

ASSESSMENT OF ALTERNATIVE CONTRACT DESIGNS FOR DEMAND SIDE
RESPONSE IN TURKISH ELECTRICITY SUPPLY SYSTEM

by

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*to my father,
who encourages me to pursue my dreams*

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ABSTRACT

ASSESSMENT OF ALTERNATIVE CONTRACT DESIGNS FOR DEMAND SIDE RESPONSE IN TURKISH ELECTRICITY SUPPLY SYSTEM

Demand Side Response (DSR) is the changes in electricity consumption of end-users from their usual consumption especially during peak consumption hours. It is expected that Turkey will become to implement interruptible load DSR program soon. These programs are based on the agreements regulating the interaction among actors who are willing to participate into the program. In this study, the impacts of alternative agreements designed by using different approaches on the revenue is assessed from the perspective of a demand aggregator (DA). These approaches are related to the allocation of the interruption order among consumers, payment options offered to consumers and the existence of upper limit of the interruption order for consumers. An agent-based model has been constructed to simulate 14 different scenarios composed of various combination of these approaches. After the model has been tested through validation procedures, model has been verified by using data sets produced from real data. The results of scenarios simulated in this study show that the DA can make profit even if it allocates all income taken from the independent system operator (ISO) among consumers. It can increase the profit by using different payment options and different methods for allocating the interruption order. For all scenarios, all consumers also can make profit. However, some experiments represent more fair profit distribution for consumers. Finally, the DA can reduce payment paid to the ISO as penalty for some scenarios. Nevertheless, the decrease in the income collected from consumers as penalty is not at a significant level.

ÖZET

TÜRK ELEKTRİK ARZ PİYASASI'NDA TALEP TARAFIGI KATILIMI İÇİN ALTERNATİF KONTRAT TASARIMLARININ DEĞERLENDİRİLMESİ

Talep tarafı katılımı (TTK) son kullanıcıların özellikle zirve tüketim anında normal elektrik tüketiminde yaptıkları değişimdir. Türkiye'nin yakın zamanda kesintili yük TTK programını uygulamaya başlaması beklenmektedir. Bu programlar programa katılmak için gönüllü olan aktörler arasındaki etkileşimi düzenleyen anlaşmalara dayanmaktadır. Bu çalışmada, farklı yaklaşımlar sergilenerek tasarlanan anlaşmaların gelir üzerindeki etkileri bir talep toplayıcının bakış açısıyla değerlendirilecektir. Bu yaklaşımlar kesinti emrinin müşteriler arasında dağıtılması, müşterilere teklif edilen ödeme yöntemleri ve müşterilere verilecek kesinti emrindeki sınırlamalarla ilgilidir. Bu yaklaşımların çeşitli kombinasyonlarından oluşan 14 farklı senaryoyu taklit edebilmek için ajan tabanlı benzetim modeli inşa edilmiştir. Doğrulama yöntemleri ile model test edildikten sonra, gerçek verilerden türetilen veriler kullanılarak model onaylanmıştır. Bu çalışmada taklit edilen senaryolar, talep toplayıcısının bağımsız sistem yürütücüsünden elde ettiği gelirin tamamını müşterileri arasında dağıtsa bile kâr edebileceğini göstermektedir. Farklı ödeme seçenekleri ve farklı yük dağıtma yöntemleri ile bu kârı artırabilir. Ayrıca, tüm senaryolar için tüm tüketiciler de kâr edebilmektedir. Fakat bazı senaryolar tüketiciler arasında daha adil bir kâr dağılımı sunmaktadır. Son olarak talep toplayıcı bağımsız sistem işleticisine ceza olarak ödediği ödemeyi bazı senaryolarda azaltabilmektedir. Fakat, müşterilerden ceza olarak toplanan gelirden dikkate değer bir azalma söz konusu değildir.

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LIST OF ACRONYMS/ABBREVIATIONS

2D	Two Dimensional
ABMS	Agent-Based Modelling and Simulations
ARIMA	Autoregressive Integrated Moving Average
C	Consumer
CL	Curtaillable Load
CPP	Critical Peak Pricing
DA	Demand Aggregator
DB	Demand Bidding
DLC	Direct Load Control
DR	Demand Response
DSR	Demand Side Response
DSM	Demand Side Management
EE	Energy Efficiency
EPDK	Energy Market Regulatory Authority
EUAS	Electricity Generation Company
IL	Interruptible Load
ISO	Independent System Operator
LM	Load Management
RTP	Real Time Pricing
TEAŞ	Turkish Electricity Generation-Transmission Company
TEDAŞ	Turkish Electricity Distribution Company
TEİAŞ	Turkish Electricity Transmission Company
TEK	Turkish Electricity Authority
TESS	Turkish Electricity Supply System
TETAŞ	Turkish Electricity Trade and Contracting Company
TOU	Time-of-Use

1. INTRODUCTION

Electricity systems are typically composed of generation, transmission, distribution and retailing functions. Electricity generation refers to the production of electrical energy using various energy sources and various technologies. Transmission of electricity implies the high voltage transportation of electricity between generating and distribution facilities. Distribution of electricity is used as the provision of the services of the distribution wires to consumers at relatively low voltages. Retailing operations means regulations for supplies of energy from generating centers, metering, billing and a variety of demand management services. These kind of retailing operations are typically considered as a complementary component of the distribution function [2].

While the electricity market structure is being assessed, the specific features of electricity should be considered. For example, the most distinct fact about electricity is that it cannot be stored easily and/or in an economic way unlike other commercial products, so there is an obligation to consume it at the time of production [3]. Therefore, the electricity sector has been traditionally operated under vertically integrated structure in which production, transmission, distribution, and trading activities maintained by a single legal cooperation, and it has been considered as a natural monopoly for a long time.

However, the idea of creating electricity markets in which all stakeholders will take advantage have begun to spread in the world, and world electricity markets have begun to be formed with new legal regulations. Thereby, the world, and especially European electricity sector, has begun to advance in the direction of separating their basic elements from each other to create more reliable and functional electric markets via increasing in private sector participation. Nevertheless, there is still a tendency for the provision of transmission services by the public and monopolization due to the high cost of transmission investments and the difficulties of expropriation in significant dimensions [3].

A similar restructuring process of electricity sector has also been taking place in Turkey. In 1970, The Turkish Electricity Authority (TEK) was established to remove dispersed structure in the electricity sector and to ensure the integrity among generation, transmission, distribution and sales services throughout the country outside the mission areas of privileged companies and municipal boundaries. Until 1990s, TEK dominated the electricity sector in Turkey as a vertically integrated, state-owned monopoly. In 1993, a period of electricity market restructuring began after the legislation had removed monopoly power. In 1994, TEK was restructured as two separate state-owned enterprises which are Turkish Electricity Company (TEDAŞ) being responsible for distribution services and Turkish Electricity Generation-Transmission Company (TEAŞ) being responsible for generation and transmission services [4].

In 2001, the way of privatization and unbundling were paved to enable participation in the electricity sector. At the first stage, TEAŞ was divided into three separate entities which are Electricity Generation Company (EUAŞ), Turkish Electricity Transmission Company (TEİAŞ) and Turkish Electricity Trade and Contracting Company (TETAŞ) by the Electricity Market Law. While EUAŞ is responsible for generation, TEİAŞ is responsible for transmission. Transmission is a critical activity that is related to the distribution of produced electricity to consumers and its transfer to the distribution network [5,6]. TETAŞ is responsible for wholesale of electricity to engage in electricity trading and contracting activities in accordance with general energy and economic policy [7]. In 2001, the independent Energy Market Regulatory Authority (EPDK) was also established to provide independent regulation and surveillance in a financially strong, stable and transparent energy market [8]. At the second stage, the number of wholesale actors has increased at a fast rate. Thereafter, more unbundling activities have occurred in distribution and retail areas.

Although there have been different advances in the history of the Turkish Electricity Market, the main concern related to provide electricity in a continuous, reliable, quality and economical way has remained stable. The way of ensuring this main aim is to provide the balance between generation and consumption of electricity in real time

to avoid sudden losses of electricity. According to the traditional approach, demand cannot be scheduled in a flexible way, and generation capacity should be built in by considering further peak demand. Therefore, to offset the supply against the demand is a quite difficult task under the assumption of strictly inelastic demand. Nevertheless, demand has been fluctuating during a specified time period. The amount of the electricity demand is observed at different levels as peak level, shoulder level and off-peak level [9]. Although there are some suggestions on energy storage instead of costly investment especially for peak demand times [10], to store the adequate electricity in an economical way is still a quite difficult task.

The investment in electricity generation in accordance with the peak level of demand may be thought as an alternative solution in the long-run. However, this investment will be an idle capacity throughout the periods outside peak level period. When electricity sector was a state-owned monopoly, the investment in electricity generation was relatively easy. With the long run perspective, the government could decide to invest in electricity generation satisfying the need, even if there was no return in the short run. Nonetheless, the total electricity consumption, on one hand, is increasing in most parts of the world owing to the growing population and implementation of high technologies to reach economic development, especially in developed and developing countries. On the other hand, some countries have a difficulty in reaching the need for increased electricity via ample investment due to a high cost of investment in electricity generation. Similarly, the difference between the peak level of demand and an available installed capacity for electricity generation begun to reduce in Turkey, so the investment option is getting difficult to implement.

Moreover, penetration of renewable energy sources into generating electricity gives rise to two main potential challenges for the offsetting process. The first challenge is related to the structure of renewable energy power with regards to its sensitivity to different weather conditions. This sensitive structure may be a problematic feature in terms of overlapping the peak in generation with the peak in demand because, renewable power cannot be scheduled as certain as conventional power plants [11]. The

second challenge is the mismatch of renewable energy power with rapid changes of demand from off-peak level to peak level. In this way, peaking power plants such as fossil-fueled thermal plants and hydro power plants are mostly dispatched to be able to provide sufficient electricity with the same amount of the peak level demand [12]. However, this use of various and different power plants leads to dramatic increase in the total cost of electricity [13]. In addition, the use of most of the peaking power plants increases the level of environmental pollution, which is an unfavorable way if we consider the issue from environmental perspective.

Fossil fuel-based energy sources are not evenly distributed throughout the world. Hence, some countries may depend on fuel imports from other countries. If the relationship between these countries is politically unstable, the side being in the position of explicit importer country run the risk of compromising reliable electricity [14]. For instance, Turkey has a weakness related to power generation because of foreign source dependency. According to an annual report of EPDK, Turkey imported 99.08% of the natural gas in July 2016, and 50.22% of this total imported amount was provided from Russia [15]. Therefore, external relations of Turkey have a powerful effect on the supply of reliable energy sources for electricity generation.

The primary handicaps mentioned above including costly investments, the intermittent penetration nature of renewable energy sources into electricity generation and foreign source dependency are all important considerations emphasizing the need of a new approach to ensure the balance between supply and demand in times of extremely high energy consumption. One of the alternative approaches of maintaining efficient use of installed capacity is the user engagement approach.

In the literature, the user engagement approach is commonly called as demand side response (DSR) or demand response (DR). In some sources, demand side management (DSM) and DSR are also used as similar terms. DSM and DSR are closely related concepts in their broadest sense, but there is essential difference between them. DSM is the proper term embracing long run actions of changing consumer habits as

well as short run actions. Nevertheless, DSR only refers to short run actions in energy markets if it is used accurately. In this study, we will use the terms DSR and DSM in different meanings.

DSM may be roughly defined as the planning, implementation and monitoring of utility activities to produce desired changes in the utility's load shape by modifying customers' energy use patterns [16]. DSM programs are typically composed of two main objectives: energy efficiency (EE) and load management (LM). EE programs are primarily preferred to reduce total energy consumption of specific systems permanently or ongoing basis by encouraging high-efficiency equipment use. LM programs, contrarily, are used for temporary reductions in consumption especially during peak demand periods. LM programs can be divided two main activities: permanent-load shifting and peak-shaving related to DSR [17]. The main focus of this study is related to the DSR. Hereafter, we will continue with just DSR after that.

The DSR approach points out that if some energy users conserve a little electricity during peak periods, then there will be sufficient and adequate electricity for each one [18]. U.S. Department of Energy has defined DSR as follows: "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." [19] The DSR approach is not a one-dimensional approach. It has a multifaceted context embracing various types of programs, procedures and rules. It is important to incentive demand-side participation in DSR programs. However, there are other participants such as policymakers, independent system operators (ISO), demand aggregators (DA) and so on in DSR programs. It is important to regulate the interaction between different participants to be able to ensure a successful implementation. Nevertheless, the dynamic interaction between different participants makes regulation of the program hard. Hereby, the DSR approach attracts serious attention of researchers.

The remainder of this study is organized as follows. Chapter 2 presents key terms related to the DSR approach. Chapter 3 focuses studies in the literature and essential motivations for this study. Chapter 4 justifies the main reasons for the selecting an agent-based modelling and simulations (ABMS) as a suitable method for this study. Chapter 5 summarizes the essential framework of this study and its structure in detail. Chapter 6 elaborates the behavior rules followed by main actors. Chapter 7 presents information about data generation approach, followed by experimentation procedure, scenarios used, tests applied for validation and verification of the model. Chapter 8 presents results obtained from the developed model. Finally, Chapter 9 discusses the results of this study and gives some advice for further studies.

2. CONCEPTUAL BACKGROUND

We have already investigated essential handicaps (including costly investments, the intermittent penetration nature of renewable energy sources into electricity generation and foreign source dependency) for the need of the DSR approach in electricity markets in Chapter 1. Now, we will explain the fundamental elements of this approach that forms main theme of this study and its different types in the literature.

2.1. Basic Elements of Demand Side Response Programs

There are various types of DSR programs. All of them share three common design components: participation components, operation components and settlement components [1].

- (i) Participation components includes both consumer segment and sanction structure applied throughout the implementation of the program. DSR programs could be set up as mandatory or voluntary programs depending on the sanction structure. In mandatory programs, consumers who signed an agreement to participate in DSR must reduce their electricity consumption when an independent system operator (ISO), asks for demand reduction. Otherwise, the consumers have to pay a penalty fee. In voluntary programs, whether to reduce electricity load in response to signals or not is optional for the consumers.

Target consumers of DSR can be divided into three main categories: large consumers (larger than 1 MW), medium consumers (100kW - 500 kW) and small consumers (less than 100 kW).

- (ii) Operation components indicate the trigger signals for load reduction, controller types for load reductions, timing of notification, and types of eligible technology.

Load reduction could begin with either reliability or economic event trigger signals. Reliability event trigger signal occurs as electricity system reliability is in jeopardy, or there is any capacity constraint of electricity generation. Economic event trigger signal is connected with electricity market prices. Consumers voluntarily reduce their load to lower their electricity billing in response to this signal. The load reductions can be checked by ISOs, DAs or consumers according to the DSR program.

