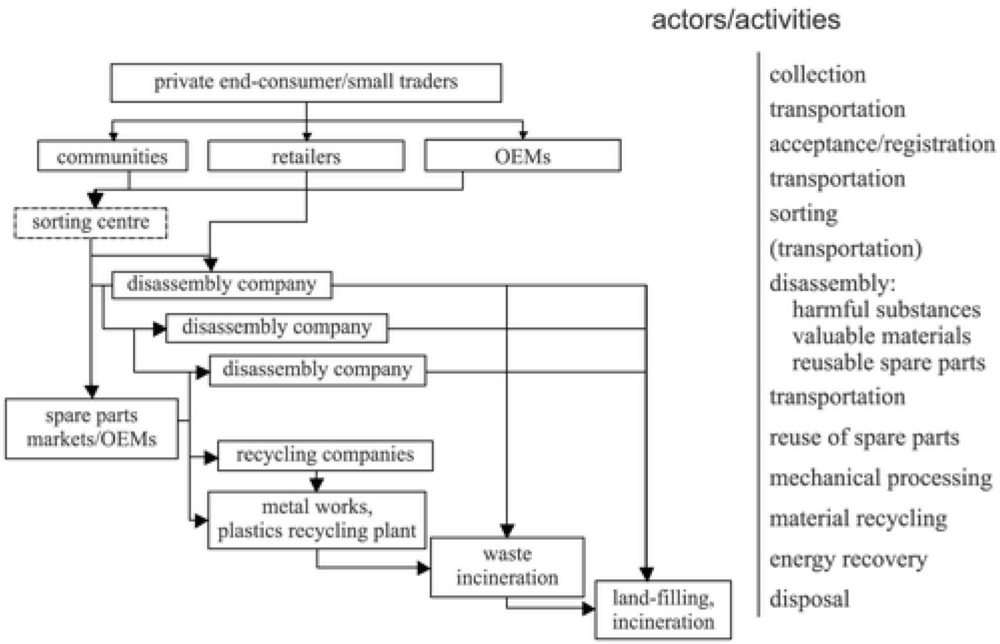

Figure 2.2: WEEE Treatment System at Germany (Walther & Spengler ,2005)

The collection of household WEEE is usually managed by the public authorities. Than the further process is starts by sending the WEEE to disassembly companies.

Not only in Germany, but also in China, Yang et al. investigated the flow of WEEE. They have tried to measure WEEE volumes and why WEEE are generated in China. After measuring and calculating, it has been resulted that the amount of recycling shall be increased because of the increasing amount of WEEE in order to deal with. Recycling of WEEE will generate alternative resources which will be used for national strategy in China (2007).

Also, implementation of different strategies has been reviewed by Wenzhi et al. in order to compare the present situation and the possible future situation of China by considering that China is the one of countries whose electronical and electric sector are very large. To have more sustainable economy, China must pursue a cleaner and greener design of WEEE (2006).

In Australia, Dias et al. show that the local governments have a little power to keep responsibility even if they are crucial channels of WEEE where they have 31 facilities to treat them (2018). In Denmark, the situation is different when compared to other countries. According to Parajuly et al. the WEEE amount in Denmark is decreasing while the other countries' e-wastes are decreasing. The EEE market can be said as saturated and is expected to keep its amount stabile in the next decade. To conclude, there will not exist any important change in WEEE quantities. Denmark can be remarked as a country whose WEEE management system is a very good system that performs uncourtly against the WEEE Directive (2017).

Waste management and sustainability are the crucial topics in 21st century (Dyllick and Hockerts, 2002). However, measuring sustainability has become an important topic and is tied to different systems (Delai and Takahashi, 2011). It is not a smooth task to implement sustainability initiatives by taking into account different countries, and companies should consider socio-cultural differences while implementing sustainability initiatives (Tata and Prasad,2015). Furthermore, sustainability consists of different aspects named as dimensions including environmental, economic and social dimensions as seen in Figure 2.1. Sustainability enables societies more equal and provides a more compromising world to generations (Dyylick and Hockerts ,2002).

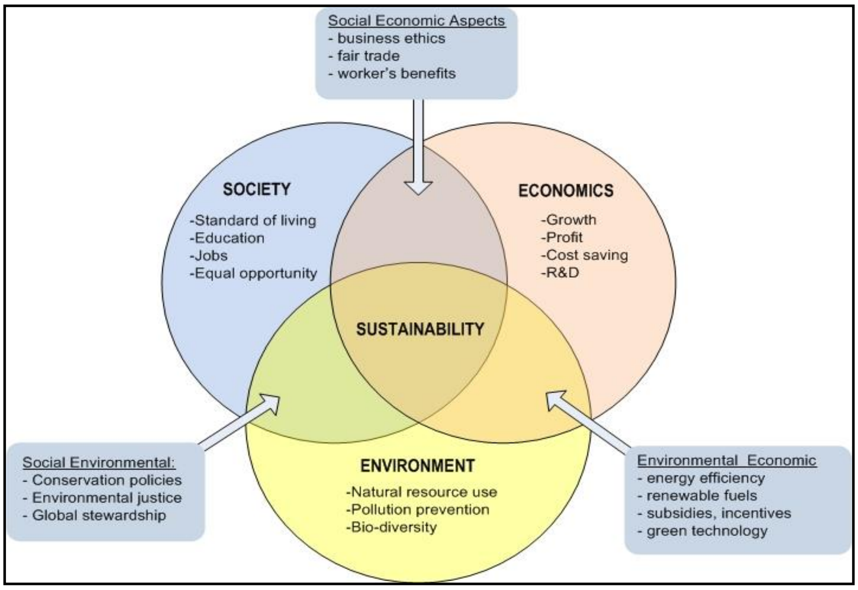

Figure 2.3: Three main dimensions of Sustainability [3]

[3] https://www.e-education.psu.edu/eme807/node/575

As the economy continues to evolve, countries start to have awareness of the significance of environmental sustainability which implies that the assessment of environmental sustainability also starts to become an important topic (Liu,2007). In this case, the transformation process to become more environmental sustainable provides institutions to keep themselves alive by adapting to external environmental changes. Sustainability not only allows institutions to stay alive, but also improves their organizational performance over time (Sisaye, 2011). On the other hand, just focusing on economical sustainability is an idea which is valid for short-term, but as it does not consider other sustainability figures, long term validity cannot be provided and based on triple bottom line principle, the three sustainability principles are tied to each other as indicated in the Figure 2.2 (Dyylick et al.,2002).

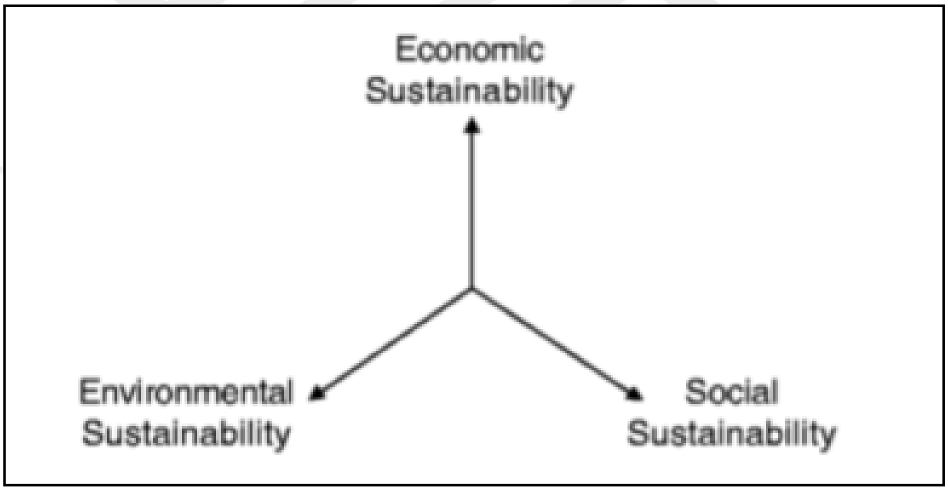

Figure 2.4: Sustainability inter-related principles (Dyylick and Hockerts,2002)

2.2. WEEE in Turkey

Wastes of electric and electronic equipment have been sharply increasing in Turkey. Managing WEEE is under the control of Ministry of Environment and Urbanization. Ministry of Environment and Urbanization has promulgated the regulation of WEEE in 2012 by the official gazette numbered 22000. According to official gazette, the materials which are suitable for recycling should be encouraged in the newly designed electronic equipment. Besides, municipalities, small towns and big cities have different collection centers based on their population. Collection of e-waste in Turkey, transports, recoveries are carried out by companies which the Ministry of Environment and Urbanization approves. When the E-device category and tags are placed; compliance documents are also given for collection, separation and reusing by the same Ministry. (Öztürk, 2015). To identify this task, recyclers should effectively have a management plan to operate recycling as well as resources. Furthermore, obtained plans give a route which resources and items of WEEE will be processed by explaining how. (Çapraz et al., 2015). Ongando et al. state that Nearly 40 million tons WEEE were disposed in 2013, which is a globally recorded data and it will increase approximately to 70 million tons by 2015 (2011). In 2005, EU WEEE amount was 5 million tons and it is reported that this amount will increase nearly to 12 million tons by 2020 according to UNU report (2008). Again, another report says this amount was nearly 560 thousand tons in Turkey in 2011 and it will reach to 890 thousand tons by 2020 (REC Turkey, 2011).

