A QUANTITATIVE ANALYSIS ON THE PARAMETERS AFFECTING THE SMART GRID TRANSFORMATION IN GENERATION, TRANSMISSION AND DISTRIBUTION OF ELECTRICITY IN TURKEY

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I fully cited and referenced all material and results that are not original to this work.

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Signature: _____

ABSTRACT

A QUANTITATIVE ANALYSIS ON THE PARAMETERS AFFECTING THE SMART GRID TRANSFORMATION IN GENERATION, TRANSMISSION AND DISTRIBUTION OF ELECTRICITY IN TURKEY

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The increasing world population has led to a significant rise in electricity demand, which traditional grids cannot meet. In response, the smart grid offers a promising solution to many issues within the existing electricity infrastructure. By integrating various information systems and technologies, the smart grid provides more efficient, cleaner, more reliable and cost-effective electrical energy to all customers, contributing to the solution of an important global challenge. In Türkiye transitioning from the traditional grid to the smart grid necessitates the involvement of all related parties including governmental entities, regulators, electricity generators, consumers, exchangers, transmission and distribution system operators, as well as Internet of Things device manufacturers. This thesis identifies and analyzes the parameters for the successful transformation from a traditional grid to a smart grid with a particular focus on the case of Türkiye. Through a comprehensive literature review, Delphi Analysis, expert views, and surveys the study determines the dependent and independent variables of smart grid transformation success, examining the country's electricity grid institutions, stakeholders and overall structure. The parameters of the successful transformation from traditional grid to smart grid in Türkiye are determined and analyzed by a survey with the participation of 474 respondents from the Turkish electricity ecosystem.

Keywords: Smart Grid, Success of Smart Grid Transformation in Türkiye, Turkish Digitalized Electricity Grid, Quantitative Analysis for Turkish Smart Grid

ÖZ

TÜRKİYE'DE ELEKTRİK ÜRETİMİNDE, İLETİMİNDE VE DAĞITIMINDA AKILLI ŞEBEKE DÖNÜŞÜMÜNÜ ETKİLEYEN PARAMETRELER ÜZERİNE SAYISAL BİR ANALİZ

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Doktora, Bilişim Sistemleri

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Artan dünya nüfusu, elektrik talebinde ve tüketiminde büyük artışlara neden olmaktadır. Bu noktada akıllı şebeke, mevcut elektrik altyapısının birçok sorununa potansiyel bir çözüm oluşturmaktadır. Akıllı şebeke, bilgi sistemlerini ve teknolojilerini mevcut geleneksel elektrik şebekesine entegre ederek tüm elektrik tüketicilerine daha verimli, daha temiz, daha güvenilir, daha uygun maliyetli elektrik enerjisi sağlamakta ve önemli küresel bir problemin çözümüne katkıda bulunmaktadır. Türkiye'de mevcut geleneksel elektrik şebekesinin akıllı şebekeye dönüştürülmesi için kamu kurumlarının, elektrik piyasası düzenleyicilerinin, elektrik üreticilerinin, elektrik tüketicilerinin, elektrik iletim ve dağıtım şirketlerinin, nesnelerin internet cihaz üreticileri gibi ilgili tüm tarafların katılımı sağlanmalı ve görüşleri dikkatle incelenmelidir. Bu tez, geleneksel şebekeden akıllı şebekeye başarılı bir dönüşümün parametrelerini, özellikle Türkiye örneğinde ele alarak belirlemekte ve analiz etmektedir. Kapsamlı bir literatür taraması, Delphi Analizi, uzman görüşleri ve anketler yoluyla yapılan çalışma, ülkenin elektrik şebekesi kurumlarını, paydaşlarını ve genel yapısını inceleyerek akıllı şebeke dönüşüm başarısının bağımlı ve bağımsız değişkenlerini belirlemiştir. Türkiye'de geleneksel şebekeden akıllı şebekeye başarılı dönüşümün parametreleri, Türkiye elektrik ekosisteminden 474 katılımcıyla yapılan anketle belirlenmiş ve analiz edilmiştir.

Anahtar Kelimeler: Akıllı Şebeke, Türkiye'de Akıllı Şebeke Dönüşümünün Başarısı, Sayısallaşmış Türk Elektrik Şebekesi, Türk Akıllı Şebekesi için Nicel Analiz

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LIST OF ABBREVATIONS

AI	Artificial Intelligence
BPM	Balancing Power Market
CEN	European Committee for Standardization
CENELEC	European Electrotechnical Committee for Standardization
DG-1	Data Group-1
DG-2	Data Group-2
DG-3	Data Group-3
DG-4	Data Group-4
DSO	Distribution System Operator
DV	Dependent Variable
EÜAŞ	Electricity Generation Company
EPDK	Energy Market Regulatory Authority
EPİAŞ	Energy Exchange Company
EV	Electric Vehicle
IS	Information System
IV	Independent Variable
RQ	Research Question
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TEDAŞ	Turkish Electricity Distribution Company
TEİAŞ	Turkish Electricity Transmission Company
TSO	Transmission System Operator
YEKDEM	Renewable Energy Resources Support Mechanism
YÖK	Higher Education Institution

CHAPTER 1

INTRODUCTION

The increasing world population is causing a significant surge in electricity demand and consumption. The demand for electricity has been increasing due to factors such as population growth, climate change, urbanization, and the rising use of electronic devices, which often represent non-linear loads that contribute to poor power quality conditions (Munoz & Ruelas, 2024). The decrease in fossil fuel-based energy reserves, the increasing dependence of individuals on energy in their daily lives because of technological and social development, the environmental effects of intensive industrialization and inefficient energy consumption make evident that the current traditional grid cannot meet this escalating demand. In this context, connectivity and the smart grid emerge as potential solutions to many problems inherent in our existing electricity infrastructure.