The ISO forecasts the expected time when system reliability will be under risk based on past electricity usage patterns. If the ISO estimates that there is a potential risk for the system, it gives notification to the program participants via event signals sent by fax, phone, e-mail or pager. These signals can be sent within the range from an hour to 24 hours ahead before giving the request for load reduction. In addition, the utility must build the technological infrastructure associated with eligible hardware and/or software enabling to manage implementation and monitoring of DSR programs in a successful way.

- (iii) Settlement components contain the incentive and penalty structures and disbursement.

A system operator typically wants to know how much electricity capacity to reduce will be available during peak period. Therefore, it needs to set up an advanced planning. Under the light of this plans the ISO offers some bill credits, discount rates and even extra payments to encourage shedding load, or some penalties to discourage non-performance during peak period for consumers.

2.2. Categorization of Demand Side Programs

In general, DSR programs may be classified according to both the event trigger criteria for load reduction and the consumer motivation method. Incentive-based programs and price-based programs are two main forms of the consumer motivation

method. Providing that the program offers consumers various economic incentives for load reduction from their non-essential consumption during specified time periods, the program is called as an incentive-based program. If the consumers voluntarily reduce their electricity usage in response to economic signals at electricity market, the program is called as a price-based program. As mentioned above, load reduction could begin with reliability or economic event trigger signal. Definitive DSR programs can be presented in detail as shown in Table 2.1

Table 2.1. Categorization of demand side response programs [1].

		Consumer Motivation Method	
		Incentive-based programs	Price-based programs
Event Trigger Criteria	Reliability Trigger	Direct Load Control (DLC) Curtable Load (CL) Interruptible Load (IL)	Critical Peak Pricing (CPP) Demand Bidding (DB)
	Economic Trigger	Direct Load Control (DLC) Curtable Load (CL)	Time-of-Use (TOU) Dynamic Pricing Demand Bidding (DB)

The incentive-based programs offer consumers various discounts, economic benefits or extra payments either for reducing their electric usage during specified time periods or shifting their electric usage to a different time from specified time periods. These programs are essentially based on agreements between the ISO and consumers. These agreements give some incentives and some flexibility options to consumers who are willing to cooperate by reducing their consumption at the time of a given request.

According to the design components and the program aims, incentive-based programs could be examined in three different forms as direct load control (DLC), curtailable load (CL) and interruptible load (IL). The essential objective of DLC programs is to pave the way for participation of great numbers of small consumers. In this program, ISOs have the right to remotely turn off the consumer's loads for limited periods of time [20]. CL programs target medium and large consumers instead of small consumers. In this program, consumers gain some incentives in exchange for turned off loads or reduced electricity usage for limited periods of time, after given signal. IL programs are addressed to large consumers. In this program, consumers turn off total load for specified time periods [21]. The specific details of each type of incentive-based programs associated with their design components are shown in Table 2.2.

Price-based programs allow customers to voluntarily reduce their load in response to economic signals. In terms of pricing structure and the amount of advance notification, these programs can be categorized into three different categories as time-of-use (TOU), dynamic pricing (DP) and demand bidding (DB).

The TOU programs are based on variations of the electricity provision cost according to peak period, shoulder period and off-peak period. DP programs can be divided into two main categories as critical peak pricing (CPP) and real time pricing (RTP). The basic idea behind CPP programs is to reflect the uncertainty and volatility of electricity provision costs better. This program calculates additional time-dependent rate throughout peak periods. RTP programs directly expose consumers to the variability and volatility of hourly actual electricity provision costs during the day in the wholesale power market [22]. DB programs are designed based on two different prices. Either the ISO proposes price to consumer at which it is willing to pay or consumers proposes price to the ISO at which they are willing to sell their load reduction. The specific details of each type of price-based programs regarding design components are summarized in Table 2.3.

Table 2.2. An overview of incentive-based programs [1].

	DLC	CL	IL
Target consumer	Small consumer	Medium and large consumer	Large consumer
Sanction structure	Mandatory	Mandatory or voluntary	Mandatory
Controller	Provider/utility	Provider/utility or consumer	Provider/utility or consumer
Timing of Advance Notification	None	Changes from minutes to hours	Changes from minutes to hours
Settlement property	Fixed credit on monthly bill	Monthly bill adjustment, penalties for non-performance	Monthly bill adjustment, penalties for non-performance

Table 2.3. An overview of price based programs [1].

	TOU	DP (CPP & RTP)	DB
Target consumer	All	All	All
Sanction structure	Mandatory or voluntary	Voluntary	Voluntary
Controller	Consumer	Consumer	Consumer
Timing of Advance Notification	None	Hours or day ahead	Hours or day ahead
Settlement property	Monthly bill adjustment	Monthly bill adjustment	Separate payment based on bid price, additional reductions beyond bip paid, locational marginal price

3. PROBLEM DESCRIPTION AND OBJECTIVES

The practice of DSM explained in Chapter 1 was proposed in the 1980s for the first time, and policymakers have begun to recognize the potential benefits of user engagement in electricity market. Since then a countless case studies, analyses and research on DSR published in the literature. After a couple of utilities performed the early pilot and permanent DSR programs in the early 1990s, some gradual changes related to these programs have begun to be observed. We have already explained the conceptual framework of DSR in detail in Chapter 2. In this chapter, we will discuss the studies on experiences related to DSR programs on different regions in the world.

We can divide studies on these programs into two main categories as an overview of articles focusing DSR programs on particular regions of the world and an overview of international experiences related to current DSR programs in electricity markets.

The first category consists of academic researches on different types of DSR programs. This category is useful to have a scientific insight of the development process of DSR programs in different regions of the world. Faruqui (2001) discusses the causes of California's power crisis, which is the result of an imbalance between demand side and supply side, and drivers to introduce demand elasticity as the major lessons for energy policy makers [23]. Adersen (2006) assesses DSR from a microeconomic perspective by examining the Denmark and the Nord Pool market cases [24]. Torriti (2010) explains initiatives, studies and policies of various European countries as well as the overview of case studies in the UK, Italy and Spain in detail [25]. Cappers (2010) focuses on the existing contribution of DSR resources in U.S. [26]. Walawalkar (2010) presents a review of the change in the DSR programs in PJM and NYISO markets, and analyzes current opportunities by considering the ability of DSR to mitigate variability of renewables [27]. Dong (2016) explains the potential of DSR in China by considering regulatory issues and relevant pilot projects [28]. Paterakis (2017) presents international DSR programs in different regions after giving information about the benefits,

the drivers and the barriers of DSR programs [22]. These studies prove that the DSR programs is a hot and important topic on various regions of the world. Moreover, each one of them emphasizes the importance of choosing the correct regulation approaches for DSR programs.

In the second category, some market experiences related to current DSR programs from the regions dominating DSR markets can be explained to understand the trend of DSR programs in the world. In California, Pacific Gas & Electric Company offers the “SmartAC program” to its commercial and residential consumers and varied of DSR programs including “base interruptible program”, “demand bidding program”, “optional binding”, “peak day pricing” and “scheduled load reduction program” for consumers which can reduce 100 kW or 15% of their monthly average peak demand at least [29]. In New York, New York Independent System Operator offers a set of different DSR programs such as “emergency DR program” and “special case resources” for large consumers, “day-ahead DR program” and “demand side ancillary Services Program” for retail consumers [30]. ConEdison Company also gives an opportunity for consumers which can reduce their load 4h at least to be able to participate in “commercial system relief program” or “distribution load relief program” provided that consumers pass the mandatory test every year [31]. In New England States, ISO-New England is responsible for operating organized wholesale power markets via “demand bidding” and “emergency demand response” to manage demand side consisting of all classes (large, medium or small consumers) [32]. Although all programs in question have similar context, they differ with regard to details such as timing of order notification, the amount of an incentive, whether the flat credit per month will be even if no event trigger is activated or not, the limit of events requested per specified time period and so on. These international experiences present a wide variety of approaches and methods to implement DSR programs. Each one of them proposes different regulations for different consumers on the different regions of the world. This is the proof that the to design suitable agreement for specific target consumer on specific region is a difficult task.

When we analyzed the development process of DSR in detail, we can easily realize two fundamental tendencies in the world. The first tendency is related to program type selection. According to the experiences in the world, ISOs prefer to implement incentive-based programs rather than price-based programs in early years of DSR because of two main potential problems of price-based programs. From policymakers' perspective, the uncertainty of DSR market potential, which can be defined as the amount of the potential load reductions in response to high prices or incentive payment offering, is one of these potential problems [33]. The other is the need of the high technological infrastructure to be able to manage price-based programs. Nevertheless, incentive-based programs have been considered as more manageable practice, since it benefits from agreements between participants of DSR. These agreements are composed of some articles including the minimum limit of load reduction for each interruption to be able to participate in this program, the limit for order given by ISO to begin the interruption, the duration time limits for each interruption and so on [34]. Moreover, they require relatively less technology to implement DSR.

The second tendency is related to target consumer. Policymakers tend to design simple programs aiming for large consumers in early years of DSR, since they can reduce a remarkable amount of load at the system with a little number of large consumers instead of negotiating a lot of small consumers individually. In the advancing years, they progress into more sophisticated programs to extend the implementation of DSR with the participation of a numerous small consumers.

In Turkish Electricity Supply System (TESS), no DSR programs (except a pilot project [35]) have been applied yet. When the tendencies in the world are considered, Turkey will highly possibly begin to implement IL programs by targeting large consumers.

In literature, there are studies on the discussion about transferability of DSR policies between countries. According to Warren, the policy transferability framework is roughly divided into three classes as direct copying, adaptation and inspiration. Direct

copying means direct translation into one country of all policies about DSR on another country. Adaptation refers the copying of policies by adapting them to current conditions of the country in question. The way adaptation could be occurred as synthesis from a couple of different countries or emulation from another country. Inspiration, on the other hand, refers to the copying of policies from other countries' past experiences or their current practices at the idea level [36]. When we have compared Turkey with other countries to assess the option of DSR policy transferability, we have realized that Turkey has some essential differences from other countries. These differences are related to electricity market structure, electricity system structure, climate characteristic, market potential for DSR and the habits of target consumers. Hereby, the inspiration approach seems more suitable option than direct copying and adaptation approaches for Turkey.

The potential actors to participate into IL programs in TESS could be divided into three main categories as independent system operator (ISO), demand aggregator (DA) and consumer (C). The ISO is the actor managing the regional load balancing to operate, maintain and develop grid stability across a specific region. DAs are intermediary firms between ISOs and consumers. They not only provide some services to numerous consumers in their portfolio but also act as just one entity with their portfolio toward ISOs. Consumers, on the other hand, form the demand side by consuming the electricity [37].

The incentive-based programs benefit from agreements to be able to encourage demand side to participate into the program. Two main agreements types are possible to be used at the IL program in TESS. The first agreement SO-DA is signed between an ISO and DAs. The second agreement DA-C is signed between a DA and consumers in its portfolio. In this case, a DA will be one of the main actors for both agreements, and it likely faces the problem with the management of the balance between two agreements SO-DA and DA-C after its participation into IL programs. Although the international experiences of DSR programs give much information about the context of agreements for both ISOs and DAs, there is the deficiency in the literature related to analyses on

probable effects of interactions of these two agreements SO-DA and DA-C. We aim to provide the experimental analysis focusing on the interactions of alternative agreements in TESS from the perspective of the DA.

The agreements in question includes procedures and rules to regulate the interaction between actors. The implementation of IL programs is based on interaction among main actors who will sign these agreements. The ISO gives the interruption orders to reduce electricity usage when it realize the potential risk causing the imbalance between generation and demand. The ISO generally prefers to interact with just DAs instead of a lot of consumers individually. A DA allocates the interruption order given by ISO among consumers in its portfolio. Hereby, it interacts with both ISO and consumers in its portfolio. Consumers form the demand side, and they shed the load at the level of the given order by DA. Therefore, they interact with just their DA.

Nevertheless, all consumers in the DA's portfolio may not shed the equal amount load. The electricity usage characteristics of each consumer may vary depending on their job. While some of them may consume electricity within a smaller range, the amount of electric consumption of others may fluctuates within a wider range. If they reduce the electricity consumption below the inadequate level to operate the vital part of their job, they will likely face crucial problems affecting their operational tasks and financial positions. Therefore, independently of their electricity consumption pattern, none of them will be volunteer to shed the load that causes to drop below their minimum load for vital part of their job. In this case, DA should decide how it should divide the interruption order given by the ISO among heterogenous consumers in its portfolio. In addition, it should offer proper payment options to be able to encourage different consumers that have concerns about load reduction.

The primary objective of this study is to discuss the probable impacts of the DA's different decisions about what to offer to consumers. For the sake of this aim, we have especially focused on three decisions related to the allocation approach of the interruption order given by the ISO among consumers, the payment options offered to

consumers and the existence of upper limit of the interruption order on the agreement DA-C. We aim to reach financially comparable results about different decisions at the end of this study.

4. METHODOLOGY

As mentioned before, the research question focused on in this study embraces two main characteristics related to IL programs in TESS. These characteristics are the interaction of different actors and different electricity usage characteristics of consumers. The interacting actors have various responsibilities and different behaviors depending on simple rules. As mentioned above, three main actors composed of one ISO, the DAs and consumers in the DA's portfolio can participate into IL programs. The ISO is the side giving the interruptions order to the DA to reduce electricity usage from its portfolio. The DA is an intermediary firm between the ISO and consumers. Moreover, it is essentially responsible for distribution of interruption orders given by ISOs among consumers in their portfolio. Consumers, on the other hand, have a responsibility to reduce their load at the level of the given order by DA.

One of main focuses in this study is to analyze the impacts of different ways for a DA to allocate the interruption order given by the ISO among the DA's consumers. Nevertheless, the electricity usage characteristics of each consumer may be differed from each other according to their job. In this case, the potential of each consumer for load reduction is varied. Depending of the diversity in consumers, the approach of the DA can differentiate towards each consumer. Besides the heterogeneity of consumers, there is interdependence among consumers. The DA allocates the interruption order in proportion to the consumers' capability. In this case, all consumers are affected from other consumers' capability.

In selecting a suitable methodology to be applied in this study, the ABMS is assessed to be the most appropriate methodology for essential characteristics of the IL program in TESS. ABMS is the approach to model complicated systems composed of agents who interact with each other. In ABMS, the pattern of the system is not explicitly programmed into the models but arises through the agent interactions. Each agent has own behavior based on its characteristic, and interactions with other agents.

By modelling agents individually, the holistic impacts of the heterogeneity and behavioral difference among agents can be observed as a whole [38]. We aim to reach the probable impacts of interaction of individual actors who have different characteristics and behaviors under the various agreement rules. Therefore, the methodology ABMS is selected to be employed in this study.

5. DESCRIPTION OF THE MODEL

In this chapter, we aim to give information about the model developed to obtain the probable impacts of the DA's different decisions that offers to consumers. For the sake of this aim, the remainder of this chapter is organized as follows. Section 5.1 presents key expressions used in the study as from this chapter. Section 5.2 summarizes the model by explaining static description of each actor, and the content of agreements. Section 5.3 gives assumptions benefitted for agreement determination. Section 5.4 represents limitations used on agreements. Section 5.5 summarizes the differences and similarities between the agreement SO-DA and DA-C.