Turkey has a complete obligation of WEEE directive for becoming a full member of EU. Hence, Turkey has published a directive in 2012, which has been taken into law (Camgöz and Meriç, 2014). The waste collection targets which are decided by Ministry of Environment and Urbanization of Turkey are shown in the Table 2.2. These targets are provided to both producers and consumers.

Table 2.2: Waste Collection targets (Source: official gazette 2012)

EEE Categories	Waste Collection Targets of MEUT (kg/person-year)				
	2013	2014	2015	2016	2018
Refrigerators and Air conditioners	0,05	0,09	0,17	0,34	0,68
Large household appliances (except refrigerators and air conditioners)	0,1	0,15	0,32	0,64	1,3
Televisions and Monitors	0,06	0,12	0,22	0,44	0,86
IT, Telecommunication and consumer equipment (except televisions and monitors)	0,05	0,08	0,16	0,32	0,64
Lighting equipment	0,01	0,02	0,02	0,04	0,08
Small household appliances, electric and electronic tools and sport/entertainment toys, monitoring tools	0,03	0,06	0,11	0,22	0,44
Total household EEE(kg/person-year)	0,3	0,5	1	2	4

According to the Directive of WEEE, Turkey has both recovery and recycling target. The official gazette published in 2012 states the recycling and recovery targets in Turkey as seen in table 2.3 and 2.4. The motivation behind this directive can be stated as building up the rules for the confinement of utilization of certain unsafe substances in electric and electronical products, assurance of the application to be exempted from this restriction and recuperating or transfer of misuse of EEE by keeping in mind the goal to ensure the protection and human wellbeing (WEEE Directive,2008).

On the other hand, the ministry of environment and urbanization of Turkey forces companies working in any e-waste category to give report monthly and in detail. The WEEE producers should be also informed. (Öztürk,2015) The WEEE mechanism in Turkey can be given in the Figure 2.5.

Table 2.3: Recycling Targets of Turkey (Source: official gazette in 2012)

EEE Category (%)	Years	
	2013	2018
	Weights (%)	
Large household appliances	65	75
Small household appliances	40	50
IT and telecommunication equipment (%)	50	65
Consumer equipment (%)	50	65
Lighting devices and equipment (%)	20	50
Gas discharge lamps (%)	55	80
Electrical and electronic tools (%)	40	50
Toys, entertainment and sports tool	40	50
Medical Equipment	---	---
Monitoring and Control devices/tools	40	50
Automats	65	75

Table 2.4: Recovery Target of Turkey (Source: official gazette in 2012)

EEE Category (%)	Years	
	2013	2018
	Weights (%)	
Large household appliances	75	80
Small household appliances	55	70
IT and telecommunication equipment (%)	60	75
Consumer equipment (%)	60	75
Lighting devices and equipment (%)	50	70
Gas discharge lamps (%)	70	80
Electrical and electronic tools (%)	50	70
Toys, entertainment and sports tool	50	70
Medical Equipment	---	---
Monitoring and Control devices/tools	50	70
Automats	70	80

On the other hand, the ministry of environment and urbanization of Turkey forces companies working in any e-waste category to give report monthly and in detail. The WEEE producers should be also informed. (Öztürk,2015) The WEEE mechanism in Turkey can be given in the Figure 2.3.

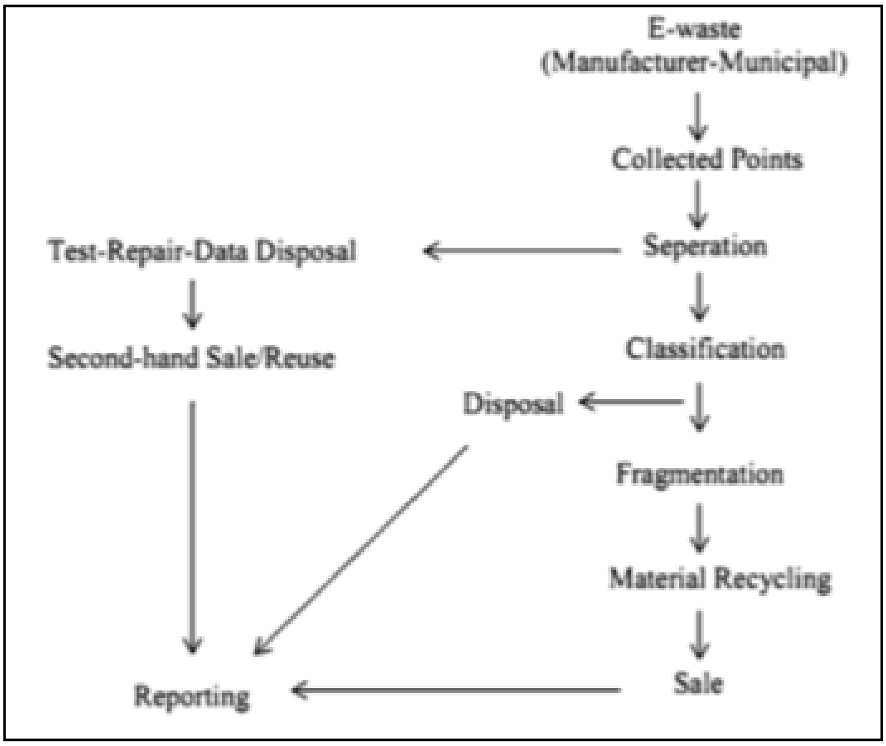

Figure 2.5: E-waste flow scheme in Turkey (Öztürk, 2015)

2.3. System Dynamics

As a definition, system dynamics makes possible to understand and improve system thinking and operations management systems. After all, as a first step, we have to deal with the real world in many steps. It is possible to define system dynamics by better understanding equations of a model, simulation to understand dynamic behaviors, evaluation of other alternatives, selection and implementation of a better method (Forrester, 1994).

According to the literature review it has been seen that there are some studies about system dynamics and its applications.

In a study, Al-Khatib et al. suggested a more understandable and sophisticated simulation method for hospital waste management by using system dynamics model (2016). Also, Lee et al. proposed a system dynamics approach based on functional dynamics to evaluate product-service systems (2015). In the production area, system dynamics is again used by Greasley to provide a discrete-event simulation method. (2005) Botha et al. used system dynamics modeling to compare three inventory management methods for theoretical and actual, daily data set by comparing the parameters of stock target settings (2017).

On the other hand, in management area, Snabe et al. used system dynamics model qualitatively to evaluate management strategies (2006). Also, as an example of management application of system dynamics modelling, Fritz tried to reveal that the product life cycle can be used in a way of strategic assessment. (1989)

System dynamics model is not only used in production field. For example, in management area, Barnabè suggested a balanced scorecard method based on system dynamics to evaluate strategic decision making (2011). In the finance area, Nair et al. revealed that the system dynamics model is used for simulation of financial parameters in the case of production capacity expansion in the electronic industry (2013). As another example, Baradaran and Keshavarz analyzed credit risk of retailers by using integrated system dynamic model. (2015) For example, Ghisolfi et al. presented a system dynamics model to investigate legal bargaining power and incentives for the waste pickers of desktops and laptops measured by the volume of wastes (2016).

In education field, Pedamallu applied a system dynamics model to evaluate educational infrastructure based on the quality of primary school of a developing country (2012).

As well, in healthcare area, Devi et al. studied system dynamics modeling for the waiting list of corneal transplants patients (2010).

In energy area, Ferreira et al. used system dynamics approach to think systematically closed loop patterns based on different energy resources in order to take into consideration sustainability (2016).

Aside from many areas, also about WEEE, system dynamics models can be proposed. As there is not many studies about WEEE in terms of system dynamics, especially about small household appliances, this gap has been tried to fulfill.

2.4.Bayesian Networks

According to Heckerman, Bayesian Network can be defined as a graphical model in which variables are evaluated in a way of probabilistic relationship (1997). It is largely used to model uncertain knowledges even if Bayesian network have difficulties (Ronan et al., 2011).

Bayesian network can be used in many areas. For example, in supply chain management area, Lockamy has used Bayesian network to evaluate supplier risks in supply chain networks. Also, Weng et al. suggested a product recommendation system by using Bayesian network (2011).