Although there is no single, universally accepted definition of a smart grid, the European Union CEN/CENELEC platform defines smart grid as an electricity and data network that intelligently integrates the behavior and actions of all users connected to it – generators, consumers and those that do both – to efficiently ensure a more sustainable, economical, and secure electricity supply (CEN/CENELEC, 2011). This integration aims to ensure an economically efficient, sustainable power system with high levels of quality, security of supply and safety. A smart grid can be described as the integration of information and communication technologies into the electricity grid, enabling the remote detection and management of real-time changes in the network, such as consumption levels, failures, and power line overloads (Rodriguez-Perez & Matanza, 2024). It plays a crucial role in the electricity market by maintaining the balance between supply and demand through the introduction of load flexibility, rather than solely relying on adjustments to generation levels, across nearly all operational time scales (Balijepalli & Pradhan, 2011).

The concept of a smart grid involves a "digital upgrade" of distribution and long-distance transmission systems, aimed at optimizing current operations by minimizing losses and creating new markets for alternative energy production (Vijayapriya & Kothari, 2011). The implementation of the smart grid, which uses digital technologies to gather and analyze electricity information, is a goal for electricity grid construction and development in many countries, as it paves the way towards the future of intelligent energy (Lee &Chiang, 2024). The smart grid necessitates a high-speed, integrated, two-way flow of electricity and information, enabling real-time monitoring and operation of the power system. This real-time capability is essential for tackling global challenges like energy sustainability, climate change, and the shift to renewable

energy sources. By improving energy management and integrating renewables, the smart grid aids in reducing carbon emissions and enhancing energy security, making it a vital element in the global effort to combat climate change (Colak & Bayindir, 2014).

Today many stakeholders working under the conceptual umbrella of smart grids, approach the field from different perspectives. Academic studies mainly focus on the problems of balancing energy generation and consumption as well as the communication, power electronics and storage technologies. Commercial research and development activities, and industrial initiatives focus on technologies such as smart meters, home, or office automation. On the other hand, political entities are mostly interested in energy price stability, energy efficiency, sustainability, and reliability. Non-governmental organizations see smart grid applications as an opportunity for environment-friendly energy generation and consumption. The shift toward a low-carbon and sustainable energy system is crucial for addressing climate change and ensuring the long-term sustainability of the global energy sector. Smart grid technologies are becoming a transformative element in this transition (Zheng, 2024). The synergy created by such a wide range of stakeholders has turned the topic of smart grids into a popular one involving interdisciplinary collaborations in a very short time.

The developments, ideas and architectures on smart grids have been shaped especially within the framework of projects initiated in the United States and the European Union. In these framework projects, the smart grid is evaluated as a technological breakthrough involving automation applications where various technologies are integrated. The importance of smart grid management systems has increased significantly due to the rising demand for more efficient energy distribution and consumption (Yang, 2024). Smart grid studies today focus on the problems of integration and optimal management of electricity production and consumption tools that can exhibit great variability. With this perspective, it is envisaged that the smart grid infrastructure will develop over time by adding functional information and technology layers to existing systems.

The main expectations from smart grid transformation can be summarized as follows (ELDER, 2019):

- Decreasing the carbon footprint of electricity operation
- Reducing the technical and non-technical loss levels
- Increasing grid sustainability and energy quality
- Increasing grid resiliency
- Increasing network situational awareness of the distribution companies through deployment of sophisticated and near real-time measurement infrastructures
- Facilitating consumer / demand side participation
- Increasing the connectible capacity for renewable generation, thereby reducing the external dependency in energy supply

- Optimal use and management of distribution grid assets
- Transformation from static grids to a dynamic infrastructure with bidirectional energy and information flow
- Increasing the security of the electricity grid

Smart grid transformation is also critical for the Turkish electricity grid. As the Turkish electricity grid is more than 100 years old, it needs a rapid transformation from the traditional grid to the smart grid structure utilizing contemporary information systems and digital technologies. This transformation requires determining the critical parameters, which directly affect the success of this transformation. Although there is a plethora of research on the Turkish smart grid, there is no study in the literature focusing on the parameters that will directly affect the success of the Turkish smart grid transformation. In this study we aim to fill this gap through a systematic comprehensive review of the literature for determining these parameters and surveys with all involved parties. This study also aims to provide guidance for the successful smart grid transformation of other countries.