5.1. Fundamental Terms

All fundamental terms used in the development of this model is as follows. *Actors* includes the ISO, the DA and consumers as classes. *Demand side* means the DA for the ISO and consumers for the DA. *Validity period* (days) defines validity period of the agreements. *Performance* (MW) means the amount indicating the calculated load reduction of demand side. *Non-performance* (MW) indicates the amount of the difference between interruption order and calculated load reduction of demand side. This amount is calculated for the case that demand side falls into penalty.

Duration (hour) defines the length of given interruption order. *Duration Options* is the list including different duration. *Activation time* (hour) means the upper limit of interruption order that can be given to demand side within validity period.

Contracted flexible load (cfl) is the available capacity that can be reduced by demand side for interruption order. *Activation stock* (MWh) defines the total available capacity during validity period. Activation stock is calculated by multiplying the contracted flexible load and the activation time. *Planned order* (MW) presents the interruption order planned to give to demand side. *Certain order* (MW) means the

interruption order given to demand side provided that some conditions are satisfied. *Postponed order* (MWh) is the amount added activation stock.

Electricity consumption at portfolio level (hour) is the sum of hourly electricity consumption of all consumers in the DA's portfolio. *Individual electricity consumption* (hour) means hourly electricity consumption of each consumer.

Demand list is the list consisting of hourly demands of previous 45 days. While the ISO has a demand list consisting of electricity consumption at portfolio level, the DA has 105 demand lists consisting of its individual electricity consumption. *Unascertained baseline window* (ubw) presents the window time over which demand data are collected to be able to establish baseline. *Baseline* shows the expected value for the usual electricity consumption of demand side if there were no interruption order. *Min-load* means the lower bound at which consumers operates just vital part of their job. *Flexible load* (flex-load) is the difference between the baseline of a consumer and the min-load of the consumer.

5.2. Overview of the Model

As mentioned above, the essential target of this study is to assess the DA's different decisions to propose consumers who are willing to participate into IL programs. For the sake of this target, we have decided to assess the results from just one DA's perspective, and we have restricted main actors of the model with one ISO, one DA and 105 large consumers who have different electricity consumption characteristics.

Each actor has own static attributes and dynamic attributes of which value change during the execution of the model. In addition, each actor follows simple behavior rules during validity period. The ISO's static description, in which all attributes and behaviors are summarized, is given in Figure 5.1. The DA's static description is given in Figure 5.2. The consumers' static description is given in Figure 5.3.

Static Attributes	Dynamic Attributes
<ul style="list-style-type: none"> • offered price for payment of the DA • offered price for penalty of the DA 	<ul style="list-style-type: none"> • duration • planned order for the DA
<p>Behaviors</p> <ul style="list-style-type: none"> • Decide whether the interruption order gives to the DA or not • Give the planned order to the DA • Measure the DA's load reduction • Assess the DA's performance • Calculate the penalty of the DA and/or payment to the DA <p style="text-align: center;">Static Description of the ISO</p>	

Figure 5.1. Static description of the independent system operator.

Static Attributes	Dynamic Attributes
<ul style="list-style-type: none"> • contracted flexible load • activation stock • offered price for payment to consumers • offered price for penalty of consumers • income from the ISO 	<ul style="list-style-type: none"> • duration • certain order given by the ISO • planned order for each consumer • electricity consumption at portfolio level • payment to the ISO as penalty • payment to consumers • income from consumers • profit
<p>Behaviors</p> <ul style="list-style-type: none"> • Take certain order from the ISO • Allocate the certain order among consumers in the portfolio (planned order for Cs) • Give the planned order to each consumer • Measure the amount of load reduction of each consumer • Assess the performance of each consumer • Calculate the payment to each consumers and/or penalty of each consumer • Calculate own profit <p style="text-align: center;">Static Description of the DA</p>	

Figure 5.2. Static description of the demand aggregator.

Static Attributes	Dynamic Attributes
<ul style="list-style-type: none"> • contracted flexible load (optional) • activation stock (optional) • features of individual electricity consumption (mean & standard deviation) 	<ul style="list-style-type: none"> • certain order • individual electricity consumption • income from the DA • payment to the DA as penalty • profit
<p>Behaviors</p> <ul style="list-style-type: none"> • Take certain order from the DA • Reduce the load from non-essential electricity consumption • Calculate own profit <p style="text-align: center;">Static Description of Consumers</p>	

Figure 5.3. Static description of consumers.

We benefits the agreements to specify actors' attributes and behaviors. The content of agreements in question is composed of rules and regulations related to the implementation of IL programs in TESS. In the scope of this study, the rules refer to limitations of IL program. These limitations are validity period of agreements, contracted flexible load of demand side, duration options, the activation stock of demand side, and offered prices for both payment to demand side and penalty of demand side. The regulation, on the other hand, refers to various procedures constructing the essential behavior followed by actors. These procedures may be divided three main categorizes as order procedure, measurement procedure and assessment procedure. The order procedure explains the behavior of giving the interruption order to demand side. The measurement procedure clarifies the measurement way of the performance of demand side. The assessment procedure elaborates the cases falling into penalty in order to calculate the gain and penalty of demand side.

Although the essential content of agreements is similar, the sides differ from each other. As mentioned before, the agreement SO-DA is signed between an ISO and a DA

while the agreement DA-C is signed between the DA and consumers in its portfolio. The diagram which summarizes the dynamics of the model by showing which content of agreements is used by which actor can be presented as shown in Figure 5.4.

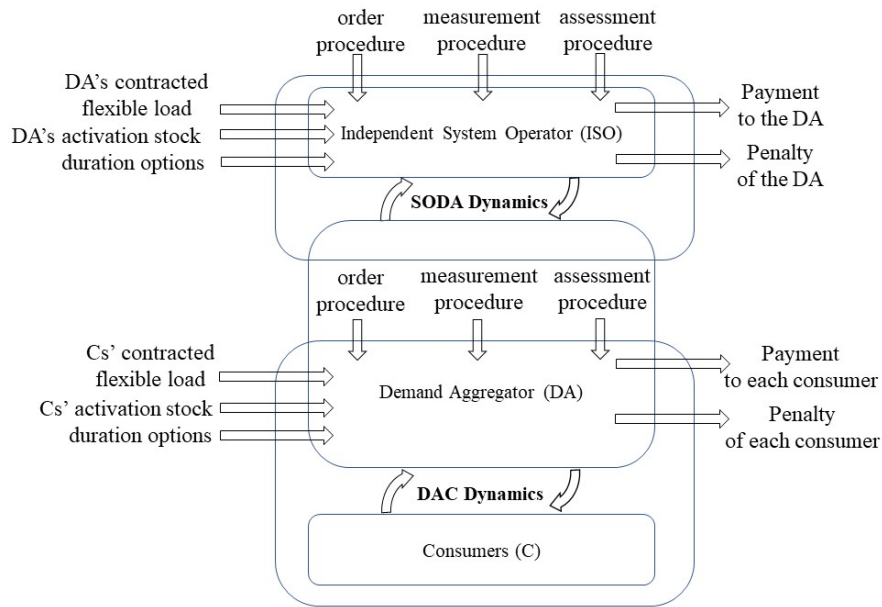


Figure 5.4. The diagram showing agreement dynamics.

In this study, we have fixed the content of the agreement SO-DA for all scenarios. However, we have changed some limitations and/or some procedures of the agreement DA-C for each scenario depending on the focus of this study (Figure 5.5).

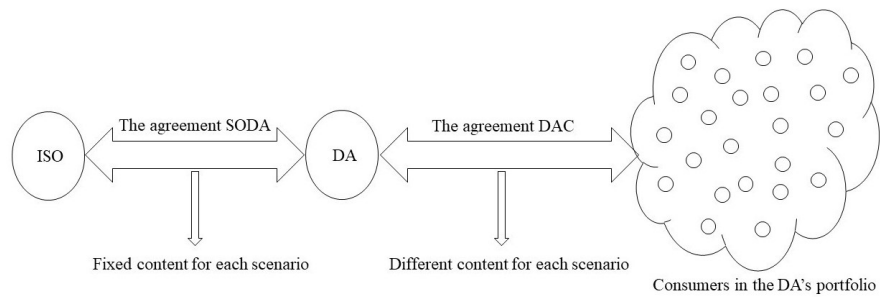


Figure 5.5. The diagram showing agreements.

5.3. Assumptions about the Content of Agreements

The assumptions benefitted in determination of agreements are:

- We have considered that peak level demand may be observed for workdays rather than weekends. We have calculated the validity period of agreements as one year including 253 days under the assumption that the interruption order can be given just on workdays, except official holidays.
- Consumers possibly reduce their load proportional to their standard deviation of electricity consumption. The DA, on the other hand, will want to ensure the load reduction potential in its portfolio. Therefore, we have assumed that the DA will participate into the agreement SO-DA with contracted flexible load calculated from one-third of the sum of consumers' standard deviation in its portfolio.
- There is no contracted flexible load on the agreement DA-C.
- In reality, the price of electricity varies over time. Nevertheless, to forecast price of electricity is a topic beyond this study, because the amount of payment in this study does not depend on the day and/or the hour that the interruption order is given. Hereby, symbolic prices have been used to be able to interpret received results. Payment to demand side and penalty of demand side will be calculated with these symbolic prices.
- The price of penalty per MWh have been determined as one and half times of the price of payment per MWh.
- The ISO offers fixed payments as much as the weighted activation stock in exchange for DA's commitment. However, it divides this amount into 12 equal part, and it gives them as monthly payment.

- The payment options offered by the DA to consumers changes depending on the scenario.

5.4. Parameters

Limitations explained in Section 5.2 determines the parameters of the model. Under the light of aforementioned assumptions, the parameters of the agreement SO-DA used in model can be represented as shown in Table 5.1.

Table 5.1. The first parameter set.

The name of parameters	Values
Validity period	1 year consisting of 253 days
Contracted Flexible Load	200 MW
Activation time	72 hours
Activation stock	14400 MWh = (200 MW * 72 hours)
Duration options	small (4 hours), medium (8 hours given as 4 + 4), long (12 hours)
Symbolic prices	1 unit for payment per MWh 1.5 unit for penalty per MWh
Monthly payment	1200 unit per month ((14400 MWh * 1 unit/MWh) : 12 month)

The parameters of the agreement DA-C used in model can be summarized as shown in Table 5.2.

Table 5.2. The second parameter set.

The name of parameters	Values
Validity period	1 year consisting of 253 days
Contracted Flexible Load	No value on the agreement DA-C
Activation time	72 hours
Activation stock	Scenario-based
Duration options	small (4 hours) medium (8 hours given as 4 + 4) long (12 hours)
Symbolic prices	1 unit for payment per MWh 1.5 unit for penalty per MWh
Payment options	Scenario-based

5.5. Comparison of the Agreements

As mentioned before, we have focused on the impacts of DA's decisions related to allocation of the interruption orders, payment options offered to consumers and the existence of activation stock in this study. Hence, we prefer using same content with the agreement SO-DA except those related to these decisions. Differently from the agreement SO-DA, the agreement DA-C does not include contracted flexible load. The DA calculates the value of contracted flexible load for each interruption order given by the ISO. However, the existence of activation stock depends on selected approach by the DA. When it uses static coefficients to calculate consumers' contracted flexible load, the agreement DA-C includes activation stock information. While the static coefficients are active, consumers' activation stock is calculated by the equation 5.1.

Let's assume:

c_i : the static coefficient of the i^{th} consumer

n : the number of consumers willing to participate into IL program (105 in this study)

a_i : the activation stock of the i^{th} consumers (MWh)

d : activation stock of the DA (MWh)

$$a_i = \left(\frac{d}{\sum_{i=1}^n c_i} * c_i \right), \forall i \in \{1, 2, \dots, 105\} \quad (5.1)$$

In addition, the DA can prefer to propose payment options different from the agreement SO-DA. However, to compare two agreements easily, the same proportion between the price of payment per MWh and the price of penalty per MWh is used for both agreements. The comparison of the content of agreements are summarized in Table 5.3

Table 5.3. The comparison of the content of agreements.

	SO-DA	DA-C
Order Procedure	Independent of scenario	Scenario based
Measurement Procedure	Fixed Formulation	Same with SO-DA
Assessment Procedure	Fixed Formulation	Same with SO-DA
Payment Options	Fixed Amount	Scenario based
Validity Period	Fixed Value	Same with SO-DA
Contracted Flexible Load	Fixed Value	No value on DA-C
Activation Time	Fixed Value	Same with SO-DA
Activation Stock	Fixed Value	Scenario based
Duration Options	Independent of scenario	Same with SO-DA
Symbolic Prices	Fixed Value	Same with SO-DA
Monthly Payment	Fixed Value	Scenario based

6. BASE BEHAVIOR OF THE MODEL

If we look at the system as a whole, we will see interacting actors. For example, the sequence of actions will be like this for just one certain order: the ISO gives the interruption orders to the DA. The DA allocates the certain order given by the ISO among consumers in its portfolio. Consumers try to reduce the load at the level of the given order by DA. The DA measures the load reduction of each consumer and assesses their performance. The ISO measures the DA's load reduction and assesses its performance. We can divide this whole process of the model into four different parts as order part, load reduction part, measurement part and assessment part. Although scenario based behaviors change depending on focus of this study, constant behaviors are composed of same behavior rules independent of scenario. We can summarize behavior types of all actors by considering which actor is active at which part of the model as given in Table 6.1.

Table 6.1. The table summarizing behavior type of all actors.

	The ISO	The DA	Consumers
Order	Scenario Based	Scenario Based	-
Load Reduction	-	Constant Behavior	Constant Behavior
Measurement	Constant Behavior	Constant Behavior	-
Assessment	Constant Behavior	Scenario Based	-

6.1. Order Part

All crucial decisions about the interruption order belongs to the ISO. The ISO decides the order day, the order hour, duration of interruption order and frequency of the interruption order.

In the real world, the ISO gives an interruption order when there is an imbalance between generation and consumption. However, to develop sensitive timing for the interruption order is the topic out of this study. However, to determine the time for the interruption order given by the ISO is important to execute this model. Therefore, we have assumed that the ISO decides the order day and the order hour randomly. For the frequency of interruption order, we have considered two different approaches by being inspired from real world cases. In the first approach, we have considered that the ISO can give an interruption order based on high electricity consumption. We have determined this case in the model as an interruption order from month to month until the DA's activation stock is exhausted. In the second approach, we have assumed that the ISO can give an interruption order when there is a technical problem about electricity system based on failure of infrastructure. In this case, the ISO wants to give order until the failure in question is repaired. We have determined this case in the model as all orders given as a block at one time until the DA's activation stock is exhausted. Therefore, we have determined the frequency of interruption order as two different ways as an interruption order once a month and block order (see Appendix A for detail).