In finance area, Sanford et al. have used Bayesian network to assess operational risks and organizational learning as well as human error factors (2015). Again, Demirer et al. analysed portfolio risks by Bayesian network and combined them in a quantitative and qualitative ways (2006). As a different application, Leong revealed that the Bayesian network with logistic regression and neural network can be used in credit risk scoring and remarked that a big data set can be more efficient in terms of real life practice (2016). Besides the Bayesian Network, Neil et al. chose to use hybrid dynamic Bayesian network in order to evaluate financial institutions whose risks are operational risks by economic capital. They concluded by using hybrid dynamic Bayesian networks that their model has statistical properties explaining large-scale losses (2009).

In management area, Chakraborty et al. have made decisions to build customer satisfaction in railway transportation (2016). Besides, Cai et al. have proposed a methodology and an application of Bayesian network in which they conduct a qualitative analysis. Then, they have analyzed the factors which are established in the model while finding that the factors including mechanical and hydraulic are the most important factors that affect operation safety (2013). Furthermore, Cheng-Gang suggested a Bayesian network model in the field of software reliability forecasting despite the complication of system. (2005)

In healthcare area, Goodson and Jang evaluated homecare qualities of nurses with Bayesian networks. They think that Bayesian network is a very useful tool to improve and assess homecare quality of nurses since Bayesian network model gives chance to see how to manage limited resources (2008).

In this study, as there do not exist many Bayesian network studies in the field of WEEE, this gap has been remarked and tried to complete in our study.

3. METHODOLOGY AND MODELLING

In the light of the literature review section, it has been seen that there is a big gap about how to treat WEEE. So in this study, we propose an integrated Bayesian network and system dynamics model to treat WEEE and evaluate probable options of treatment.

3.1.System Dynamics (SD)

System dynamics is mainly defined as an approach to explain complex systems and to understand how this system behaves by time-to-time. As a whole system, system dynamics models are based on the behavior of closed loops and stocks or dynamic variables. Stocks, Dynamics variables and links in terms of system dynamics concept are especially tried to understand how the whole system is interrelated and how the change of a variables effects on another variable. Firstly, to apply system dynamics modelling, one should decide whether the designed thing is a system or not. Because, system dynamics models contain a cause-effect relationship. By understanding the whole system, the control of stocks, dynamic variables can be probable. The main components of system dynamics are as follows;

- *Dynamic variable* can be defined as a function of stock variables. Hence, it can be said that dynamic variables should be affected by stocks and links.
- *Stocks* are not dynamic part of systems, they are generally static parts of systems. They might include an accumulation of any variables such as material, money or people.
- *Links* are the relation of two different variables. Generally, interrelated variables must include a link to understand the relation between them.

- *Flows* are the change of variables in which includes a rate of change. [4]

According to Forrester J., system dynamics can also be defined as a discipline used in the areas of medicine, engineering and other important places. The most important factor in system dynamics concept is *Feedback Loops.* Feedback loop concept in system dynamics is mainly interested in control mechanism. As an example, to explain feedback mechanism in the system dynamics, Forrester illustrated how the perception is in the Figures 3.1 and 3.2 in order to understand and give a realistic example in the world.

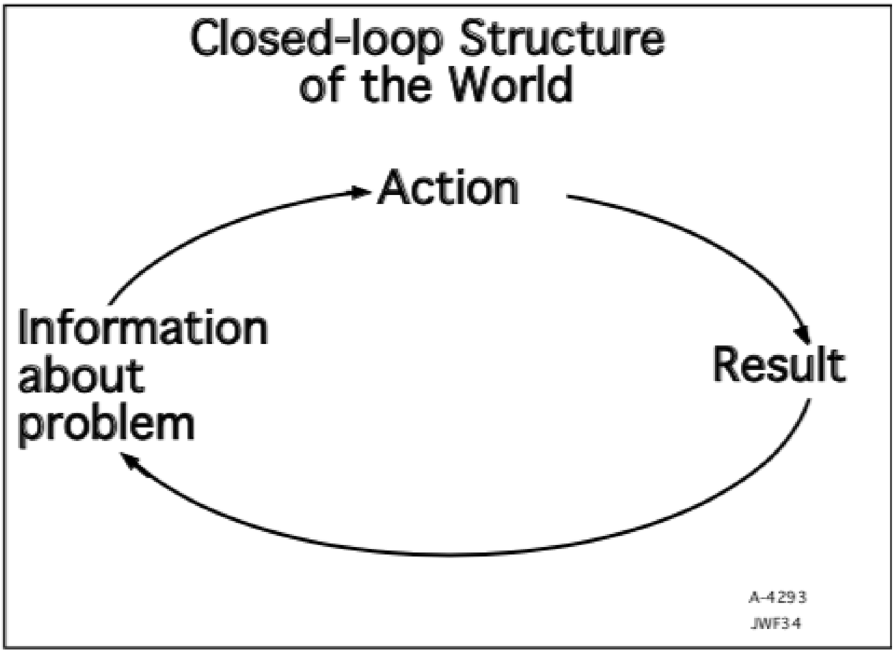

Figure 3.1: Closed loop structure example of the World as a SD relationship (Forrester, 1961)

As another example of system dynamics thinking, one may give the mechanism structure of the system dynamics. The example is given as a filling of water mechanism in the Figure 3.2. The feedback loop in the example has been set according to the water level. Systematically, Figure 3.2 implies the mentality of how a system dynamics model works. Inputs and outputs in this mechanism show how importantly they are related. Here, hand is a control mechanism, eye can be defined as an observer, who realizes the simulation and water level is the model.

[4] https://www.anylogic.com/

Then, it should be remarked that system dynamics works as seen in the Figure 3.2.

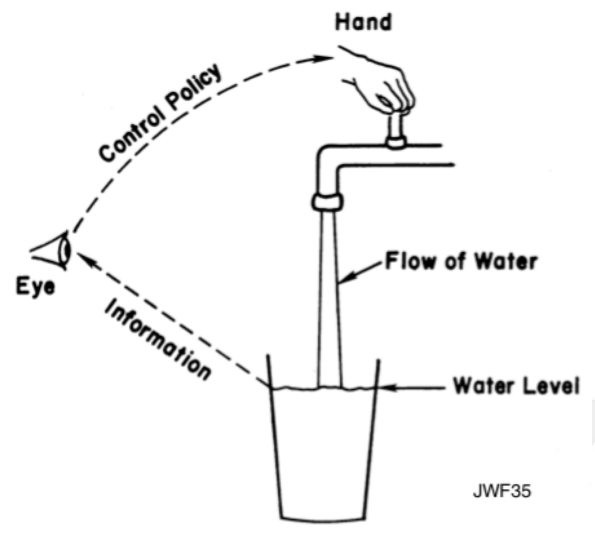

Figure 3.2: A system dynamics mechanism indicated as water level controlling (Meadows, 1989)

As explained at the beginning of the System Dynamics methodology, a system dynamics model principally consists of 4 components. The Figure 3.3 shows the main components of a system dynamics model and in order to explain in details, It also shows the exact mechanism of system dynamics.

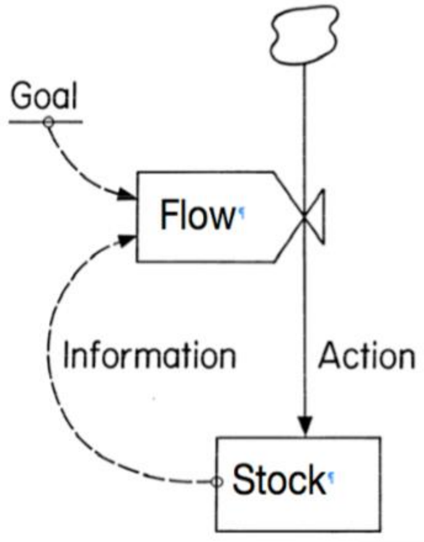

Figure 3.3 : The main components of a system dynamics model (Forrester, 1975)

The modelling approach is important in a system dynamics theory. Before starting to explain, it is needed to expand the definitions of main components of a system dynamics model presentation.

Stock and Flow Diagrams are the most important diagrams in the system dynamics because of interfering directly to the model. In the figure 3.4, a simple distribution network modelled by system dynamics can be seen. Here, the flow diagrams are indicated as integrated arrays.