1.1. Significance of the Study

In the literature there is currently no study on determining the parameters and factors affecting the success of smart grid transformation in Türkiye. This study aims to guide smart grid transformation activities in Türkiye through the introduction of a smart grid transformation success model. Accordingly, the subcomponents of the dependent variable (smart grid transformation success) and associated independent variables were determined by collecting data from Turkish electricity grid stakeholders. Furthermore, these variables and their effects and importance levels were analyzed with respect to different regions of Türkiye. The amount of time it will take to achieve required levels of the independent variables were also determined for the different regions. A further contribution of this study to the smart grid literature is the comprehensive review of the concepts, studies and dissertations on various aspects of smart grids.

1.2. The Research Phases

The research in this study was conducted in six main phases following the steps shown in Figure 1.

The first phase defines the need for the research and establishes the theoretical base for the intended discussion through a comprehensive literature review.

The second phase introduces the stakeholders, institutions, and structure of the Turkish electricity grid.

The third phase develops the methodology and the tool to be used in the research. In this phase, research methods, subcomponents of the dependent variable, and the independent variables were determined. These variables were clarified by Delphi analyses and survey statements were established.

The fourth phase focuses on building the hypotheses related to the possible relationships between the variables. This phase contains five research questions focusing on the relationships and five different sets of hypotheses formed for these questions. The required sample size for the survey was also determined in this phase.

The fifth phase establishes the validity and reliability of the study and decides on the types of statistical analyses to be used, collects the real data, organizes it by removing erroneous and incomplete results and forms the data sets for analyses.

The sixth and last phase applies statistical analyses on the organized data and presents the results of these analyses for the following discussions. This phase also presents and discusses the main results and the proposed smart grid success model to provide a basis for future research.

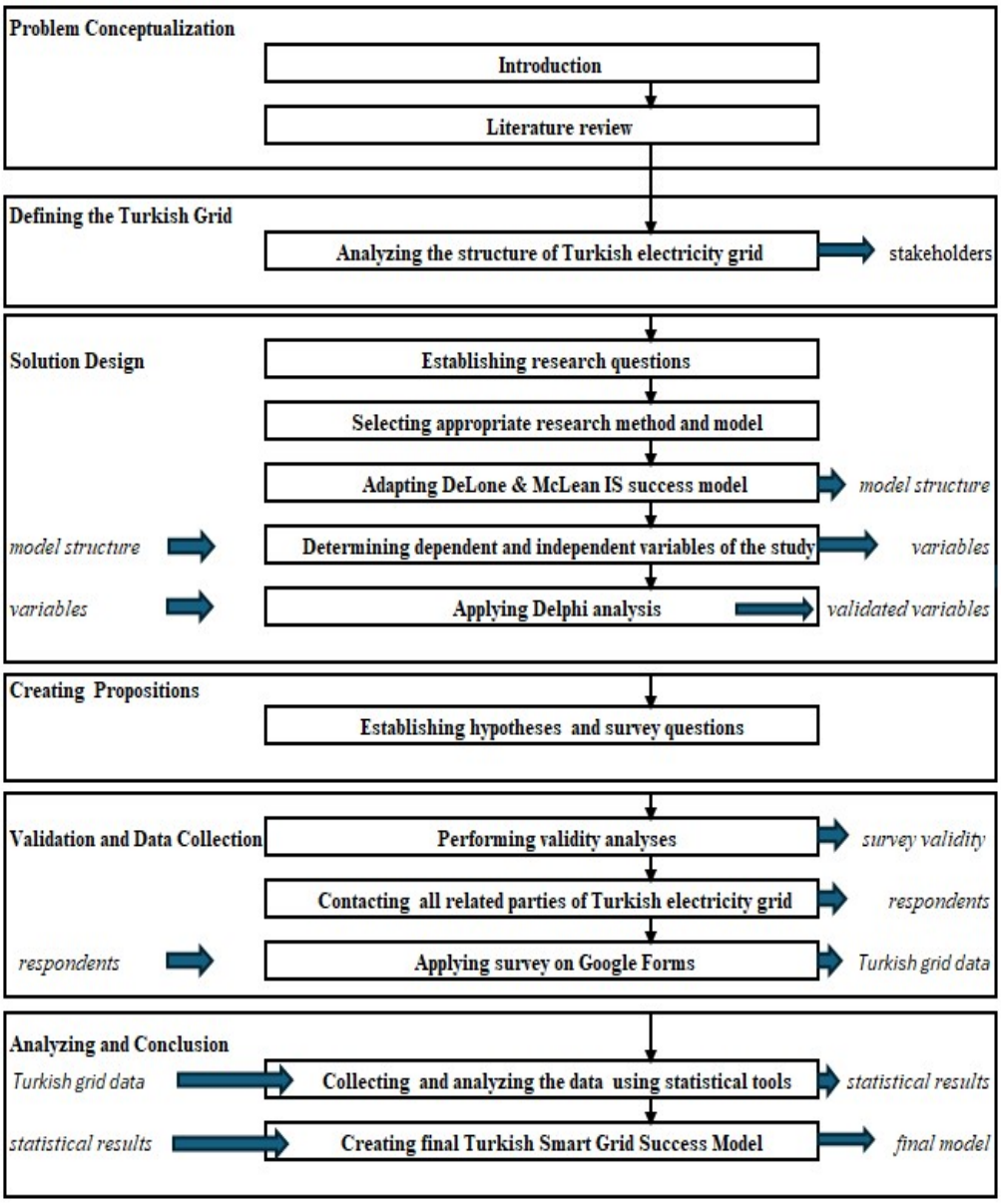


Figure 1: Thesis Study Phases

1.3. Dissertation Organization

This thesis is organized under eleven chapters. Chapter 1 introduces the research topic and the significance of the study. Chapter 2 provides a review of the existing literature on smart grid studies. In Chapter 3, the institutions, entities, governmental bodies,