The ISO will want to assess the DA's performance at the end of the day on which the interruption order is given. Hereby, it does not give the planned order to the DA as an interruption order unless it determines the DA's baseline that enables to measure the performance of the DA (for more detail about baseline, please see Section 6.3). If the ISO can calculate the baseline of the DA for each hour of the planned order's duration, it gives planned order to the DA as a certain order. Otherwise it cancels planned order (see Appendix A for detail). Similar rule for certain order also is available for consumers.

The DA takes the information about interruption order determined by the ISO. In addition, it decides which consumer will take how much interruption order. It could allocate the interruption order given by the ISO among consumers in proportion of their coefficients by using the equation 6.1.

Let's assume:

c_i : the coefficient of the i^{th} consumer

y : certain order for the DA (MW)

n : the number of consumers that have enough activation stock for interruption order

p_i : the planned order for the i^{th} consumers (MW)

$$p_i = \left(\frac{y}{\sum_{i=1}^n c_i} * c_i \right), \forall i \in \{1, 2, \dots, 105\} \quad (6.1)$$

We have assumed that the DA could use static or dynamic coefficients to allocate the interruption order. Static coefficients offer constant value for calculation consumers' interruption orders. However, the amount of interruption order per consumer is not static value since the amount may change due to the number of consumers that have enough activation stock for interruption order change. On the other hand, dynamic coefficients offer adaptive calculations using the dynamic attributes of consumers for each interruption order.

We have designed two different static coefficients as mean-based coefficient and sd-based coefficient. For the mean-based coefficient, we determine average electricity consumption for each consumer by looking their past consumption at the beginning of the year. After that, we use these values as static coefficients. We assume that the DA divides the certain order given by the ISO in proportion of these static coefficients under the mean-based method.

For the sd-based coefficient, we determine standard deviations of consumers' electricity usage by looking their past consumption at the beginning of the year. After that, we use these values as static coefficients. Under the sd-based method, we have supposed that the DA divides the certain order given by the ISO in proportion of these static coefficients. These orders calculated by using static coefficients are planned orders. As mentioned before, the DA gives a planned orders as a certain order to a consumer provided that the DA can calculate the baseline of the consumer.

When we try to allocate interruption orders in proportion of dynamic coefficients, we have used the consumers' flexible load calculated by the equation 6.2. To calculate the flexible load for each hour of duration is possible but impracticable approach for consumers. In real world, consumers are not willing to reduce their load at different amount during each hour of duration. Hereby, we choose to calculate one flexible load used for each duration period. While the dynamic coefficients are active, the planned order calculated by using flexible load is certain order. Because the DA uses baseline while it calculates flexible load.

Let's assume:

$baselinelist_{ij}$: the i^{th} element of the list composed of the j^{th} consumer's baseline for each hour of duration of interruption order

n : the length of baseline list

$flexload_j$: the flexible-load of the j^{th} consumer (MW)

$minload_j$: the min-load of the j^{th} consumer (MW)

$$flexload_j = ((\frac{\sum_{i=1}^n baselinelist_{ij}}{duration}) - (minload_j)), \forall j \in \{1, 2, \dots, 105\} \quad (6.2)$$

6.2. Load Reduction Part

Consumers consumes electricity at their usual consumption level depending on their business cycle. If a DA gives an interruption order to a consumer, the consumer tries to reduce its load as much as the interruption order given by the DA from its non-essential consumption during duration. However, none of consumers reduces their load below their min-load (see Appendix A for detail). Otherwise, they cannot operate their crucial operations.

In reality, the DA does not consume electricity, so it does not reduce any load. Nevertheless, it behaves as if it is demand side towards the ISO. Its electricity consumption consists of the sum of all consumers' load reduction in its portfolio. Therefore, its

load reduction is calculated over its consumer by using the equation 6.3.

Let's assume:

y : the amount of load reduction at portfolio level (MW)

x_i : the amount of load reduction of the i^{th} consumer (MW)

n : the number of consumers in the DA's portfolio ($n = 105$ for this study)

$$y = \left(\sum_{i=1}^n x_i \right), \forall i \in \{1, 2, \dots, 105\} \quad (6.3)$$

6.3. Measurement Part

To measure the performance of demand side is one of the important steps of the implementation of the IL program. After load reduction of demand side, its measured load should be compared to its baseline. The baseline methodology is one of the methodologies that enable to measure the performance in the literature. It tries to forecast the usual electricity consumption of demand side that the consumption would have been if there is no interruption order. The formulation of beneficial baseline for all actors is not easy task owing to the inherent volatility of electricity consumption at the demand side [39].

Studies in the literature proposes various calculations to formulate the baseline. Most of these studies emphasize that to calculate the baseline by using simple formulation that enables for all actors to calculate is important for its use. If demand side cannot calculate own baseline due to complexity, they worrisome for fairness and uncertainty of measurement. In this case, it makes difficult to convince the demand side to participate into IL program. Therefore, we try to formulate the baseline with understandable and simple method by benefitting expert's opinion.

We have followed 5 steps to calculate the baseline for each hour of duration (see Appendix A for detail). In step 1, five days baseline window that is the window of

days over which electricity consumption data of demand side are collected to establish a baseline. These data should be consisted of across like days (excluding order days) selected within the demand list from back to front. In step 2, five hours ubw is formed by the hours, at which to give an interruption order are planned, within the baseline window. In step 3, upward adjustment approach is used for the ubw. Until each element of the ubw will be above the 0.75 of average of the ubw, all elements is updated by starting the last day selected before. In step 4, the highest 4 hours among 5 hours within the ubw is selected. In step 5, the average of the highest 4 hours is calculated as baseline.

We have used same baseline formulation for both the agreement SO-DA and the agreement DA-C. However, the ISO calculates the baseline of the DA at portfolio level while the DA calculates the baseline of consumers at individual level. The measured load reduction of demand side is calculated from the difference between its baseline and its measured load.

6.4. Assessment Part

Assessment part is composed of two steps. The first step explains the performance of demand side. The second step of assessment part is related to accounting.

6.4.1. Performance Measurement

The performance of demand side is calculated by comparing the measured load reduction with the given interruption order. We use the performance to update activation stock of demand side and to find weighted revenues of actors.

The assessment procedure for the performance designed in this study benefits from deterministic limits. The defined upper limit is determined to minimize unintended consequences such as irregular consumption throughout duration of order or probable attempts of demand side to game the system. The defined lower limit, on the

other hand, provides flexibility to demand side before penalizing the non-performance.

We can examine the hourly performance over one example to understand the main idea behind the assessment procedure of performance designed in this study. Let's assume an 4 hours interruption order given to the DA as shown in Figure 6.1. In this figure, the y axis represents measured load reduction of the DA while the x axis shows time of interruption order. Each columns points out the DA's measured load reduction for each hour of duration.

The ISO accepts the load reduction of the DA until the upper limit (a). In this case, the DA's performance will be b at the first hour, a at the second hour, a at the third hour and d at the fourth hour. When the DA's performance is above the lower limit, its activation stock is reduced as much as its performance. If its performance is below the lower limit, its activation stock is lowered as much as interruption order. Moreover, its non-performance will be calculated by the difference between the interruption order and its measured load reduction (b - d). In this case, it will fall into the penalty in proportion of its non-performance.

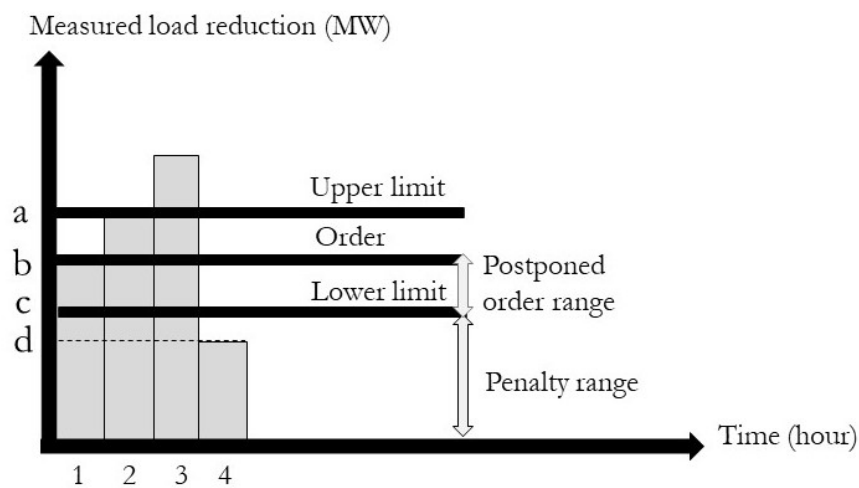


Figure 6.1. An example for performance measurement.

We have used both hourly assessment and daily assessment to measure the DA's performance on the day given order. We have used the approaches of hourly perfor-

mance for daily performance calculation. Moreover, the value of upper limit is as much as 125% of the interruption order for both assessment approaches. However, the value of lower limit differs from each other. The value of lower limit is as much as 75% of the interruption order in the hourly assessment approach while its value is as much as 90% of the interruption order in the daily assessment approach. The daily assessment dominates the hourly assessment. If the DA falls into penalty for daily assessment, its right in hourly assessment to postpone the interruption order will be canceled. We have preferred using same procedure to calculate both the DA's performance and consumers' performance (see Appendix A for detail).

6.4.2. Accounting

After the performance of demand side is determined, there is the need to calculate payment and penalty of demand side according to their performance. Although sensitive calculations for both gain and loss is possible, we want to compare the received results from different scenarios. Therefore, we use weighted gain and weighted loss for all results. For all scenarios, we assign 1 to price of payment per MWh and 1.5 to price of penalty per MWh.

In exchange for DA's commitment to reduce its load, DA receives fixed monthly payments independently of the its performance. Hereby, the DA earns 1200 unit $((14400 * 1) / 12)$ as weighted gain at the end of every month without considering running scenario.

The agreement DA-C, on the other hand, is designed as two different forms in this study. In the first form, the agreement DA-C provides fixed tired payments based on the of consumers' activation stock as much as committed amount on the agreement. Each consumer receives weighted gain as much as its committed activation stock times the price of offered payment per MWh at the end of the year. In the second form, it suggests payment option in proportion of the given order by the DA. According to this scenario, each consumer receives weighted gain calculated from given order during the

year times the offered price of payment per MWh. Regardless of payment option, both agreements impose penalties calculated by multiplying the total non-performance (all daily non-performance + all hourly non-performance), by the offered price of penalty per MWh at the end of every year.

7. SIMULATION EXPERIMENTS

We have clarified the agent-based model composed of the main actors, their attributes and their behavior rules followed during IL program in TESS. In this chapter, we will elaborate the experimental procedure presented to execute the agent-based model. The remainder of this chapter is organized as follows. Section 7.1 presents the method to generate the electricity consumption data of demand side. Section 7.2 clarifies the nested replication approach used in this study. Section 7.3 summarizes all scenarios experimented in this study. Section 7.4 focuses testing procedure of the model developed in the scope of this study.

7.1. Data Generation

There is the need of various information about electricity usage of the demand side to execute the designed model. The electricity consumption data at portfolio level consist of the sum of all consumers' electricity consumption in the DA's portfolio. If we reach individual electricity consumption for each consumer, we can calculate electricity consumption at portfolio level.

To execute an agent-based model, we essentially need random hourly electricity consumption of consumers in the DA's portfolio. However, the electricity consumption of large consumers at t hour is not independent from the electricity consumption at $(t-1)$ hour in real life. Therefore, we need autoregressive and autocorrelated time series for individual electricity consumption instead of random consumption.

Under the assumption that the DA creates a portfolio embracing 105 large consumers that each one has different mean and different standard deviation, we have produced 105 individual electricity consumption data for each year. For the sake of being able to produce realistic data, we have benefited from various yearly data sets consisting of real hourly electricity consumption of large consumers in Turkey. When

we have scrutinized the key features of these data sets, we have realized that the method ARIMA (Autoregressive Integrated Moving Average) using for forecasting of time series is the most suitable method to estimate hourly electricity consumption of large consumers in this study. Thus, we have produced 10 years data for each consumer by using real data sets with the function “ARIMA” on the software “R” that is one of software environments used widely for statistical computing [40].

We can look at standard deviations (sd) and means of hourly electricity consumptions of each consumer to get general idea about the produced data sets. The boxplot that gives information about sd of hourly electricity consumption of each consumer is as given in Figure 7.1.

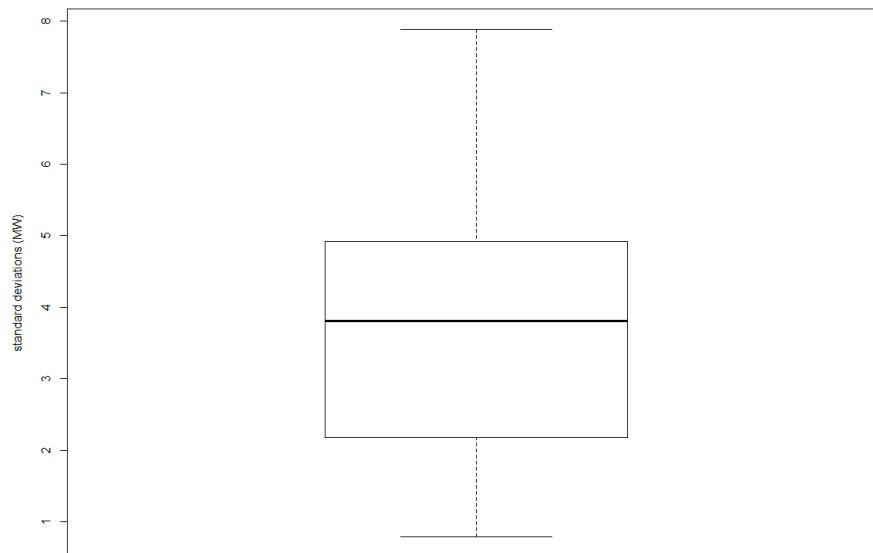


Figure 7.1. The boxplot showing standard deviations of consumers’ consumption.

The boxplot that gives information about mean of hourly electricity consumption of each consumers is as given in Figure 7.2. We also look at hourly electricity consumption of some consumers in a year. The plot that represents the hourly electricity consumption of the consumer (with mean 49.26 MW and sd 0.79) for a year is as given in Figure 7.3. The plot that represents the hourly electricity consumption of the consumer (with mean 44.77 MW and sd 7.88) for a year is as given in Figure 7.4.