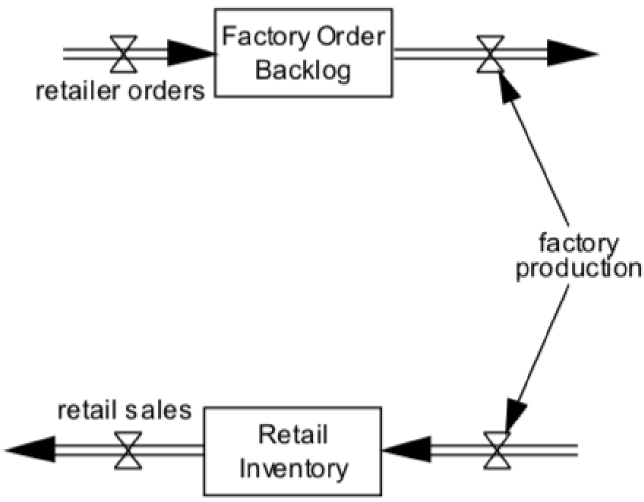

Figure 3.4: A simple system dynamics distribution network

Besides, the stock variable which is Retail Inventory in the Figure 3.4 can be found as given in the equation (1).

$$Retail\ Inventory = Inventory\ at\ the\ beginning + \int_0^{t_1} f_{production}(t)\,dt - \int_0^{t_1} f_{sales}(t)\,dt \qquad (1)$$

In the Closed Loop Supply Chain system dynamics models, stock equations can be different but mainly the equation (1) implies stock equation by considering the flow which is defined as production process in the Figure 3.4.

3.2. Bayesian Network

According to Heckerman, Bayesian Network can be defined as a graphical model in which variables are evaluated in a way of probabilistic relationship (1997). It is largely used to model uncertain knowledges even if Bayesian network have difficulties (Ronan et al., 2011).

Bayesian Network simply identifies the probable relationships between dependent or independent variables by using nodes. Also, it can be said that decision nodes can be used by Bayes formula to decide which node is more or the most probable.
Firstly, by using probabilities of each option under nodes, interdependency is measured and assigned a probability. The chance of realizing each situation or condition is measured by Bayes networks and shown as nodes.

To give an introduction for Bayesian networks, it is required to define conditional probabilities and independency's mean according to Learning Bayesian Network book by Richard E. Neapolitan.

Conditional probability can be defined as;
Let A and B be any events such that $P(B) \neq 0$, then the conditional probability of A and B which is denoted by $P(A|B)$ can be given in the formula (2).

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \qquad (2)$$

Independency is given according to these two events if and only if one of these holds;

a. $P(A|B) = P(A)\ and\ P(A) \neq 0\ and\ P(B) \neq 0$
b. $P(A) = 0\ or\ P(B) = 0$

Bayes Theorem is crucial to explain Bayesian Network. Bayes Theorem is defined in the formula (2) and (3);

Bayes Theorem: Let A and B be two given events such that $P(A) \neq 0$ *and* $P(B) \neq 0$ Then,

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \qquad (3)$$

Besides, n mutual exclusive events form the formula (4) such that $A_1, A_2, A_3, A_4 \ldots . A_n$ such that none of them is equal to zero for all i where $1 \leq i \leq n$

$$P(A_i|B) = \frac{P(B|A_i)P(A_i)}{P(B|A_1)P(A_1) + P(B|A_2)P(A_2) + \cdots P(B|A_n)P(A_n)} \qquad (4)$$

Joint Probability Distribution: Let us consider the set including n random variables such that $P(X_1 = x_1, X_2 = x_2, X_3 = x_3, \ldots X_n = x_n)$ whose x_i is chosen from the set of X. The function is defined as *joint probability distribution* in the set of X if the following conditions hold:

a. For every combination including the values of x_i

$$0 \leq P(X_1 = x_1, X_2 = x_2, X_3 = x_3, \ldots X_n = x_n) \leq 1$$

b. $\sum_{x_1, x_2 \ldots . x_n} P(X_1 = x_1, X_2 = x_2, X_3 = x_3, \ldots X_n = x_n) = 1$

In this case, one may define the Bayesian Network after defining joint probability distribution by considering P as a joint probability distribution of the set of X which is a set of random variables. P is called as Bayesian network if it holds Markov condition.

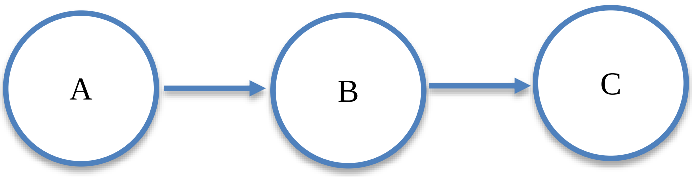

Figure 3.5: Casual Bayesian Network Diagram implying A causes B and B causes C

4. APPLICATION

The explanations of system dynamics and Bayesian networks have been given in the methodology section. Apart from this, it should be said that based on recovery and recycling targets published in Turkish official gazette, an integrated system dynamics model and Bayesian network evaluation for small household appliances' waste management in Turkey will be explained in Application section. For these evaluations and modelling, Anylogic and Netica softwares will be used.

4.1. System Dynamics Model of Small Household Appliances

The proposed model, given in Figure 4.1, aims to increase recovery options for decreasing environmental damage by decreasing CO2 emission and increasing recovery options. The model runs without any error by using simulation software; Anylogic.

The supply chain starts from suppliers, which provide raw materials for production. In the model, three suppliers have been taken into consideration as a representation. These three suppliers defined as stock variable, provide raw materials for production process. The production process which is in the model is hereby considered as a total amount of all small household appliances companies in Turkey. As there is not an effective and real data, system dynamics model has been constructed by using the total sold out small household appliances in Turkey and 2018 target. According to GFK's press release [5], the number of small household appliances sold out in Turkey is estimated as 17, 3 million (2017).

[5] http://www.gfk.com/en-gb/insights/press-release/kuecuek-ev-aletleri-yeni-trendlerle-bueyueyor/

Besides, after the main distributor, there are 3 sub-distributors to reach end consumers. End consumers are assumed to change their products intentionally or at the end of life cycle in the model. The used products are collected in general waste collection centers or municipality waste collection centers. For attracting wastes and increasing social benefit, municipalities can apply a campaign or inform the public to create awareness. In this case, small household appliances are collected to be recycled, incinerated or be landfilled.

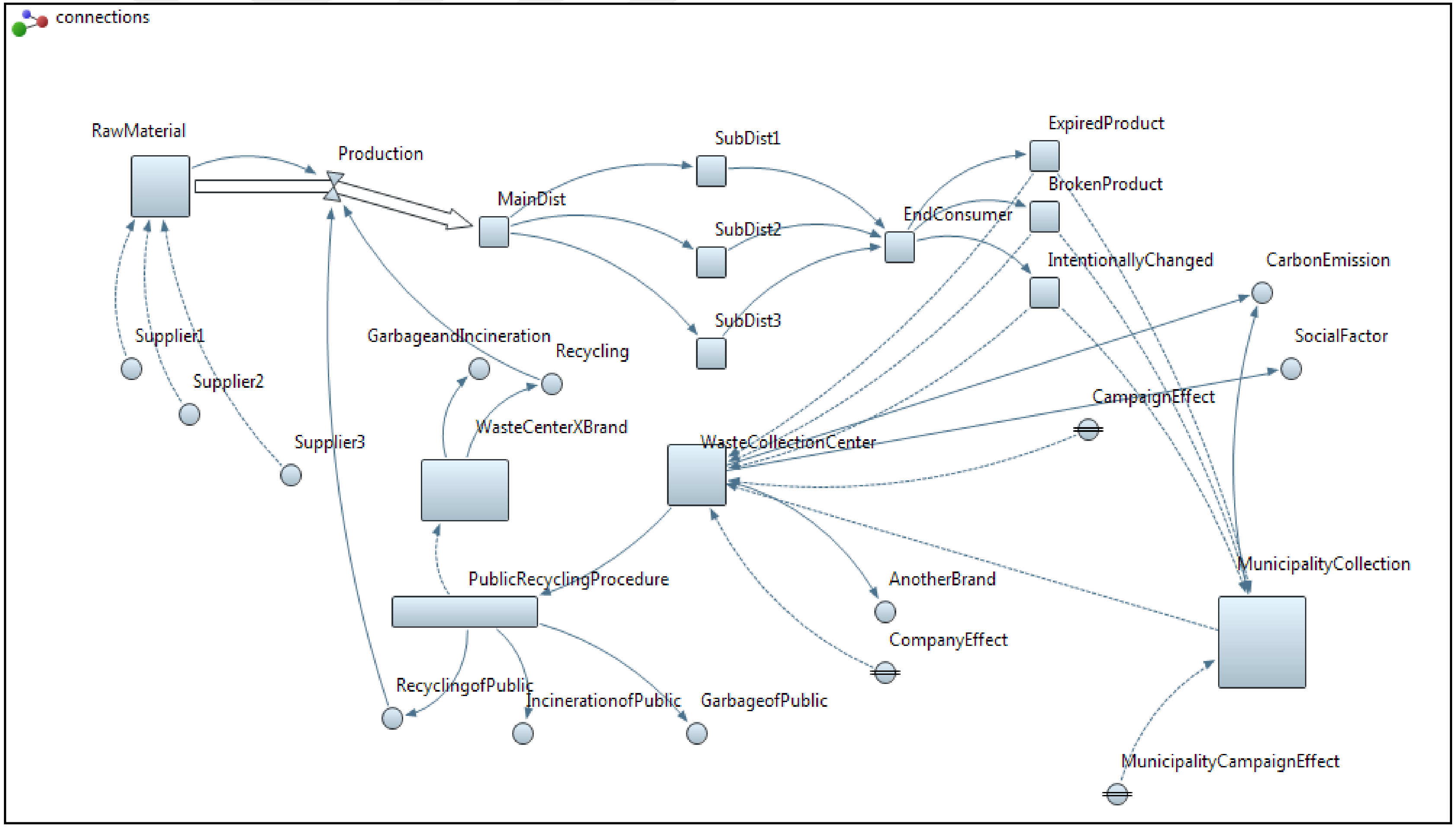

Figure 4.1: System dynamics model of small household appliances’ waste management in Turkey

In Figure 4.2, the relationship between production and waste amount is given. The amount of production and waste is directly proportional. The decreasing point of production is explained as the raw material taken from suppliers is a dynamic variable. It seasonally changes according to the demand. Besides, as production increases, wastes also increase. Wastes thereby change and sometimes have different increasing and decreasing points. Model has been simulated for *nearly 65 years* and the result is in Figure 4.2. The horizontal and vertical axes imply years and amount respectively.