actors and stakeholders in the Turkish electricity ecosystem and the structure of the Turkish electricity grid are discussed in detail. Chapter 4 reviews possible analysis techniques and research methods in the literature to select the appropriate research method for this study. This chapter also explains the basis of this study, which is the DeLone & McLean information success model, to determine the subcomponents of dependent variable – smart grid transformation success in Türkiye – and the related independent variables. Chapter 5 validates the subcomponents of the dependent variable and the independent variables by Delphi Analysis. Chapters 6 and 7 provide the survey statements, hypotheses, and the appropriate sample size of the survey to be conducted. Chapter 8 provides a validity and reliability discussion of the survey study with "Cronbach Alpha" test results. Chapter 9 discusses the data collection structure for the final survey. Chapter 10 analyzes the survey data collected. Chapter 11 concludes the study with an introduction of the proposed Turkish Smart Grid Success Model.

CHAPTER 2

LITERATURE REVIEW

The literature review is a critical component of this study, which is instrumental in determining the important and critical parameters of the successful transformation from the traditional grid to the smart grid in Türkiye. Within the scope of the literature review, 236 studies were reviewed. As the smart grid concept is a newly emerging topic, most of these studies were conducted after 2010.

2.1. Smart Grid Doctoral and Master's Theses in Türkiye

As the first step of our literature review, we reviewed both doctoral and master's theses on the smart grid in the YÖK (Higher Education Institution) theses database[1] of Türkiye in detail.

For doctoral and master's theses we searched the YÖK theses database with the key words "smart grid", "smart grids", "akıllı şebeke" (in Turkish), and "akıllı şebekeler" (in Turkish). As smart grid is an emerging topic, the earliest doctoral thesis "*Smart grid connections and energy managements of electric vehicles*" in the database is from 2014 and the earliest relevant master's thesis "Intelligent networks and their applicability" is from 1992.

In the YÖK database there are 38 doctoral studies about smart grids, conducted at Turkish universities between 2014 and 2024 as shown in Table 1. None of these doctoral theses analyzes smart grid transformation of the Turkish power grid, the success of this transformation, structure of this transformation, factors affecting this transformation and stakeholders' (distribution system operators, transmission system operators and regulatory bodies) views and expectations from the smart grid transformation.

The 38 doctoral studies in the database were mostly conducted at Engineering Departments such as Electrical Engineering, Electronics Engineering, Electrical and Electronics Engineering, Energy Systems Engineering, Industrial Engineering, Software Engineering and Computer Engineering. Electrical and Electronics Engineering departments are at the top of the list with 28 doctoral theses. In the smart grid research area, İnönü University and Yıldız Technical University have the biggest number of doctoral theses in the database, with İnönü University contributing 5 and Yıldız Technical University contributing 4.

[1] https://tez.yok.gov.tr/UlusalTezMerkezi/

In the YÖK database there are also 107 master's theses. Most of this master's studies were conducted at Electrical and Electronics Engineering and Computer Engineering departments, and none of them was studied under the Information Systems discipline.

2.2. Smart Grid Doctoral Theses in Türkiye between 2014-2024

The doctoral theses on the topic of smart grids in the YÖK theses database are in different areas of smart grid. Twelve of these doctoral theses are about Energy Management, seven of them are about Integration of Renewables, three of them are about Power Electronics, five of them are about Optimization and the rest are about Communication Technologies, Privacy, Cyber Security, EV Charging, Computation, IoT (Internet of Things) and Power Quality. The list of these theses is given Table 1.

Table 1: 2014-2024 Smart Grid Doctoral Theses in the YÖK Database

Author	Year	University	Department	Thesis Title	Area
ALİ RIFAT BOYNUEĞRİ	2014	Yıldız Technical Uni.	Electrical Engineering	*Smart grid connections and energy managements of electric vehicles*	EV Charging
ABDUL KERİM KARABİBER	2015	İnönü Uni.	Electrical and Electronics Engineering	*The power integration of the energy supplies used in smart grid via direct current*	Integration of Renewables
BARIŞ BAYKANT ALAGÖZ	2015	İnönü Uni.	Electrical and Electronics Engineering	*Energy balancing in smard grids under varying generation and demand conditions*	Energy Management
ONUR ELMA	2016	Yıldız Technical Uni.	Electrical Engineering	*Development and implementation of a new home energy management algorithm for smart grids*	Energy Management
ULAŞ BARAN BALOĞLU	2017	Fırat Uni.	Electrical and Electronics Engineering	*Applications of computational methods in smart grids*	Computation
CEMAL KELEŞ	2017	İnönü Uni.	Electrical and Electronics Engineering	*Energy and load management of smart homes with renewable energy generation in smart grids*	Energy Management