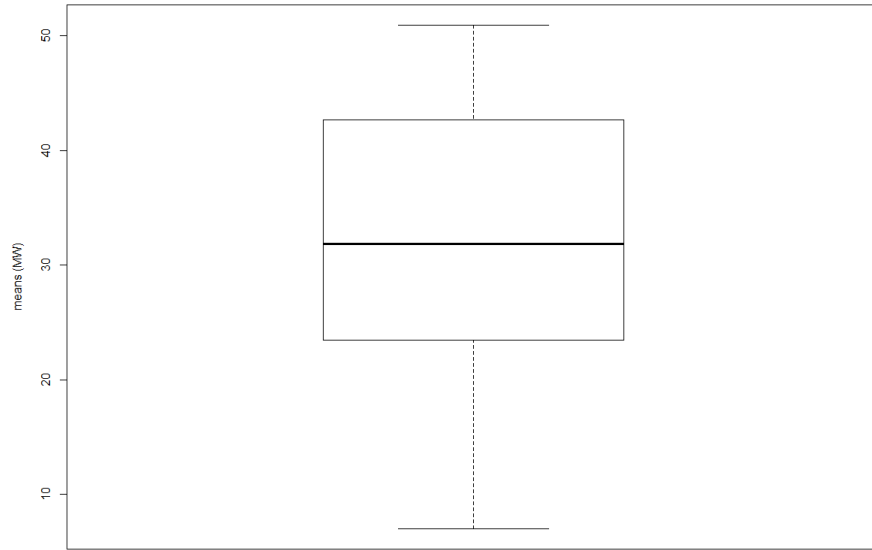


Figure 7.2. The boxplot showing consumers' average consumption.

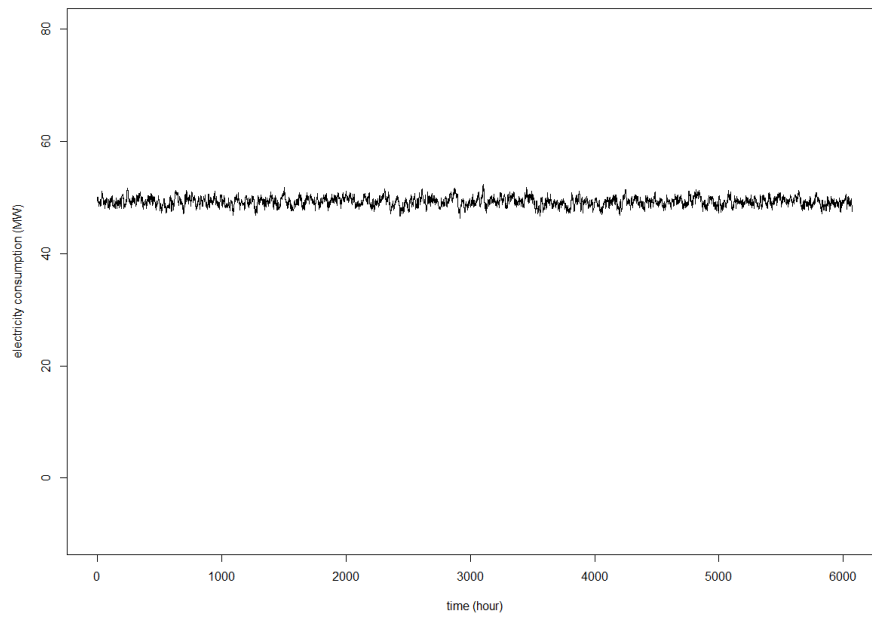


Figure 7.3. Hourly electricity consumption of the first consumer.

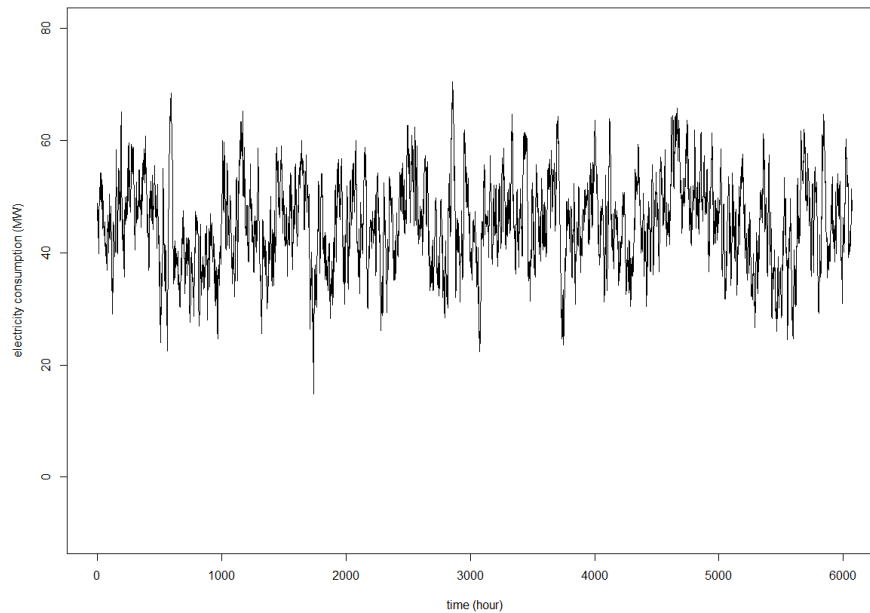


Figure 7.4. Hourly electricity consumption of the second consumer.

7.2. Experimentation Procedure

We build the agent-based model in NetLogo that is one of multi-agent programmable modeling environments [41]. While we run the model, we have used nested replication approach in two steps. In the first step, we have created 10 different data sets including hourly electricity consumption of each consumer in a year. The reason for working with different data sets is to reduce the dependence of results on data set. We have already produced 10 years data for each consumer in data generation part. For each consumer, we have divided this 10 years data into 10 equal parts. Each part is composed of yearly data list including 6072 hourly electricity consumption data (253 days * 24 hours). Hereby, each consumer has the pool including 10 different data lists. We have formed 10 different data sets for the model by randomly selecting different one data list from the pool of each consumer.

In the second step, we have executed the model for each data set with 15 different runs. In addition, we have paid attention to generate different random seed for each replication. The essential idea behind replication usage is to reduce the effect of

randomly given order on the result. We have used the BehaviorSpace tool of NetLogo to run multiple simulation with replications.

Hereby, we have run the model 150 times for each scenario by using nested replication approach. The diagram summarizing nested replication approach is given as in Figure 7.5.

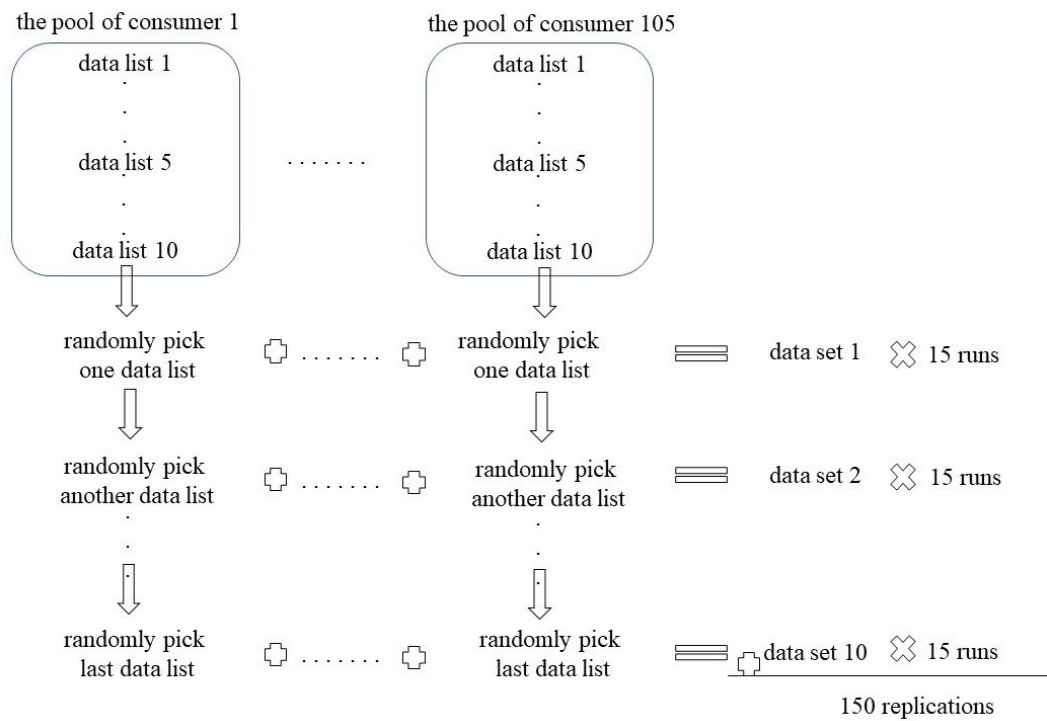


Figure 7.5. The process of nested replication approach.

All results represented in Chapter 8 have acquired by averaging over 150 different replications (15 runs * 10 data sets).

7.3. Scenarios

In this study, we aim to analyze the probable impact of various decisions of the DA on its own profit by considering consumers' benefit. For the sake of this aim, we design 9 different factors. We can divide these scenarios into 4 groups. The first group is related to different approaches for allocation of interruption orders among consumers. The second group is associated with the frequency of interruption orders given by ISO. The third group is connected whether there is activation stock ensured with the DA-C or not. The last group focuses on the offered payment options in exchange of consumers' participation into IL programs.

We have tried 14 different scenarios. The process summarizing the determination of scenarios used in this study is given as in Figure 7.6. Each scenario composed of four different factors, which each one of these factors belong to different group.

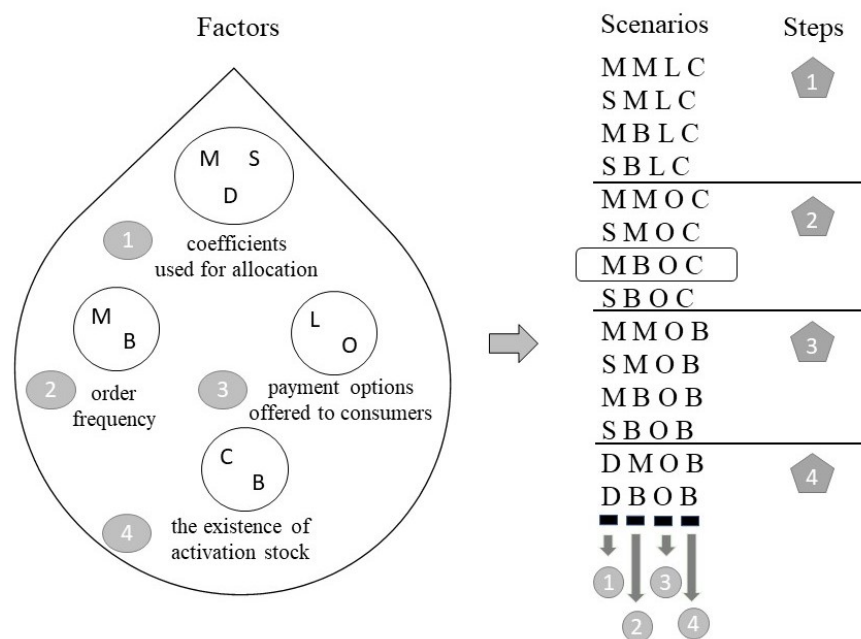


Figure 7.6. The determination process of scenarios.

We have represented these scenarios with names consisting of four letters. First letter represents the way of allocation the interruption order including mean-based (M), sd-based (S), dynamic (D) coefficients. Second letter points out timing of given order consisting of an interruption order once a month (M), all orders as a block (B) factors. Third letter gives the information about payment options offered to consumers such as lump-sum payment (L) and payment per interruption order (O). If the option “lump-sum” is active, the DA allocates its total income from the ISO among its consumers in proportional to consumers’ activation stock. Consumers have fixed income independent of the given interruption order during validity period of the agreement DA-C. For the other option, the DA offers the payment per interruption order during validity period of the agreement DA-C. Fourth letter explains whether there is any limitation about consumers’ activation stock on the agreement DA-C. If the agreement DA-C includes the information about activation stock, the letter C is used as a sign of “constrained activation stock”. Otherwise, the letter B is used as a sign of Big-M.

To illustrate, the scenario “MBOC” is composed of four factors. In this scenario, the DA allocates the interruption order given by the ISO among consumers in proportion of the average electricity consumption of consumers (mean-based coefficient). The ISO gives all order as a block (block factor). The DA offers payment in proportion of interruption order given to consumers (payment per interruption order). Finally, the agreement DA-C has limit for the activation stock of consumers (constrained activation stock).

We have assessed the results of these scenarios in four steps. In the first step, the scenarios “MMLC”, “SMLC”, “MBLC” and “SBLC” are explained. In the second step, the scenarios “MMOC”, “SMOC”, “MBOC” and “SBOC” are discussed. In the third step, the scenarios “MMOB”, “SMOB”, “MBOB” and “SBOB” are evaluated. In the fourth step, the scenarios “DMOB” and “DBOB” are assessed.

7.4. Validation and Verification

We have built the agent-based model in NetLogo. We have done both front-end development and back-end programming in the NetLogo. For back-end programming, we have used code tab of the NetLogo. The whole structure of the model composed of attributes and behaviors of all actors is programmed in this tab.

We have needed front-end development for validation and verification of the agent-based model developed via back-end programming in addition to easy of use. For easy usage, we have used the interface tab of the NetLogo. We have interacted with codes by working with interface elements in Figure 7.7. We have used buttons, "Setup" and "Run", to execute the model. We have benefitted from input boxes to enter some of global variables. Finally, we have represented all factors via chooser. These choosers let us determine a scenario by choosing these predetermined factors from a list of choices, so we have easily performed all scenarios.

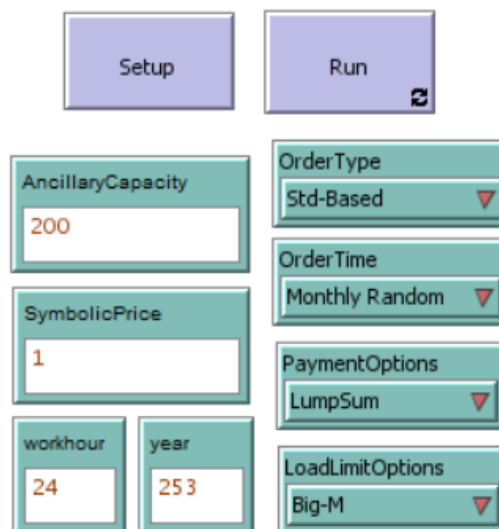


Figure 7.7. The interface elements used to execute the model.

For validation, we run the model composed of one ISO, one DA and one consumer. We have tried all extreme cases for all conditional statements (if & ifelse) in this model.

We have made the NetLogo write all results calculated at each step on the command center. We have checked these results step-by-step for all extreme cases. After we are sure that the conditional statement gives expected results, we have moved the model including one ISO, one DA and two consumers. We have tested all extreme cases for the interaction between actors with the same checking approach.

For verification, we have executed the model composed of one ISO, one DA and 105 consumers. We have benefited from interface elements of NetLogo to test all experiments. The screen shot of the model interface composed of 2D views, monitors and plot is given in Figure 7.8.