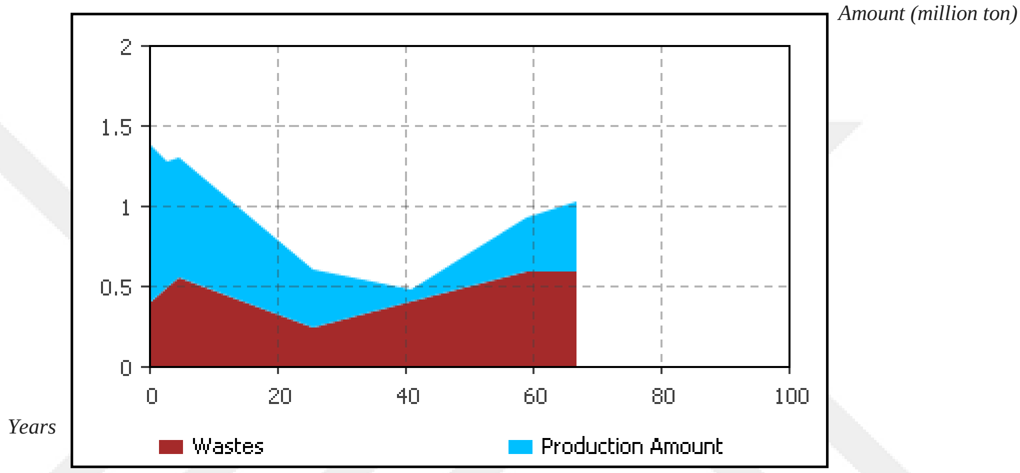

Figure 4.2: The relationship between wastes and production amounts

It is assumed that 50% of small household wastes in Turkey are going to be recycled by 2018 according to the recycling target of small household appliances which was published in the Official Gazette of Turkey in 2012[6]. All assumptions are based on this official target. Hence, in this model, 50% of total expired, broke-down and intentionally changed products go into recycling process. The proposed model has two main recycling collections places which are municipality collection center and waste collection center. According to the official Gazette (2012)[6], Municipality collections have different targets changed city by city.

Municipalities can use a campaign effect to increase public awareness for bringing expired, break-down of changed small household appliances to municipalities' recycling centers. In this model, it is used as a motivating and positive factor affecting municipality collection amounts.

[6] http://www.resmigazete.gov.tr/eskiler/2012/05/20120522-5.htm

Generally, all appliances are collected in waste collection centers in the model. The quantity of small household appliances gone into waste centers is assumed according to the target of 50% and proportionally, expired, broken or changed products are distributed assumingly. In Turkey, some electronic equipment companies have their own recycling centers. However, only one of these companies is put in the model as representation. Government or municipalities can sell the products to be recycled to electronic companies and these companies can use campaigns to attract appliances to their recycling centers. Companies can use these appliances in favor of their-own companies or sell to public or governments after recycled or during recycling process.

As indicated in the model, appliances recycled by government or companies can directly go into production processes. On the other hand, the rest of the appliances which is not recycled, named as garbage, cannot be in the production process again. They can be incinerated or landfilled in order not to be reused. In this case, government and companies can make campaigns to create awareness for public. In Turkey, some companies exchange old appliances by new ones to recycle them.

Furthermore, it is obtained that Incineration-Garbage rate decrease while recycling amount increases as given in Figure 4.3. This relationship shows that the amount of small household appliances landfilled or incinerated decreases by the campaign effects and awareness.

In this model, there are 3 additional effects that are used. These effects are assumed as constant numbers and while running the model, it is seen that they have a positive and enhancing effects on waste collection amount and recovery options.

These effects are as follows:

Campaign Effect: This effect considers “bring the old one and take the new one” situation that means consumers can pay a lower price for a new appliance. By the point of producers’ view, it means reaching governmental target by collecting appliances.
Company Effect: This effect includes the governmental effect that provides the company, government support if they encourage recycling and recycling centers. This effect is

provided mainly by government by supporting companies or giving them money to create awareness.

Municipality Campaign Effect: Consumers sometimes do not prefer to bring their old small household appliances to companies or private recycling centers. In other words, they can bring their appliances to municipality recycling centers. Municipalities can provide public awareness by campaigns about environmental protection.

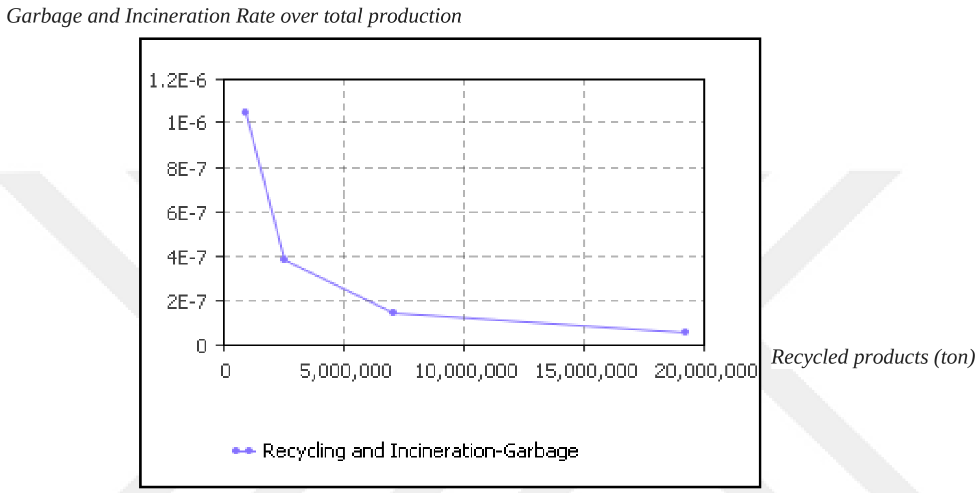

Figure 4.3: Relationship between recycling and Incineration-Garbage Rate

In the model, carbon emission and social factor also take place. The carbon emission has been affiliated by the number of appliances brought to waste collection center. The carbon emission decreases as the incinerated or garbage products decreases in lieu of landfilling or incinerating which implies that if wastes are gained to production process, they will provide a material reduction instead of using new materials. New material production makes carbon emission increased and using wastes in place of new materials will decrease carbon amount. It is also preferred that these appliances go into production process.

Also, Carbon emission decreases when incineration rate decreases. They have a direct proportion as seen in the system dynamics model in the Figure 4.1.

4.2. Bayesian Network Model's Decision Nodes

By the reference of system dynamics model of small household appliances in Turkey, Bayesian network methodology can be used in terms of decisions to be made. As given in the figure 4.1, it can be easily seen that the model includes two main dynamic variables whose names are "PublicRecyclingProcedure" and "WasteCenterXBrand". It is indicated in the system dynamics model that the small household appliances in Turkey which are expired, intentionally changed or broken , will be recycled by the government or a private company. The Bayesian network has been used to evaluate which system will recycle appliances. The evaluation has been made in a probabilistic way.

Actually, brands and Turkish government have different waste collection centres. Companies have campaigns to receive electronic and electric equipment to recycle them. For instance, the biggest electronic equipment brand in Turkey has its own recycling centre. [7]

In the study, NETICA Bayesian Network software application has been used and the results have been given in Appendices section. As mentioned in the system dynamics modelling, Turkey has a target of 50% to recycle WEEE by the end of 2018 declared in the official gazette. Netica application has been done by taking into consideration this target.