Table 1: 2014-2024 Smart Grid Doctoral Theses in the YÖK Database

(Continued)

Author	Year	University	Department	Thesis Title	Area
SERKAN BAHÇECİ	2017	Erciyes Uni.	Electrical and Electronics Engineering	*Optimum usage of energy storage systems for pv array integration to smart grid*	Integration of Renewables
DERYA BETÜL ÜNSAL ÇELİMLİ	2018	Selçuk Uni.	Electrical and Electronics Engineering	Controlling the distributed energy resources using smart grid communication technologies	Integration of Renewables
GADDAFI SANI SHEHU	2018	Selçuk Uni.	Electrical and Electronics Engineering	Optimal active and reactive power dispatch in smart grid (Nature-inspired optimization algorithms-based approach)	Optimization
MELİKE YİĞİT KAPDAN	2018	Bahçeşehir Uni.	Computer Engineering	Quality of service aware communication framework for wireless sensor network based smart grid applications	Communication Technologies
RECEP ÇAKMAK	2018	Karadeniz Technical Uni.	Electrical and Electronics Engineering	*Smart demand management system for PV powered residential areas in smart grids*	Energy Management
SERKAN GÖNEN	2018	Gazi Uni.	Information Security Engineering	*Providing information security in micro type smart grid systems controlled by PLC*	Cybersecurity
BİLAL ERMAN BİLGİN	2019	Bahçeşehir Uni.	Computer Engineering	Smart grid data collection with vehicular ad-hoc networks using public transportation buses	Communication Technologies
CEM AYYILDIZ	2019	Bahçeşehir Uni.	Computer Engineering	Internet of things (IoT) for effective post-disaster management	IoT
TURGAY YALÇIN	2019	19 Mayıs Uni.	Electrical and Electronics Engineering	*The identification of power quality disturbances in smart grids through signal processing methods*	Power Quality

Table 1: 2014-2024 Smart Grid Doctoral Theses in the YÖK Database

(Continued)

Author	Year	University	Department	Thesis Title	Area
MUSTAFA YILMAZ	2019	Karabük Uni.	Electrical and Electronics Engineering	*Optimization of power quality in smart grids and integration with renewable energy sources*	Integration of Renewables
EFE İSA TEZDE	2019	Karadeniz Technical Uni.	Electrical and Electronics Engineering	*Optimization based power management for a smart grid connected hybrid energy system*	Energy Management
HAMZA YAPICI	2019	Konya Technical Uni.	Electrical and Electronics Engineering	*The improvement of a new optimization method for integration of renewable energy sources to smart grids*	Integration of Renewables
MEHMET ŞEFİK ÜNEY	2019	Konya Technical Uni.	Electrical and Electronics Engineering	*Load forecasting and load management in smart grid*	Energy Management
KENAN YİĞİT	2019	Yıldız Technical Uni.	Electrical Engineering	*Development of a new electrical energy management system for the ships in accordance with the smart grid infrastructure*	Energy Management
İLTER ŞAHİN AKTAŞ	2020	Gazi Uni.	Energy Systems Engineering	*Risk analysis of smart grids*	Risks Analysis
MEHMET ÇINAR	2020	İnönü Uni.	Electrical and Electronics Engineering	*Auto-optimization algorithms used in smart grids and application to an actual system*	Optimization
CİHAN EMRE KEMENT	2020	TOBB ETU.	Electrical and Electronics Engineering	*Comparative analysis of load shaping based privacy protection strategies in smart grids*	Privacy
MEHMET TAN TURAN	2020	Yıldız Technical Uni.	Electrical Engineering	*Grid integration of renewable energy power plants and protection system design with smart grid infrastructure*	Integration of Renewables

Table 1: 2014-2024 Smart Grid Doctoral Theses in the YÖK Database

(Continued)