We have followed the load reduction part by monitoring shapes and colors of agents on the screen of 2D view (Figure 7.9). When there is no interruption order, all consumers have a neutral face with a yellow color. If there is an interruption order, they change face expression and colors in a harmony with the load reduction state. Moreover, we have observed the change in activation stocks with monitors (Figure 7.8).

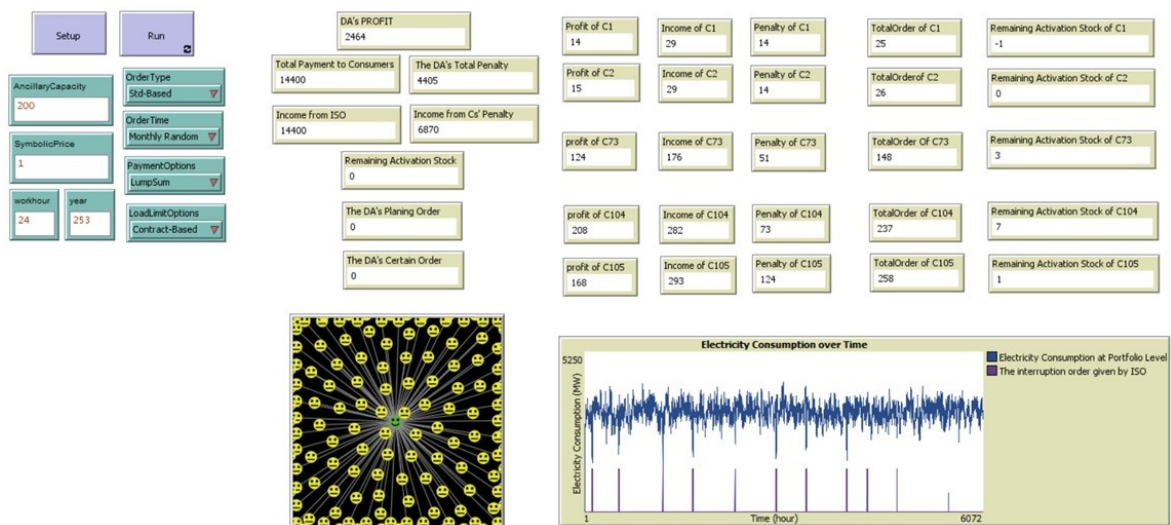


Figure 7.8. The interface elements used for verification.

Finally, we have analyzed results based on yearly simulations by looking at monitors representing the revenues of the demand side and the plot showing hourly electricity consumption at portfolio level with given interruption orders. For testing of consumer side, we have chosen five consumers randomly. If there is any doubtful result for any consumer, we have added the individual electricity consumption of the consumer into the graph. We have run the model again with same seed. If we are not satisfied with the information on the plot, we have checked the results step-by-step from the command center. Moreover, we have scrutinized the data list of the consumer used in the run to sure the accuracy of the generated data. All these testing have been continued until we feel comfortable about received results. We have moved to replicate the model when we thought that NetLogo gives possible outcomes for the conceptual model developed in this study.

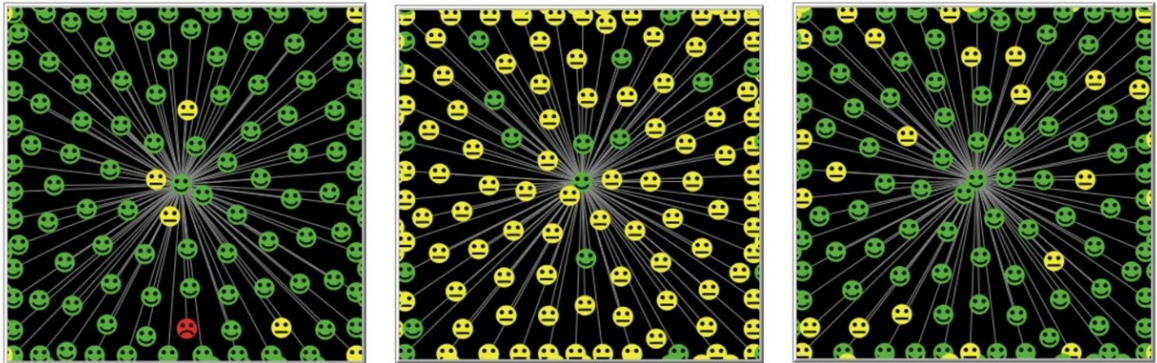


Figure 7.9. The screen shot of 2d view.

8. RESULTS

We analyzed all scenarios based on weighted profits of the DA by considering weighted profits of consumers. There are two main factors affecting weighted profits. These factors are weighted incomes and weighted payments. The DA's weighted incomes are composed of the weighted income in exchange for the commitment on the agreement SO-DA and the weighted income collected from consumers as penalty. Its weighted payments, on the other hand, include weighted payment to the ISO as penalty and total payment given to consumers in exchange for their load reduction. Consumers have just one weighted income given by the DA and just one weighted payment given to the DA. The flow chart of calculated weighted profits is as given in Figure 8.1. All financial values in this chapter calculated by using symbolic prices so all of them mean weighted revenues. However, we have called them without the term weighted from now on.

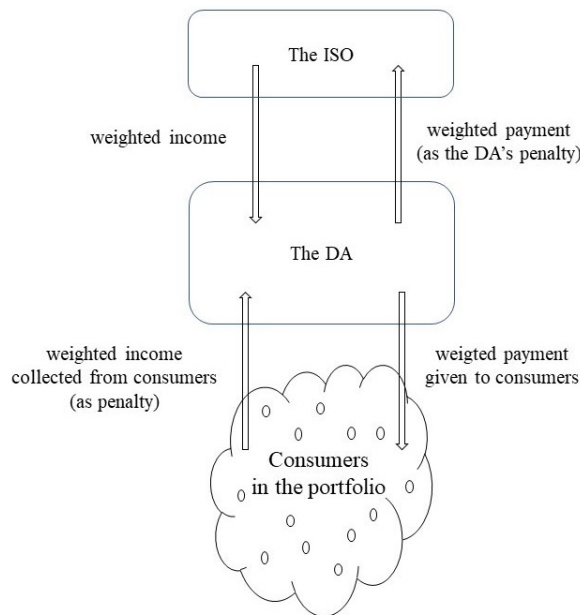


Figure 8.1. The flow chart of weighted revenues.

As mentioned in Section 7.2, we have executed all scenarios with 150 replications. NetLogo gives outcomes of these scenarios separately for each replication. All results represented in this chapter have acquired by averaging over 150 different replications (15 runs * 10 data sets).

8.1. Results Of The Model

We have tried 14 different scenarios consisting of various combination of 4 different factors as mentioned before. We have assessed the results of these scenarios in four steps. We have used similar sequence to analyze the received outcomes, but we have showed just meaningful results for each step except the first step under the light of the results of previous step.

8.1.1. The First Step: Lump-Sum Payment

In the first step, the DA allocates all income from the ISO among its consumers. Mathematically, we have equalized total income from the ISO (activation stock * symbolic price) to total payment to its consumers (sum of payment to each consumer). In this case, the DA's profit will be calculated from the difference between total income from its consumers and total payment to the ISO. The revenues obtained from the DA's perspective are given in Table 8.1.

Table 8.1. The revenues obtained from lump-sum payment.

Experiments	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
MMLC	14400	14400	5333.76	3120.49	2213.27
SMLC	14400	14400	5967.69	3122.78	2844.91
MBLC	14400	14400	5686.54	2434.71	3251.83
SBLC	14400	14400	6485.47	2701.99	3783.49

We have checked whether all consumers make profit with this approach. We do not confirm the comparison over consumers' profits because both the amount of payments and the amount of given interruption order varied in the features of consumers. For fair comparison, consumers' profits have been converted to revenue per order calculated by the equation 8.1.

Let's assume:

r_i : revenue per order of the i^{th} consumer

p_i : profit of the i^{th} consumer

o_i : sum of the interruption order given by the DA to the i^{th} consumer

$$r_i = \left(\frac{p_i * 100}{o_i} \right), \forall i \in \{1, 2, \dots, 105\} \quad (8.1)$$

From the consumers' perspective, the revenue earned per interruption order as given in Figure 8.2.

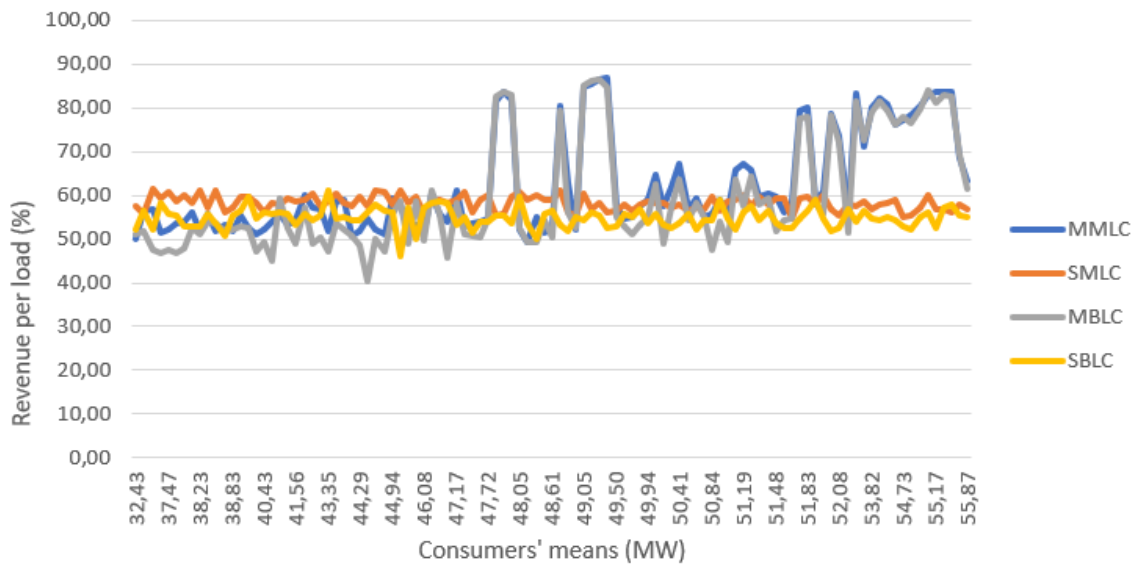


Figure 8.2. Consumers' percental revenues for lump-sum payment (1).

In Figure 8.2, the axis y represents percental revenue per interruption order while the axis x represents the consumers' average electricity consumption. We have observed no certain relationship between percental revenue per order and average electricity consumption. Therefore, we have checked the relationship between percental revenue per interruption order and standard deviations of consumers' electricity consumption.

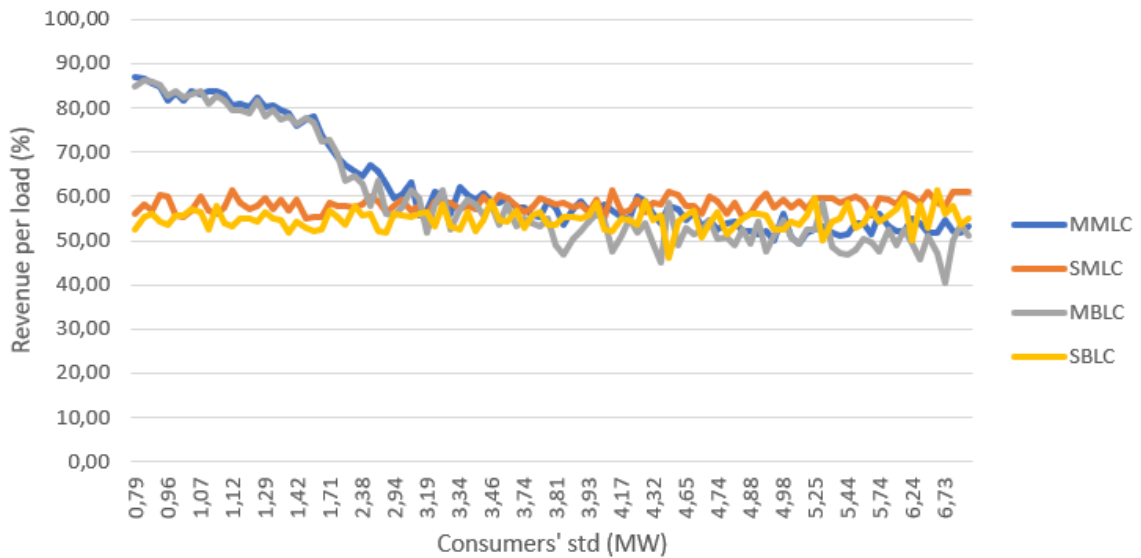


Figure 8.3. Consumers' percental revenues for lump-sum payment (2).

In Figure 8.3, the axis y represents percental revenue per interruption order while the axis x represents standard deviations of consumers' electricity consumption. According to Figure 8.3, all consumers can make profit. However, consumers which have standard deviations under approximately 2.5 make much more profit than others. The consumers' average electricity consumptions range from 32 MW to 56 MW while their standard deviations range from 0.79 MW to 7.88 MW. Hereby, mean-based scenarios offer more equal distribution among consumers in terms of the amount of interruption order given by the DA. Consumers with low standard deviation fall into the less penalty when they take more interruption order in a lump because the comparative level calculated by the multiplication of order with 0.75 increases. In this case, consumers which have lower standard deviation could have postponed order without any penalty.

The Figure 8.3 represents more meaningful relationship than the Figure 8.2. Therefore, we will show results of consumers over plots representing the relationship with percental revenue per interruption order and standard deviation. According to the received results in the Figure 8.3 and Table 8.1, both the DA and its consumers can make profit by using the lump-sum factor.

We have realized that the activation stock of some consumers is not exhausted while we have observed the interface of NetLogo (Figure 8.4). We have not determined any conditions enables to give interruption order until all consumers' activation stock is used up. In this study, the DA just allocates the interruption order given by the ISO. In this case, the DA could pay more money than it gives the amount of interruption order with the approach in question.

Profit of C1 11	Income of C1 29	Penalty of C1 18	TotalOrder of C1 24	Remaining Activation Stock of C1 2
Profit of C2 17	Income of C2 29	Penalty of C2 11	TotalOrderof C2 24	Remaining Activation Stock of C2 1
profit of C73 108	Income of C73 176	Penalty of C73 68	TotalOrder Of C73 145	Remaining Activation Stock of C73 9
profit of C104 183	Income of C104 282	Penalty of C104 98	TotalOrder of C104 232	Remaining Activation Stock of C104 15
profit of C105 246	Income of C105 293	Penalty of C105 47	TotalOrder of C105 241	Remaining Activation Stock of C105 11

Figure 8.4. The interface showing outcomes of consumers.

8.1.2. The Second Step: Payment Per Interruption Order

In the second step, we have assumed that the DA will offer payment per interruption order given to consumers during validity period of the agreement DA-C. In this case, the payment to one consumer is calculated by multiplying symbolic price with total order given by the DA. The revenues obtained from the DA's perspective

are given in the Table 8.2.

Table 8.2. The revenues obtained from payment per interruption order.