Firstly, the first node of network is products which are expired, changed or broken. In this case, the probabilities have been given logically to reach 100%. Because the rates of sub-nodes are not extremely important for recycling process. All products located in decision node are tended to be recycled anyway. It is estimated that expired products have 40% of probability, broken and intentionally changed products have respectively 30% of probability to be included in total product out of %100 according to the GFK report in Turkey based on small household appliances which implicates that over total production and life cycle, people decide to change their appliances by a probability of 40% and the other probabilities are expected respectively as given above.

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[7] http://www.arcelikas.com/sayfa/947/Beklenen_Degisim_Kampanyasi_Basladi

Over the decision nodes, the main problem is how to decide whether wastes coming from consumers will be recycled by the government or a company. In order to decide, the nodes starting from products have firstly been divided into two nodes which are "WasteCollectionCenter" and "MunicipalityCollection". These nodes include a general waste collection centre located in big cities of Turkey, and they are responsible for collecting all wastes. "MunicipalityCollection" implies the waste collection centres located in big or small towns of Turkey. The conditional probabilities have been encouraged by "campaign effects". Furthermore, the decision nodes are supported by campaigns put in the model as well.

The first campaign effect which directly affects decision nodes put in the model as an effecting factor is "MunicipalityCampaignEffect". As explained in the system dynamics model part, this campaign aims to attract consumers' old small household appliances to companies or private recycling centers. In other words, they can bring their appliances to municipality recycling centers. Municipalities can provide public awareness by campaigns about environmental protection. Here, municipality campaign effect realization probability is taken 70% as municipalities have recently had awareness of recycling so that consumers are able to bring their appliances. The decision node has been built by 70% in a positive way and %30 in a negative way which are indicated as YES or NO. This assumption is based on Official Gazette (2012) which implied that even the municipalities whose population is less than 10.000 must gather WEEE starting from 1st of January, 2018. Therefore, every municipality in Turkey must have a target that aims to collect WEEE. The node is hereby associated with this law and tied to 70%, however it has been thought that there is a gap of 30%.

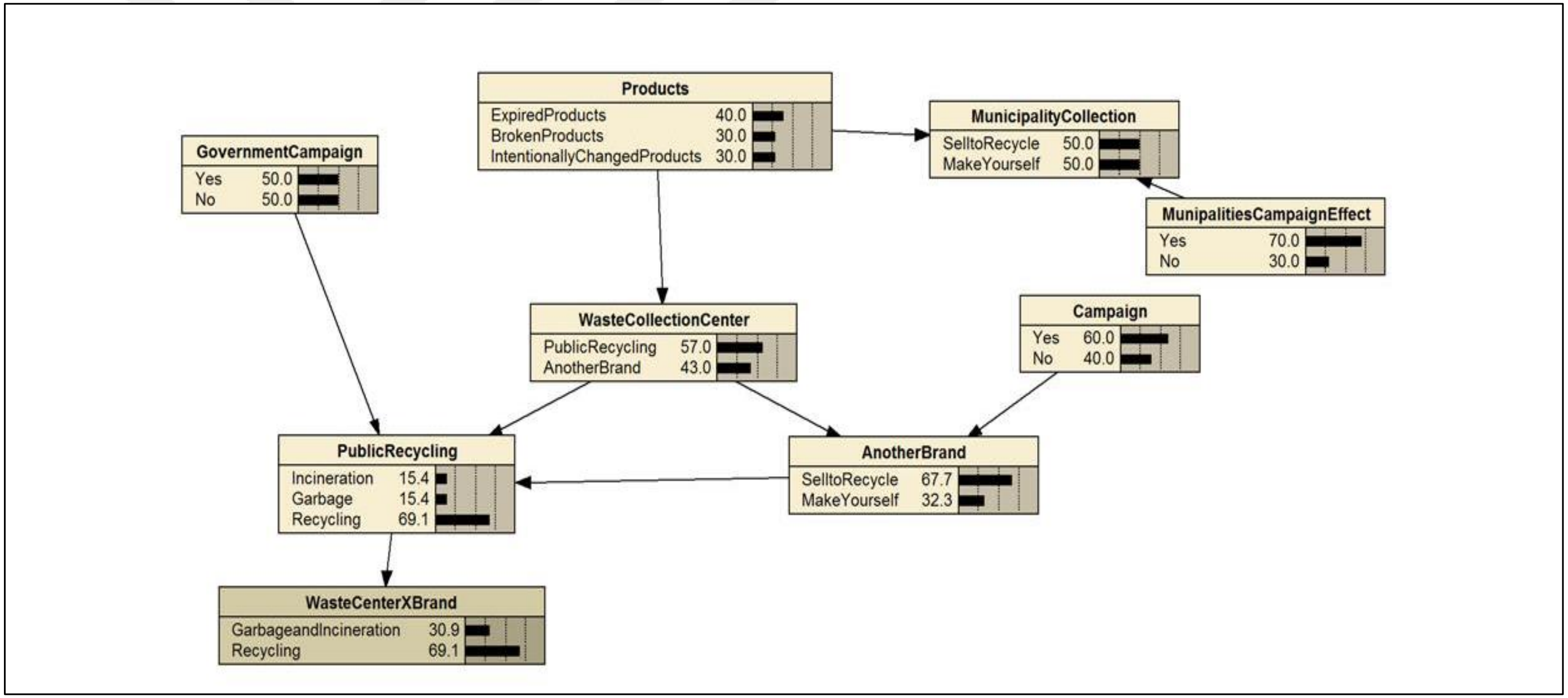

Figure 4.4. Bayesian Network for small household appliances’ system dynamics

“MunicipalityCollection” is affected by MunicipalityCampaignEffect and directly tied to this effect. In the MunicipalityCollection node, there are two options SelltoRecycle and MakeYourself. These options mainly indicate and are used to decide whether the Municipalities in Turkey will recycle the wastes in their own recycling centres or sell them to the government or any company. Municipalities choose both to sell to government or recycle them in their own facilities. So, the probabilities have chosen as %50.

On the other hand, as explained in the system dynamics model, all wastes are gathered in the “WasteCollectionCenter”. Here, the decision should be made by taking into consideration two situations: the wastes will be sold or sent to be recycled by government facilities located in big cities. Municipalities and big cities have been differentiated because big cities have their own facilities for recycling. “WasteCollectionCenter” node’s probability is related to “MunicipalityCampaignEffect” and the other campaign effects. In this case, which will be explained in details in analysis section, “GovernmentalRecycling”, which implies to be recycled in governmental recycling facilities as explained above, takes its wastes to be recycled from waste collection centres.

Furthermore, as seen in the Figure 3.5, there exist two options for Another Brand which aims to Sell to the government recycling centre for profit or recycle in its own recycling facility. In government facilities for recycling as “GovernmentalRecycling”, it is expected that every waste will not be recycled. Some of them will be incinerated or gone to the landfill areas. The last node “WasteCenterXBrand” implies that the other company may want to recycle the wastes and reuse them but here also all wastes cannot be recycled. Some of them may be incinerated. In this case, brands can consider their own company profit. These decision nodes are based on the assumptions given above. As these nodes are conditionally probabilistic, the recycling rates change the conditions given in other nodes.

5. ANALYSIS

The analysis of the results has been done in separate sections. Two main models including system dynamics model and Bayesian network decision model have been investigated by different points of views. Firstly, it should be mentioned that the system dynamics model has been run according to the target of 2018 published in official gazette and it has been seen that nearly 52% of wastes have been recycled according to the system dynamics model result given in Figure 4.2. However, in the analysis section, we will mainly emphasize the Bayesian network decision results based on system dynamics model. *This analysis is taken as a sensitivity analysis based on 50% official target and has been done to decide which facility will be the most probable to reach the target according to the simulation results.*

5.1. Government Campaign Effect

Given that the probabilities of government Campaign for collecting wastes which are equals, the recycling probability is 69.1% as seen in the Figure 4.1.. As mentioned above, government campaign effect includes the governmental effect that provides the company, government support if they encourage recycling and recycling centers. In this case, if we consider that government is certain about the campaign, which means there will be a campaign with a probability 100%, the recycling probability increased to 76.7% as seen in the Figure 5.3. In this case, we can mainly conclude that campaign effect is an important factor to support recycling regulatory. On the other hand, we can mention about two different cases: there is or there is not a campaign effect for small household appliances. The figures 5.1 and 5.2 given above show these two situations and probabilistic effects on recycling.