Author	Year	University	Department	Thesis Title	Area
AYŞE AYBİKE ŞEKER	2021	Gebze Technical Uni.	Electronics Engineering	Distribution network reconfiguration for smart grid operation	Energy Management
VAHİT FERYAD	2021	Karadeniz Technical Uni.	Electrical and Electronics Engineering	Classification of home electrical appliances using deep learning for smart grid	Energy Management
ELİF ZEYNEP SERPER	2022	TOBB ETU.	Industrial Engineering	*Developing optimal usage plans for wireless sensor networks in smart grid*	Optimization
MİKAİL PÜRLÜ	2022	Istanbul Technical Uni.	Electrical Engineering	*Examination of the effects of distributed generation on smart grids*	Integration of Renewables
AHMET NUR	2022	İnönü Uni.	Electrical and Electronics Engineering	*Power flow analysis of AC/DC hybrid energy systems in smart grids*	Power Electronics
RAMAZAN GÜNGÜNEŞ	2023	Kırıkkale Uni.	Electrical and Electronics Engineering	*Artificial intelligence based energy optimization of rail systems integrated into virtual power plants in smart grids and its impact on the plant*	Optimization
BURAK ESENBOĞA	2023	ALPARSLAN TÜRKEŞ S&T Uni.	Electrical and Electronics Engineering	*Design and realization of a solid-state transformer for smart grids*	Power Electronics
ALPEREN SARI	2023	Ömer Halis Demir Uni.	Electrical and Electronics Engineering	*Using modern methods for load frequency control in smart grids and the design of robust controllers*	Power Electronics
RABİA ULUSOY YILMAZ	2023	Middle East Technical University	Earth System Science	*Household electricity consumption analysis under the use of smart grid applications a demand-side approach*	Energy Management
ONUR AYAN	2023	Istanbul Technical Uni.	Electrical Engineering	*Techno-economic comparative analysis of grid-connected and islanded hybrid renewable energy systems and smart home applications in smart grids*	Energy Management

Table 1: 2014-2024 Smart Grid Doctoral Theses in the YÖK Database

(Continued)

Author	Year	University	Department	Thesis Title	Area
KADİR OLCAY	2024	Konya Technical Uni.	Electrical and Electronics Engineering	*Integration of electric vehicles into the smart grid and analysis of their effects on the grid with artificial intelligence methods*	EV Charging
AHMET KARYEYEN	2024	Konya Technical Uni.	Electrical and Electronics Engineering	*Examination of pricing and generation-related load balance in smart grids*	Optimization
ABDÜLKADİR GÖZOĞLU	2024	19 Mayıs Uni.	Electrical and Electronics Engineering	*Demand side energy management system for future smart grids*	Energy Management
MUHAMMED ZEKERİYA GÜNDÜZ	2024	Fırat Uni.	Software Engineering	*Developing new approaches for detecting and solving security vulnerabilities in internet of things based smart grids*	Cybersecurity

The main contributions of the smart grid doctoral theses listed in Table 1 are summarized below.

Boynueğri researched electric vehicle charging, focusing on power management to minimize battery stress and address potential issues related to grid connectivity. A power conditioning unit was developed for connecting EVs to the grid, allowing for controlled charging. Furthermore, the study examined the system's operation with a smart home at Yıldız Technical University to assess its compatibility with smart grid technology (Boynueğri, 2014).

Karabiber introduced a direct current power integration method to connect distributed energy sources of different scales to the existing grid. This approach enhances the efficiency of the power system, reduces the reliance on electronic devices, lowers costs, and improves power quality (Karabiber, 2015).

Alagöz investigated energy balancing challenges in scenarios of uncertain generation and demand. He conducted theoretical analyses of smart grid architectures using a hierarchical tree topology and highlighted its benefits in addressing generation and

demand uncertainties. He showed that energy balance in smart grids with this architecture can be achieved through closed-loop generation control with dynamic energy pricing. Additionally, he created a simulation environment for managing smart grid closed-loop energy markets, proposed dynamic models for generation and demand, and performed simulations for energy balancing (Alagöz, 2015).

Elma created a new home energy management algorithm for a smart home powered by renewable energy. The algorithm aims to enhance customer comfort while reducing electricity costs by taking real-time pricing into account. It primarily utilizes voltage reduction to decrease power consumption of household appliances, distinguishing itself from traditional methods such as load shifting and load shedding found in existing literature (Elma, 2016).

Baloğlu explored various computational methods in information technologies and integrated them with the conceptual model of electric networks to address challenges in smart grids. He developed and successfully applied new methods to common issues in smart grids, including demand-side management, privacy protection, and electric vehicle charging (Baloğlu, 2017).

Keleş introduced a local load shedding method for managing load under conditions of distributed generation and varying energy pricing tariffs. When total energy demand surpasses the dynamically set maximum power consumption limit, based on real-time energy prices and local generation, the method curtails local energy use by turning off electrical loads according to user-defined priorities and the power needs of household appliances (Keleş, 2017).

Bahçeci examined the selection of locations for energy storage systems within specific distribution networks. To achieve this, he modeled a photovoltaic array connected to distribution networks at random, simulating unlicensed manufacturers. He also investigated a location planning algorithm aimed at selecting optimal sites for energy storage systems and determining charge-discharge timings to enhance energy quality in the distribution networks (Bahçeci, 2017).

Çelimli investigated the communication structures necessary for control requirements and the integration of renewable energy sources. He designed a microgrid system model that utilizes power line communication infrastructure, distributed energy resources, and electric vehicle systems, and simulated the entire setup using MATLAB Simulink (Çelimli, 2018).

Shehu proposed optimization and hybrid algorithms to address the power dispatch problem. He also concentrated on ensuring secure and stable grid operations, given the highly variable nature of load demand resulting from the frequent charging and discharging of electric vehicles in low-capacity distribution grids (Shehu, 2018).