Experiments	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
MMOC	14400	11838.04	5321.55	2997.77	4885.73
SMOC	14400	11689.51	5929.94	3192.97	5447.45
MBOC	14400	12098.42	5962.27	2694.19	5569.66
SB0C	14400	12222.55	6427.81	2332.92	6272.34

The change in both the payment to consumers and the DA's profits against the results in the first step is given in the Table 8.3.

Table 8.3. The comparison between lump-sum payment and payment per order.

Experiments	Payment to consumers	Profit
MMOC versus MMLC	↓17.79%	↑120.75%
SMOC versus SMLC	↓18.82%	↑91.48%
MBOC versus MBLC	↓15.98%	↑71.28%
SMOC versus SMLC	↓15.12%	↑65.78%

As can be easily seen, the DA's profit has increased within the range between 66% and 121% compared to the profits in the previous step depending on experiments. The essential cause of the increase in profits is the decrease in the payments to consumers. The change in both the income from the ISO and the payment to consumers are around 3% compared to the previous step. Therefore, we can ignore the effects of these changes in the DA's profit.

If we purify revenues in Table 8.2 from the effect of the price, we can receive the information about the performance of the demand side as given Table 8.4. For total interruption order given by the ISO, we can use the equation 8.2. For the sum of consumers' non-performance, we can use the equation 8.3. For total non-performance of the DA, we can use the equation 8.4.

Let's assume:

$payment_i$: payment to the i^{th} consumer

x : symbolic price for payment

$order_i$: total interruption order given by the ISO to the DA

$$order_i = \left(\frac{payment_i}{x}\right), \forall i \in \{1, 2, \dots, 105\} \quad (8.2)$$

Let's assume:

sum : the sum of consumers' non-performance

$income$: income collected from consumer

y : symbolic price for penalty

$$sum = \left(\frac{income}{y}\right) \quad (8.3)$$

Let's assume:

non : total non-performance of the DA

$payment$: payment from DA to the ISO

$$non = \left(\frac{payment}{y}\right) \quad (8.4)$$

Table 8.4. The results purified from the price for the payment per interruption order.

Experiments	Total Interruption Order	Sum of consumers' non-performance	Total non-performance of the DA
MMOC	11838.04 MWh	3547.7 MWh	1998.5 MWh
SMOC	11689.51 MWh	3953.29 MWh	2128.65 MWh
MBOC	12098.42 MWh	3974.84 MWh	1796.13 MWh
SBOC	12222.55 MWh	4285.21 MWh	1555.28 MWh

The model designed in this study assumes that the DA allocates the interruption order given by the ISO to itself. In the model developed in this study, we have assumed that the ISO gives the interruption order as much as DA's activation stock. Although the DA's activation stock committed on the agreement SO-DA is 14400 MWh, the interruption order given by ISO changes within the range between 11689,51 MWh and 12222,55 MWh (Table 8.4). In this case, the ISO and so the DA can give the interruption order within the range between 81% and 85% of the amount agreed on the agreement SO-DA. We have scrutinized the model step by step to understand the main reason for this interesting situation. For the scenario MMOC, we have tried two extreme tests by using the same seed. By using the same seed, we have guaranteed that the ISO will give the interruption order at the same time and at the same amount.

In the first extreme test, we force the model for the case that there is no load reduction at portfolio level during the year. In this case, the DA will always fall into the penalty. For the first extreme test, the change in the DA's activation stock can be followed in Table 8.5.

Table 8.5. The results of the first extreme test.

Remained activation stock	The amount of interruption order	Measured Load Reduction
14400 MWh	(200 MW * 8) = 1600 MWh	0 MWh
12800 MWh	(200 MW * 12) = 2400 MWh	0 MWh
10400 MWh	(200 MW* 4) = 800 MWh	0 MWh
9600 MWh	(200 MW* 4) = 800 MWh	0 MWh
8800 MWh	(200 MW* 4) = 800 MWh	0 MWh
8000 MWh	(200 MW* 12) = 2400 MWh	0 MWh
5600 MWh	(200 MW* 12) = 2400 MWh	0 MWh
3200 MWh	(200 MW* 4) = 800 MWh	0 MWh
2400 MWh	(200 MW* 4) = 800 MWh	0 MWh
1600 MWh	(200 MW* 4) = 800 MWh	0 MWh
800 MWh	(200 MW* 4) = 800 MWh	0 MWh
0		

In the second extreme test, we force the model for the case that the load reduction at portfolio level always is above 25% of the interruption order during a year. For the second extreme test, the change in the DA's activation stock can be followed in Table 8.6.

Table 8.6. The results of the second extreme test.

Remained activation stock	The amount of interruption order	Measured Load Reduction
14400 MWh	(200 MW * 8) = 1600 MWh	2000 MWh (1600 + 1600 * 0.25)
12400 MWh	(200 MW * 12) = 2400 MWh	3000 MWh (2400 + 2400 * 0.25)
9400 MWh	(200 MW* 4) = 800 MWh	1000 MWh (800 + 800 * 0.25)
8400 MWh	(200 MW* 4) = 800 MWh	1000 MWh (800 + 800 * 0.25)
7400 MWh	(200 MW* 4) = 800 MWh	1000 MWh (800 + 800 * 0.25)
6400 MWh	(200 MW* 12) = 2400 MWh	3000 MWh (2400 + 2400 * 0.25)
3400 MWh	(200 MW* 12) = 2400 MWh	3000 MWh (2400 + 2400 * 0.25)
400 MWh	(200 MW* 2) = 400 MWh	500 MWh (400 + 400 * 0.25)
-100MWh		

According to the results in Table 8.6, the ISO can give only 11600 MWh order instead of 14400 MWh when the DA always reduce 25% more load than the interruption order given by the ISO. Although the DA's load reduction in the second extreme test is 100 MWh more than the first one, the interruption order given by the ISO is 2800

MWh less than the previous. For two extreme tests, the DA reduce its load as much as its activation stock at least. However, the timing for load reduction may be not in a harmony with the time requested by the ISO.

Similarly, the DA could give less interruption order to consumers. Therefore, the interesting differences among allocated order amount seems possible since surplus amount load reduction of consumers until %125 of the interruption order can lead to less interruption order given by the DA. To be sure for our claim we have executed the model for both MMOC and SMOC experiments by using the same seed. The results have supported our claim. However, we have caught another interesting situation attracted our attention. We have realized that some consumers have exhausted their activation stock before the DA's activation stock. There is no certain amount for contracted flexible load on the agreement DA-C. The DA just offers the calculation approach about allocating the order. The limitation on the agreement DA-C is just for activation stock. Hereby, the DA cannot give any orders to some customers that have already deplete their activation stock at last orders. In this case, the DA will have to allocate the interruption order given by the ISO among less consumers towards last orders. Therefore, the consumers which can take order starts to take more order towards the end of the year.

8.1.3. The Third Step: No Limit For Activation Stock

In the third step, the DA gives interruption order without considering consumers' activation stock and gives payment in proportion of the given interruption order. While the revenues obtained from the perspective of the DA is as given in Table 8.7, the revenues purified from the effect of the price is given in Table 8.8. The change in both total interruption order and total non-performance of the DA against the results in the previous step is given in the Table 8.9.

Table 8.7. The revenues obtained from non-existence of activation stock.

Experiments	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
MMOB	14400	12015.17	5408.27	2815.42	4977.69
S MOB	14400	12176.81	6201.72	2652.34	5772.57
MBOB	14400	13383.30	6176.25	936.05	6256.89
SBOB	14400	13449.02	7070.57	990.49	7031.06

Table 8.8. The results purified from the price for non-existence of activation stock.

Experiments	Total Interruption Order	Sum of consumers' non-performance	Total non-performance of the DA
MMOB	12015.17 MWh	3605.51 MWh	1876.95 MWh
S MOB	12176.81 MWh	4134.48 MWh	1768.23 MWh
MBOB	13383.30 MWh	4117.5 MWh	624.03 MWh
SBOB	13449.02 MWh	4713.71 MWh	660.33 MWh

Table 8.9. The comparison between constrained and limitless activation stocks.

Experiments	Total interruption order	Total non-performance of the DA
MMOB versus MMOC	↑1.5%	↓6.08%
SJOB versus SJOC	↑4.17%	↓16.93%
MJOB versus MBOC	↑10.62%	↓65.26%
SJOB versus SBOC	↑10.03%	↓57.54%

The first remarkable change in the results is that the increase in the amount of interruption order given by the ISO. For constrained activation stock scenarios, the DA falls into the penalty because some consumers deplete their activation stock before the DA depletes own activation stock. As mentioned above, the DA has to allocate the interruption order given by the ISO among less consumers towards last orders. Therefore, it falls into more penalty. In limitless activation stock scenarios, there is no limit related to activation stock on the agreement DA-C. The DA can allocate the interruption order among 105 consumers during a year. Hereby, some of non-performance case of the DA is converted to postponed interruption order by passing out the border (75% of the interruption order) for penalty. That is the main reason for the increase in the amount of given order.

The second remarkable change is that an abrupt decrease in the total non-performance of the DA for experiments with block order scenario. According to aforementioned assessment approach, the model benefits from deterministic borders to update remaining activation load. The lower border (75% of the interruption order) also is the border for the penalty. If the DA pass over this border, its penalty will reduce abruptly as this step.

We have checked whether all consumers can reach profitable results without any limitation about consumers' activation stock or not. From consumers' perspective, the revenue obtained per interruption order converted by the equation 8.1 are given in Figure 8.5.

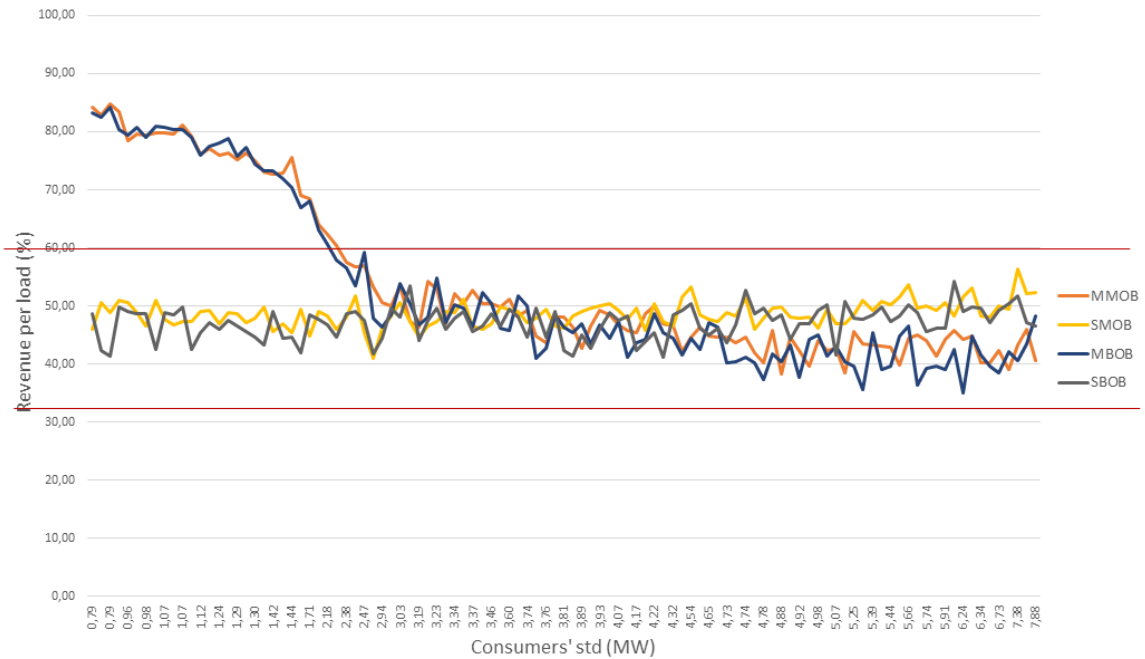


Figure 8.5. Consumers' percental revenues for limitless activation stock.

According to Figure 8.5, all consumers can make profits even if any limitation about their activation stock is not on the agreement DA-C. However, we can easily observe an unfair distribution among consumers' profit in mean-based scenarios.

8.1.4. The Fourth Step: Dynamic Coefficients

In the fourth step, we have run the model by using dynamic coefficients. For all scenarios in this step, the DA allocates the interruption order in proportion to consumer's flexible load. The revenues obtained from the DA's perspective is given in Table 8.10. The results purified from the effect of the price is given in Table 8.11.

Table 8.10. The revenues obtained from the scenarios using dynamic coefficient.

Experiments	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
DMOB	14400	12098.42	5962.27	2694.19	5569.66
DBOB	14400	13351.43	6913.49	878.98	6913.49

Table 8.11. The revenues purified from the price for dynamic coefficient.

Experiments	Total Interruption Order	Sum of consumers' non-performance	Total non-performance of the DA
DMOB	12098.42 MWh	3974.85 MWh	1796.13 MWh
DBOB	13351.43 MWh	4608.99 MWh	585.99 MWh

From consumers' perspective, the interruption order given by the DA are as given in Figure 8.6. According to Figure 8.6, the DA shows the similar tendencies for both dynamic factor and sd-based factor when it allocates the interruption order. Therefore, we will compare the results of these factors.

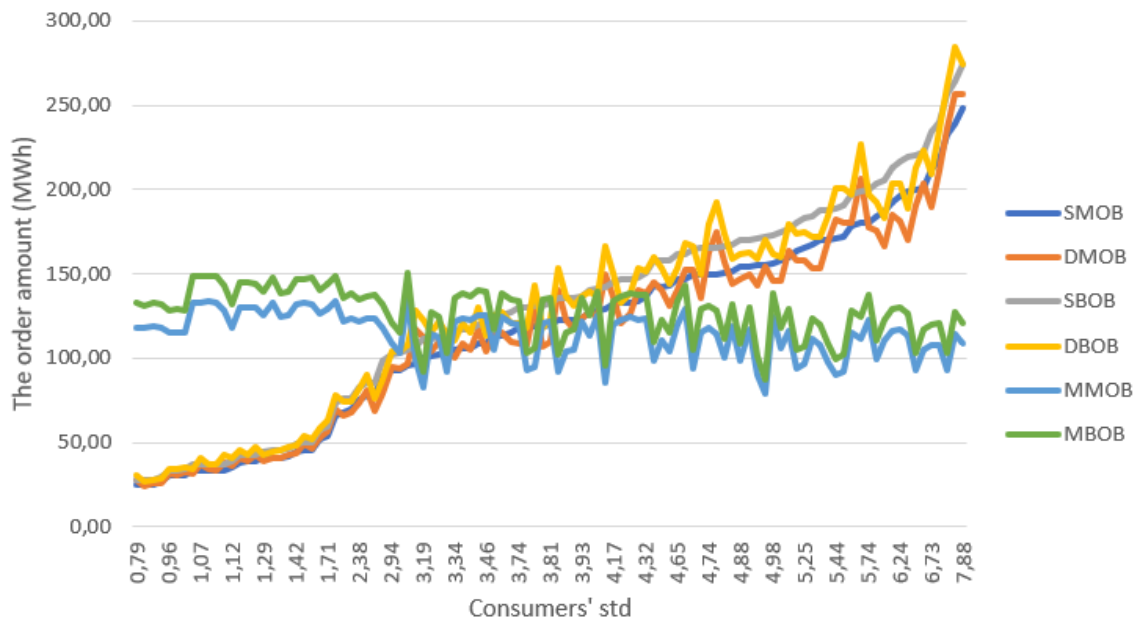


Figure 8.6. Consumers' percental revenues for limitless activation stock.