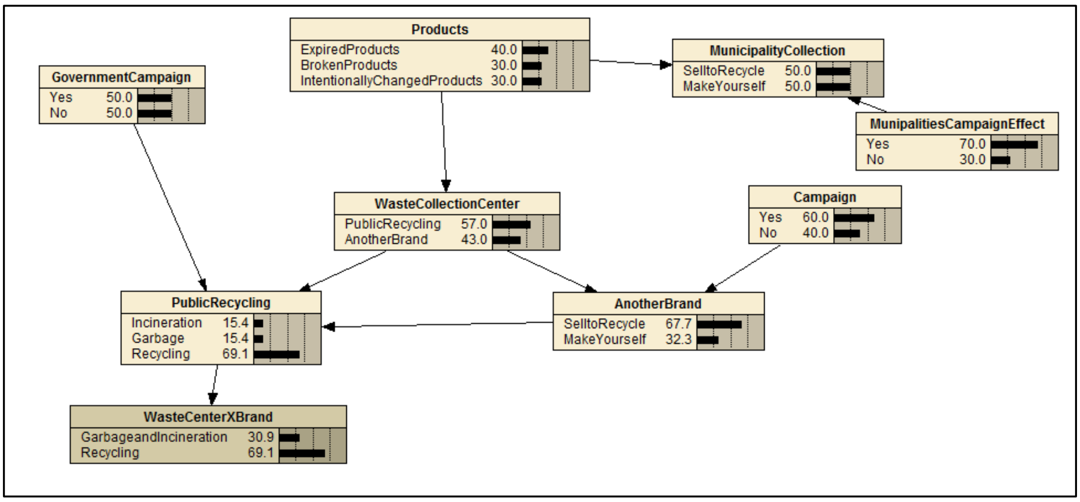

Figure 5.1: Recycling probability according to equal campaign effects

Furthermore, it can be concluded that not only government campaign but also other campaigns outstandingly affect the recycling probability which also indicates the recycling rate of small household appliances.

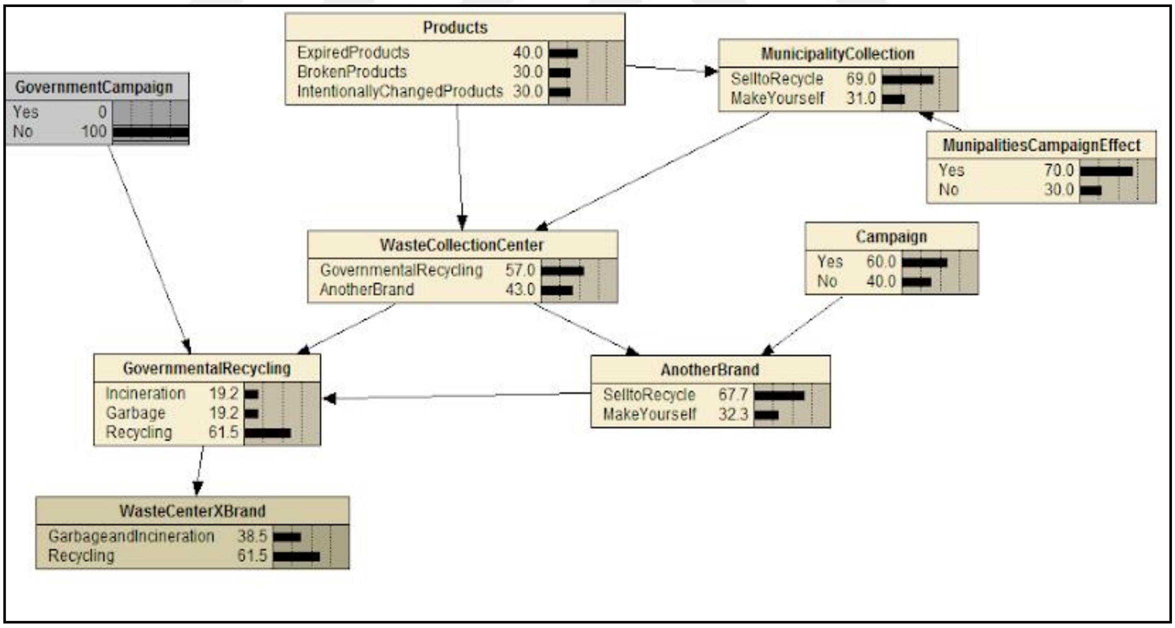

Figure 5.2 : Absence of government campaign situation

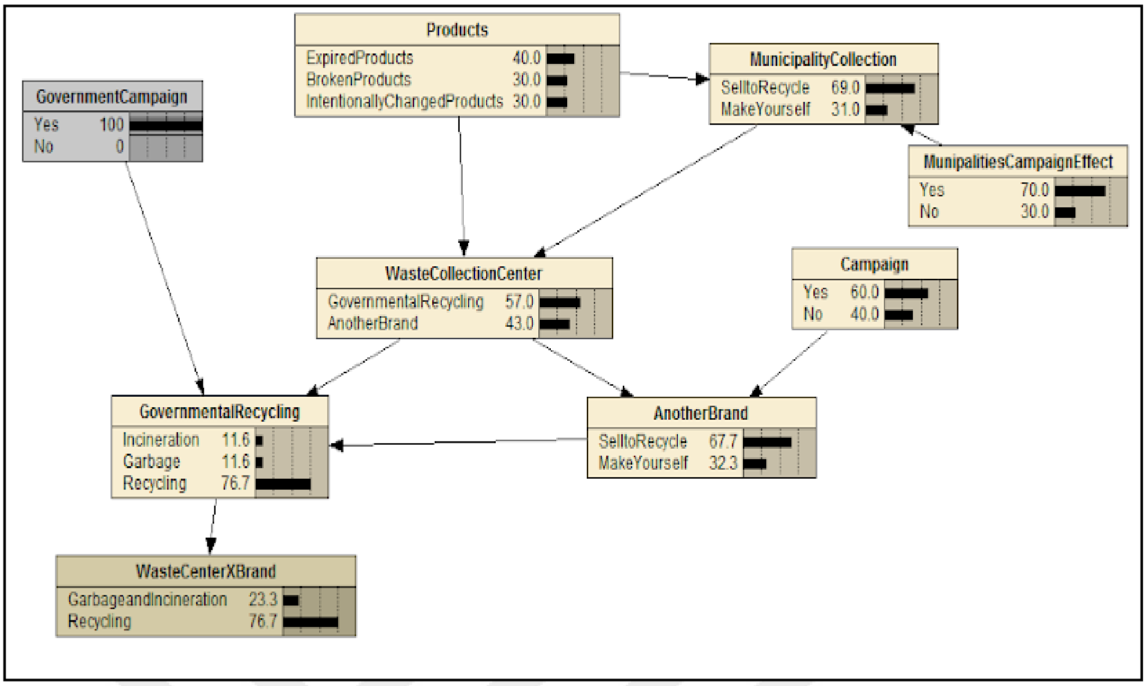

Figure 5.3 : Existence of government campaign situation

5.2. Governmental Recycling and A Brand Facility Recycling

In system dynamics model, brand facility and government facilities located in big cities have been considered separately. This is because people can choose to bring their old small household appliances to a brand or public facility. In this situation the question is where the recycling rate will be maximized and which facility will be more effective to recycle small household appliances in Turkey. To have a clearer idea, the Bayesian network has been used to have a sensitivity analysis. The maximum recycling rate occurs when the company put in the model gives a campaign to receive appliances and sell them to government with a profit margin. Governmental recycling nodes reaches to 80% as seen in the Figure 5.5 and that's the maximum obtaining compared to other situation.

When we assume that in the waste collection center, some of wastes go to brand facility and most of wastes go to governmental recycling facilities, the recycling rate reaches to 77.4%. The figures 5.4 and 5.5 given below show a systematic scheme for each case. All findings have been valid with the condition to apply absolute campaigns. In case of not applying campaigns, the findings are not valid.

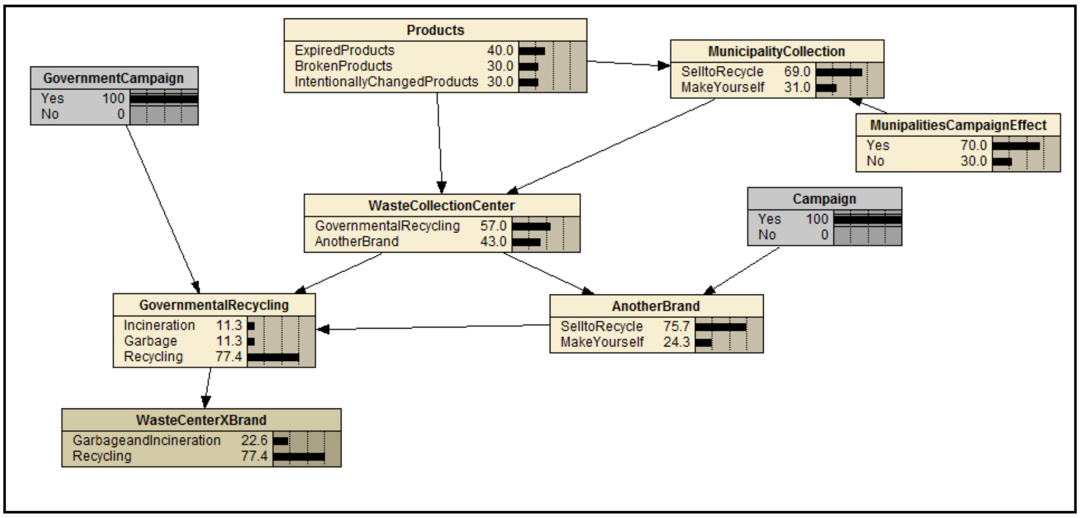

Figure 5.4: Overall campaign effect on recycling

As seen in the figure 5.4, given that the brand recycles a small part of total wastes with a proportion of 24.3% and sells to government with a proportion of 75.7%, the recycling rates presents a rate of 77.4%. This is a high probability but not maximized. The maximized probability occurs when the brand certainly makes a campaign, and totally sells its wastes to the government in order to recycle them. The main operation in the model is that the brands can try to attract the wastes to make profit from wastes. With this operation, brand makes profit, and gets a maximized recycling rate. The figure 5.5 shows the optimized recycling probability based on the official target.