Kapıdan concentrated on ensuring reliable and timely data transmission across unreliable and error-prone wireless sensor networks in a smart grid setting. To meet the smart grid application's quality-of-service demands, several new protocols were developed, taking into account the specific features of the application data. The influence of the wireless environment on the communication performance within the smart grid was also examined to offer more precise solutions (Kapıdan, 2018).

Çakmak introduced an innovative smart demand management system (SDMS) based on a metaheuristic optimization algorithm, focused on efficiency and scalability, along with a new pricing and billing system for homes using grid-connected photovoltaic systems. The goal of the proposed system is to minimize losses by lowering the peak-to-average consumption ratio and to mitigate voltage fluctuations in distribution network (Çakmak, 2018).

Gönen conducted a cybersecurity analysis of programmable logic controllers, which are critical components in integrated circuit systems. In this study, the Siemens S7 1200 (Firmware 2.2) programmable logic controller was analyzed for security vulnerabilities using a testbed specifically set up for the investigation. The impact of various attacks on both the hardware and the system was examined, and attack packets were captured using a mirroring technique to prevent adding extra load to the system (Gönen, 2018).

In his work, Bilgin proposed the implementation of the IEEE 802.11p protocol for smart grid applications. The study describes a method where data is sent from smart meters to a bus via infrastructure-to-vehicle communication, and transmitted from the bus to a bus stop using vehicle-to-infrastructure (V2I) communication. Moreover, he introduced a secure routing protocol that aims to detect and remove blackhole nodes from the network (Bilgin, 2019).

Ayyıldız introduced new communication, security, and battery-saving methods for post-disaster management applications. His thesis focuses on improving communication capabilities, extending battery life, and enhancing security and data integrity in a real-world earthquake disaster management IoT system. He also developed a sensor for structural health monitoring after earthquakes, and the sensor's accuracy was tested in an earthquake laboratory in collaboration with civil engineering experts (Ayyıldız, 2019).

Yalçın investigated power quality disturbances in smart grids, focusing on advancements in effective signal processing and the application of machine learning algorithms and methods that leverage these improvements (Yalçın, 2019).

Yılmaz proposed a solution to integration challenges by conducting simulation studies on wind power plants and solar panels, two of the most commonly used renewable energy sources. He conducted a time-based and continuous state analysis of the

asynchronous generator utilized in wind turbines to forecast the scenario after integration. Additionally, he experimentally investigated how the operating conditions of photovoltaic panels affect inverter output power and grid power quality, using data collected in January and July from an 8 MW production facility located in the Burdur province (Yılmaz, 2019).

Tezde introduced a novel two-stage hybrid optimization algorithm to manage household power consumption in homes equipped with distributed generation and storage. The study modeled a home energy management system (HEMS) at the residential level, incorporating various power components such as photovoltaic systems, wind turbines, electric vehicles, energy storage systems, and electrical appliances (Tezde, 2019).

Yapıcı introduced a new heuristic algorithm called improved swarm optimization with eagle strategy. This algorithm was applied to simultaneously minimize power loss, installation costs, voltage deviation, and gas emissions. The effectiveness of the method was evaluated using several classical benchmark tests (Yapıcı, 2019).

Üney focused on creating a management strategy for smart grids aimed at helping power system operators reduce power losses and enhance the operational speed of the network. He emphasized the importance of load forecasting, which plays a critical role in power system management. Additionally, he explored optimal reactive power dispatch, which is essential for the economical and safe operation of power systems (Uney, 2019).

Yiğit proposed a novel "Ship Electrical Energy Management System" designed for vessels equipped with alternative energy sources and a smart grid infrastructure. He developed two distinct algorithms for managing electrical energy on ships, which were integrated into the system and tested using MATLAB (Yiğit, 2019).

Aktaş developed an advanced risk assessment index framework for smart grid systems, encompassing various risks such as financial, security, environmental, technological, and management risks. The significance of these risks was evaluated using Chang's Fuzzy Analytic Hierarchy Process, along with the Enhanced Integral Value and Quadratic Mean methods (Aktaş, 2020).

Çınar created a wound healing algorithm inspired by the clonal selection principle to achieve optimal load distribution in smart grids. He developed a software package in the MATLAB environment that implemented this algorithm, along with clonal selection, artificial bee, firefly, and cuckoo algorithms. These algorithms were applied to functions for optimizing fuel costs, minimizing power loss, and adjusting voltage level (Çınar, 2020).

Kement conducted comparative analyses of privacy protection strategies based on load shaping. His thesis offers a balanced evaluation of various load shaping methods for privacy protection and their impacts on the objectives of utility providers. It also explores the concept of holistic privacy and delves into privacy protection strategies based on both real and reactive power (Kement, 2020).

Turan concentrated on sizing and optimization studies for electric vehicle charging stations and solar power plants within microgrids, aiming to stabilize voltage levels. The modeling of solar power plants was conducted with a focus on utilizing their nominal capacity while taking into account the physical and electrical constraints of the microgrids. The proposed sizing methodology aims to minimize the impact of solar power plants on voltage levels in microgrids (Turan, 2020).