The decrease in the DA's profit compared to the scenario with sd-based coefficient in the third step results from the decrease in the income from consumer. The change in both total interruption order and total non-performance of the DA as against the results in the previous step is given in Table 8.12.

Table 8.12. The comparison between dynamic and std-based coefficients.

Experiments	Total interruption order	Total non-performance of the DA
DMOB versus SMOB	↓0.64%	↑1.58%
DBOB versus SBOB	↓0.73%	↓11.26%

If we want to look at the non-performance per the given interruption order, we can receive non-performance ratio by using the equation 8.5. The results of all scenarios without lump-sum factor about non-performance ratio are given in Table 8.13.

Let's assume:

r : non-performance ratio

n : sum of non-performance in a year

o : sum of the interruption order

$$r = \left(\frac{n}{o}\right) \quad (8.5)$$

Table 8.13. Non-performance ratios for all scenarios without lump-sum payment.

Experiments	The sum of consumers' non-performance ratio	Total non-performance ratio of the DA
MMOC	0.30	0.17
SMOC	0.34	0.18
MBOC	0.31	0.13
SBOC	0.35	0.13
MMOB	0.30	0.16
SMOB	0.34	0.15
MBOB	0.31	0.07
SBOB	0.35	0.07
DMOB	0.33	0.15
DBOB	0.34	0.04

From consumers' perspective, the revenue obtained per interruption order in two last steps are given in Figure 8.7.

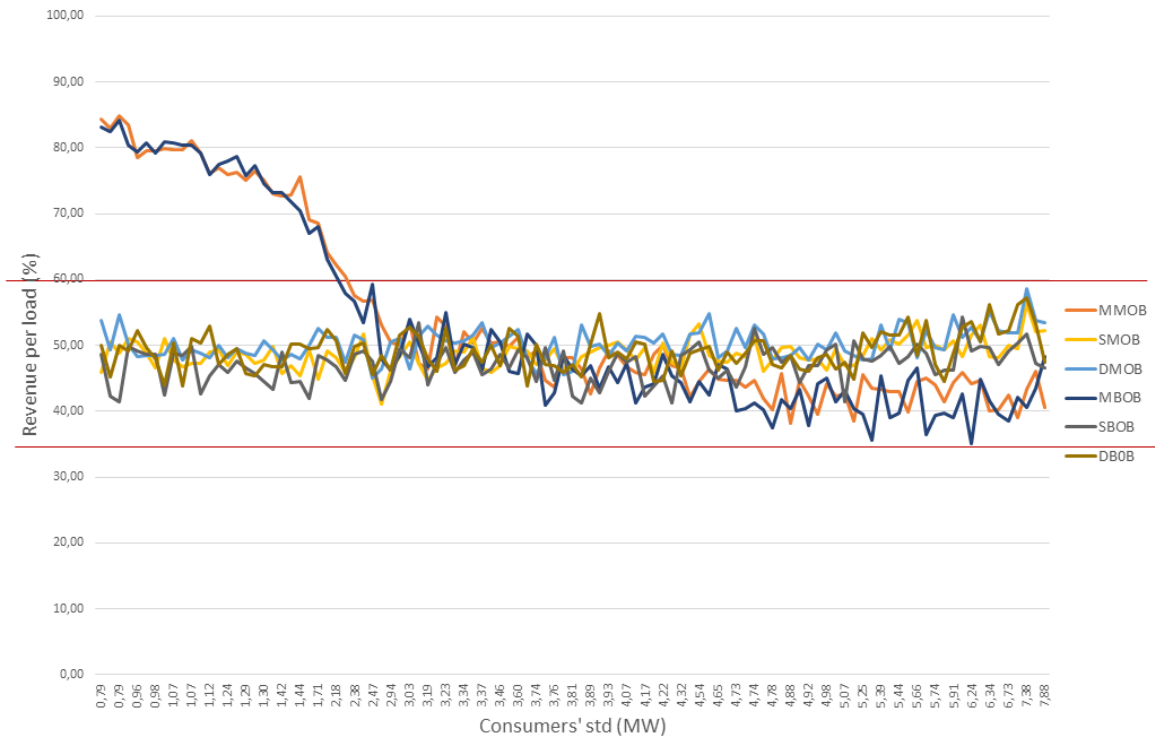


Figure 8.7. Consumers' percental revenues for the third and the fourth steps.

According to the results of Table 8.13, the DA's non-performance ratio reduces at the significant level when the ISO gives all interruption order as a block. The change in consumers' non-performance ratios is at a level that can be ignored even if the experiment is changed. With these scenarios, the DA do not reduce the sum of consumers' non-performance. Nevertheless, the DA can offer more fair distribution among consumers' profit by using dynamic and sd-based coefficients rather than mean-based coefficient (Figure 8.7).

8.2. Sensitivity Analysis

There are two prices used in this model. These are the price of payment per MWh and the price of penalty per MWh. At the beginning of the model development, we have an assumption about the proportion of prices. According to our assumption,

the price of penalty per MWh is one and half of the price of payment per MWh. We have applied sensitivity analysis to understand the effect of this proportion on revenues. The proportion one and half is used reference proportion in sensitivity analysis.

We have realized that results obtained by using some scenario comes into prominence. These scenarios are "SMOC", "SBOC", "SMOB", "SBOB", "DMOB" and "DBOB". We have applied sensitivity analysis by using these scenarios.

In this study, our focus is the DA's decisions. Thus, we have changed some rules and some procedures of the agreement DA-C when we have tried various scenarios. However, we have used same rules and procedures for the agreement SO-DA of which content depends on the decision of the ISO. We will use same approach during sensitivity analysis. That is to say, we will continue to use same proportion on the agreement SO-DA. Nevertheless, we will change the proportion of prices on the agreement DA-C.

For sensitivity analysis, we have tried two different proportions. For the first one, we have assumed that the price of penalty is 1.2 times of the price of payment. For the second one, we have considered that the price of penalty is 1.7 times of the price of payment. The revenues obtained from the DA's perspective by using these proportions is given in Table 8.14.

Table 8.14. The revenues of the demand aggregator obtained by sensitivity analysis.

For Lower Proportion	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
SMOC	14400	11959.29	4862.79	2840.24	4463.26
SBOC	14400	12229.14	5140.18	2439.39	4871.65
SMOB	14400	11999.36	4903.86	2900.03	4404.46
SBOB	14400	13368.73	5590.41	859.88	5761.80
DMOB	14400	11915.79	4647.22	2787.52	4343.91
DBOB	14400	13401.88	5444.90	831.60	5611.43
For Higher Proportion	Income from the ISO	Payment to Consumers	Income from Consumers	Payment to the ISO	Profit
SMOC	14400	11879.42	6855.64	2942.80	6433.42
SBOC	14400	12221.62	7361.05	2744.63	6794.80
SMOB	14400	11995.26	6881.92	2859.60	6427.06
SBOB	14400	13429.95	7992.18	881.24	8080.99
DMOB	14400	12209.70	6842.61	2631.92	6401.00
DBOB	14400	13436.13	7766.01	901.85	7828.02

We do change nothing in the model except the proportion of prices on the agreement DA-C. Thus, the changes in payment to consumers and payment to the ISO depends on randomness of timing of an interruption order. To compare the results obtained by sensitivity analysis with results obtained by using reference proportion is more meaningful. The comparison between results obtained by using reference proportion and the revenues obtained by sensitivity analysis is given in Table 8.15.

Table 8.15. The comparison between reference model and sensitivity analysis.

For Lower Proportion	Income from Consumers	Profit of the DA
SMOC	↓18.00%	↓18.07%
SBOC	↓20.03%	↓22.33%
SMOB	↓20.93%	↓23.70%
SBOB	↓20.93%	↓18.05%
DMOB	↓22.06%	↓22.01%
DBOB	↓19.26%	↓18.83%
For Higher Proportion	Income from Consumers	Profit of the DA
SMOC	↑15.61%	↑18.10%
SBOC	↑8.33%	↑14.52%
SMOB	↑10.97%	↑11.34%
SBOB	↑13.03%	↑14.93%
DMOB	↑14.77%	↑14.93%
DBOB	↑15.16%	↑13.23%

According to the results in Table 8.15, the change in profit of the DA majorly depends on the change in the income collected from consumers. If the DA offers the price of penalty as much as 1.2 times of the price of payment, its profit decreases around 20% depending on scenario. When the DA offers the price of penalty as much as 1.7 times of the price of payment, its profit decreases around 13% depending on scenario. As expected, the increase in the proportion offered to consumers lead to the increase in the profit of the DA. Similarly, the decrease in the proportion offered to consumers cause the decrease in the DA's profit.

9. CONCLUSION AND FURTHER RESEARCH

In this study, we assess alternative agreements for interruptible load program, which is one type of incentive-based demand side response program for the Turkish Electricity Supply System from the perspective of a demand aggregator. We have determined a possible agreement that an independent system operator may offer to a demand aggregator to be implemented. Under the assumption that this agreement is given, we have assessed different approaches that have an impact on the profitability of an agreement that the demand aggregator offers to consumers in its portfolio.

We have restricted the scope of this study one independent system operator, one demand aggregator and 105 large consumers. To assess the effects of the demand aggregator's various choices about the agreement, both the independent system operator and consumers are assumed behaviorally passive actors. They do not act strategic and adaptive in this study, or they do not adapt their behavior to changes in the system. In this case, the demand aggregator is the only actor that has strategic behavior. That is why, unintended and ineffective results will be the consequence of a poor tactical decision of the demand aggregator.

We have built an agent-based model suitable for behavioral structure of actors in the Turkish Electricity Supply System. In the scope of this study, the demand aggregator is the side which makes choices on the existence of consumers' activation stock on the agreement, the allocation approach of the interruption order among consumers in its portfolio and the payment options offered to its consumer. These choices have an impact on the content and profitability of the agreement that the demand aggregator offers it to its consumers. We have analyzed different scenarios composed of different combinations of possible choices.

Even if the demand aggregator allocates whatever it receives from the independent system operator to its consumers, it can still make profit in all scenarios. The

essential reason for the profit is the penalty collected from consumers rather than the payment received from the independent system operator. The difference between the penalty collected from consumers and the penalty of the demand aggregator constructs the profit of the demand aggregator. This difference results from the baseline calculation approach. While the independent system operator calculates the demand aggregator's baseline at portfolio level, the demand aggregator calculates consumers' baseline individually. This result supports the studies in the literature.

When the demand aggregator offers payment in proportion to the interruption order given throughout a year instead of activation stock committed on the agreement, it can increase its profit around 85% compared to the previous one. This increase in its profit results from the decrease in the payment to consumers. We have to pay attention to the point that this approach is more beneficial for the demand aggregator rather than consumers. Because the demand aggregator earns money from the independent system operator in proportion of its activation stock, but consumers earn money per interruption order given by the demand aggregator.

If the demand aggregator restricts the activation stock of consumers, it may face a problematic issue. The activation stock of some consumers may be depleted before the demand aggregator's activation stock. In this case, the demand aggregator may need to allocate the interruption order among fewer consumers towards the end of the year. Therefore, the consumers that have enough activation stock to take interruption order have to take more orders towards final interruption orders.

For the scenarios with no limit of consumers' activation stock, the DA could increase its profits approximately 3.93% provided that it offers payment per interruption order to consumers. If the demand aggregator insists on the limit of consumers' activation stock to reduce the uncertainty of consumers, it should consider the range from upper limit to lower limit allowed for load reduction. In this study, to allocate the activation stock as much as 125% of the demand aggregator's activation stock committed to the independent operator is enough to prevent undesirable cases.

When the demand aggregator uses dynamic coefficients to allocate the interruption order among consumers, its profit is decreased compared to scenarios using standard deviations of consumers' electricity consumption as static coefficients. The decrease in the its profit results from the decrease in income collected from consumers as penalty. For most consumers, dynamic coefficients are more profitable than using their standard deviation as an order allocation coefficient while not significant worse for the demand aggregator.

When we have assessed all results as a whole, we have realized that all consumers can make profit for all scenarios analyzed in this study. That is to say, the demand aggregator have a chance to persuade consumers to participate to the interruptible load program by using any scenario defined in this study. Moreover, none of these scenarios provides significant improvement in the sum of all consumers' non-performance ratio. However, the demand aggregator could present more fair profit distribution for consumers by using coefficients except the average of consumers' electricity consumption. In addition, the demand aggregator's non-performance ratio decreases significantly when the independent system operator gives all order as a block for scenarios with limitless consumers' activation stock.

Finally, we realized one problematic issue related to the payment per interruption order approach. Although this approach is considered as more profitable for the demand aggregator, we realize one potential risk. In the scope of this study, consumers are determined as behaviorally passive actors. However, consumers can game with the system when this approach is applied, because the demand aggregator offers payment in proportion to given interruption order. If consumers reduce their load within the range that lead to postponed order (75-100%), they will earn more money than their load reduction by staying within postponed order range. In this case, demand aggregator pays more money to consumers than their performance, but it falls into more penalty due to lackness of consumers' load reduction. Therefore, the demand aggregator could fall into more penalty whereas consumers could make more profit with this approach.

In this study, we have used constant price for payments throughout the validity period of agreements. This approach ignores the change of electricity prices. The change of electricity prices in real time would affect overall revenues obtained at the end of the study. Payments may be based on spot markets prices at the time of an interruption order in further research.

In reality, the independent system operator wants to give an interruption order when there is an increased chance of generation shortage. If electricity consumption of large consumers had seasonality, the overall results obtained in all scenarios would have been affected from timing of the interruption orders. As a follow up, impact of seasonality on the demand side on demand side response contracts can be examined.

We have focused primarily on financial results from the perspective of one demand aggregator. However, the essential idea behind these programs is to reduce load in electricity system. We are not interested in the way load is reduced by consumers in this study. Consumers may just shift the time for their electricity consumptions, or may eliminate it.. That is to say, consumers may consume more electricity after interruption order is finished or not. From a more extended perspective, analyzing the way load is reduced will be one of attractive research areas for the independent system operator.

We have restricted the model with one DA and its consumers. Moreover, we have assumed consumers to follow fixed behavior rules. A system embracing actors that exhibit adaptive behavior in a competitive environment may be interesting for further studies.

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APPENDIX A: BEHAVIORS OF ACTORS

All codes related to behaviors of actor can be found in CD attached.