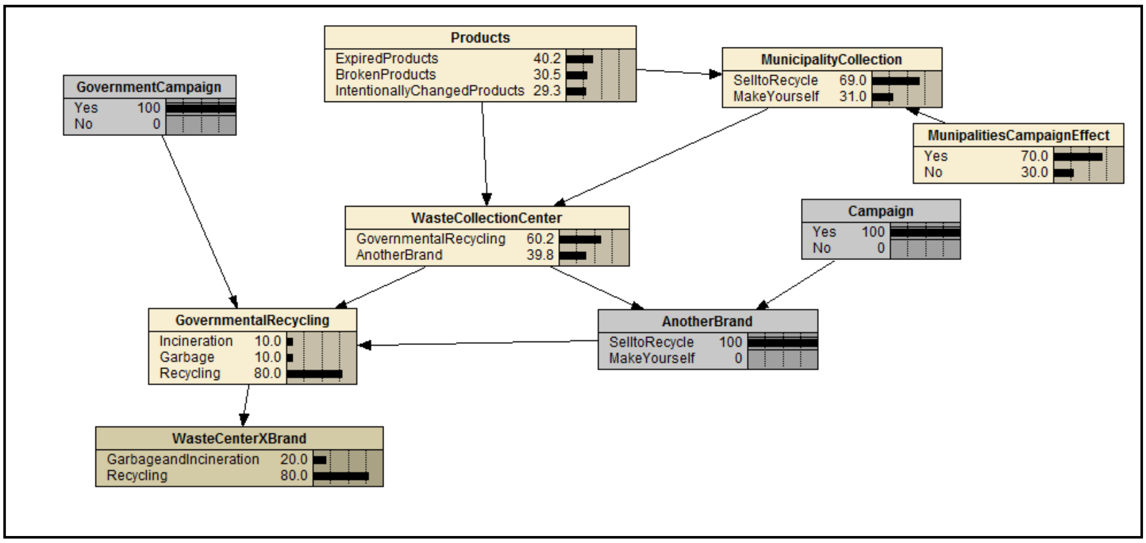

Figure 5.5: Overall campaign effect on recycling

As seen in Figure 5.5, the recycling probability has been found as 80%. As a perspective, it has been seen that as an advantage, the brand should sell the wastes to the government in order to recycle them in big cities, and campaigns should be applied. The problem is hereby that if the government recycles them in its own recycling facilities or it sells them. Nevertheless, it is sure that the analysis clearly explains that government recycling rate will be better compared to other situations.

6. CONCLUSION

WEEE is one of the most important problems in the 21st century. Because the amount of EEE is dramatically increasing year by year and WEEE causes not only global warming but also air, water pollution. To deal with WEEE, governments have published several regulations and recycling, recovery and collection targets have been decided by governments. Turkey also has put its targets into effect by the regulation published in 2012. In this study, it is investigated how a waste management policy should be implemented to reach these targets.

In this study, an integrated system dynamic and Bayesian network approach has been studied for small household appliances’ waste management in Turkey. First, the system dynamics model was run by using Anylogic simulation program. The study mainly shows that the proposed model can support a more effective and enhanced view about small household appliances’ waste management. Developed and supported waste collection centers by municipalities, government or companies provide a more intensive and increased recovery options while it decreases landfill and incineration rate. In the model, several factors have been considered with the purpose that the recycled products can be added to production line according to the target of Turkey. The system dynamics model at this point suggests also that campaign effects and company effects are outstandingly important in order to bring wastes to the waste centers, to inform public, and to increase public awareness about recycling. It has also been obtained that carbon emission decreases and social factor increases when the system works without any errors. The model also calculates how many of small household appliances in Turkey will be in process of recycling in order to reach the target of Turkey by 2018.

Secondly, by Bayesian Network Model, it has been found that the government will be a better option to reach to the targets compared to the private brand recycling facilities based on probabilistic findings. Also, when all assumptions are handed, the recycling target of Turkey assigned in system dynamics model has a probability %80 to reach. By noticing that WEEE recycling is one of the most crucial problem in Turkey, this probabilistic approach gives an illuminating and beneficial idea to recover and recycle small household appliances.

The main limitation of this thesis is that the real data of the proposed system couldn't be used in every dimension of the model because of the lack of data but main future targets have been put in the system dynamics model.

The main contribution of this thesis is that currently there is no study in the literature that integrates Bayesian network and system dynamics model in sustainable production area. System dynamics models in WEEE topic have been developed as given in literature review section but a combined way with a Bayesian network has not been developed. With this contribution, even if there is a lack of data, a systematic and probabilistic approach have been designed to pursue a more environmentally friendly production and recycling system.

For future studies, real data of all components in system dynamics model hopefully can be obtained and used. Furthermore, the integrity of the government and the private sectors should be taken into consideration in order to provide a more socially and environmentally sustainable Turkey. Also, as indicated in the model, carbon emission has been tried to decrease by a realistic appliance recycling. As a recommendation, carbon emission study can be done by using other dynamics model.
To give another future study recommendation, cell phones are increasingly used around the world and end of life-cycle telephones are producing important amounts of wastes. The given model can be developed and applied for cell phones' waste treatment. Proposed future study will give an opportunity to have an environmentally sustainability.

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APPENDICES

Appendix A.

2760 Some node(s) (e.g. GovernmentCampaign) don't have conditional probability tables (CPTs) (they will be taken as having uniform probabilities).

Probability of findings = 50 %.

Probability of new finding = 32.3 %, of all findings = 16.15 %.

Probability of findings = 33.85 %.

Probability of new finding = 67.0901 %, of all findings = 22.71 %.

Probability of findings = 7.29 %.

Probability of findings = 30 %.

Probability of new finding = 75.7 %, of all findings = 22.71 %.

Probability of findings = 7.29 %.

Probability of findings = 22.71 %.

Probability of findings = 7.29 %.

Probability of findings = 30 %.

Probability of findings = 30 %.

Probability of findings = 30 %.

Probability of findings = 20 %.

Probability of findings = 30 %.

Probability of findings = 50 %.

Probability of new finding = 60 %, of all findings = 30 %.

Tez_Bayes   Last changed 18/04/28 01:47

9   Nodes   (not including constants)

2   Decision nodes

0   Utility nodes

0   Constant nodes

0   Title or text notation entries

----

10   Links   (not disconnected)

0   Disconnected links

0   Time delay links

0   Directed cycles   (without delays)

2   Loops   (disregarding link directions)

1   Separate networks   (ignoring constants)

----

71   Conditional probabilities total

0   Decision conditions

----

2   Findings nodes (not including constants)

0   Negative or likelihood findings nodes

Clique [Joined To] Size   Member nodes (* means home)

0 [1 3 4]   24 (WasteCollectionCenter, AnotherBrand, *GovernmentCampaign, *GovernmentalRecycling)

1 [0 2]   12 (*Products, MunicipalityCollection, *WasteCollectionCenter)

2 [1]   12 (*MunipalitiesCampaignEffect, Products, *MunicipalityCollection)

3 [0]   8 (*Campaign, WasteCollectionCenter, *AnotherBrand)

4 [0]   6 (*WasteCenterXBrand, GovernmentalRecycling)

Sum of clique sizes = 62 (with sepsets = 77)

(but under current findings = 61)

BIOGRAPHICAL SKETCH

Aziz Kemal Konyalıoğlu, educated at Istanbul Technical University in the department of Mathematical Engineering and Management Engineering as a double major student as well as at Université de Nantes as an Erasmus Student, is now a research assistant in Istanbul Technical University at the department of Management Engineering Department.

PUBLICATIONS

Aziz Kemal Konyalıoğlu, İlke Bereketli Zafeirakopoulos, "A System Dynamics Model for Small Household Appliances' Waste Management: A Case of Turkey" (accepted), Protection and Restoration of the Environment XIV July 3-6, 2018, Thessaloniki, Greece.

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