Şeker created an analytical approach to address the reconfiguration problem for distributed load profiles. He explored a sensitivity index-based method for systems with spot loads. Additionally, he developed a new method for representing changes in the topology of a distribution network through a bus-injection to branch-current matrix, which is used for load flow analysis in distribution networks. This proposed method was tested with the grid search algorithm. He also examined the effects of load modeling on the reconfiguration of distribution networks, focusing on voltage-dependent and time-varying loads (Şeker, 2021).

Feryad created an efficient energy disaggregation model, evaluating its performance using publicly available benchmark data and success metrics. He developed a device classifier model based on a Turkish electrical appliances dataset and assessed its effectiveness (Feryad, 2021).

Serper explored a scenario in which transmission paths are adjusted in response to topology changes, provided that the existing set of sensors with sufficient residual energy can maintain the necessary coverage level and connectivity to the base station. He proposed an innovative 0-1 mixed integer programming model along with two alternative models that optimize network performance through unit time decomposition, focusing on energy consumption (Serper, 2022).

Pürlü implemented single and double optimal distributed generation allocations to minimize total power losses and enhance the voltage profile. To achieve this, he proposed and applied genetic and particle swarm optimization algorithms—both heuristic methods—on the IEEE 33-bus radial distribution system (Pürlü, 2022).

Nur conducted a 24-hour power flow analysis in a 13-bus AC system utilizing variable renewable distributed sources and variable loads. This analysis produced graphs for voltage, active power, reactive power, and complex power across the buses. Additionally, he designed a hybrid 13-bus AC/DC test system featuring voltage source

converters using the MATLAB platform and performed the power flow analysis for this system (Nur, 2022).

Güngüneş proposed an energy-efficient dynamic driving model that employs heuristic optimization techniques to enhance the driving dynamics of rail system vehicles equipped with regenerative braking energy generation capabilities. The optimal model design focuses on determining the best idle locations on a horizontal curving track for cars, where regenerative braking energy can be harvested. The goal is to maximize energy efficiency by utilizing optimal speed profiles (Güngüneş, 2023).

Esenboğa introduced a three-level solid-state transformer model along with a power management scheme specifically designed for solar photovoltaic power plants integrated with smart grids. He also outlined the operating strategies of the solid-state transformer, including voltage and current management between converters and pulse-width modulation control (Esenboğa, 2023).

Sarı studied the incorporation of electrical aggregators as a resource in both single-area and multi-area traditional load frequency control systems to enhance frequency regulation and flexibility within smart grids. To analyze the impact of time delays arising from various communication requirements—particularly those related to digitalization in smart grids—two frequency domain methods were employed to determine the time delay margins necessary for the system to remain stable (Sarı, 2023).

Yılmaz investigated the relationship between electricity consumption behavior and the use of smart grid applications through the lens of habitual behavior. In addition to considering social norms and self-efficacy, the study utilized a habitual behavior framework to examine the impacts of awareness, attitude, and intention (Yılmaz, 2023).

Ayan conducted a comparative analysis of hybrid renewable energy systems for residential areas within the framework of smart grids and smart building applications. In this study, 21 provinces in Türkiye were compared based on technical, economic, and environmental factors using HOMER Pro software, taking into account the lowest, median, and highest solar radiation values across the seven regions of Türkiye (Ayan, 2023).

Olcay investigated the impact of electric vehicle chargers on the electricity network. A MATLAB Simulink model of power test systems with varying bus numbers was created to analyze how electric vehicle chargers affect these networks. Furthermore, future impacts were forecasted using deep learning techniques applied to the collected data, enabling the prediction of potential malfunctions related to infrastructure planning and analysis for the networks (Olcay, 2024).

Karyeyen explored load balancing based on dynamic pricing through modeling a closed-loop electrical power control system, where the demand-supply balance aligns with the electric energy price at a common point. In his system model, three different controllers were utilized to achieve the demand-supply-price balance in the electricity market, in line with smart grid technology. He applied classical proportional integral controllers, fuzzy logic proportional integral controllers, and neural network model reference controllers to various demand change scenarios as part of his thesis research (Karyeyen, 2024).

Gözoğlu developed a home automation server centered around the concept of low-cost smart devices connected through a Wi-Fi network. The primary goal of this design is to establish a home management system that is adaptable and to create an environment that can manage demand-side energy consumption in future smart grids (Gözoğlu, 2024).

Gündüz conducted a detailed analysis of the various types of cyber attacks on IoT-based smart grids, categorized by network layers. He presented potential threats and corresponding solutions. Additionally, he proposed two artificial intelligence-based approaches for detecting and addressing security vulnerabilities in smart grids (Gündüz, 2024).

2.3. Related Work in the Literature

As the main goal of our work is to determine the parameters and factors affecting the success of smart grid transformation in Türkiye, we also reviewed similar studies in the literature. For related work, we performed searches in the sciencedirect.com, researchgate.net, escholarship.org, openresearch.surrey.ac.uk, cadmus.eui.eu, and semanticscholar.org databases with the keywords “smart grid”, “smart grid in Turkey”, “smart grid in EU”, “smart grid parameters”, “success of smart grid in Turkey”, “*smart grid transformation success*”, “*parameters of smart grid transformation*”, and “*DeLone and McLean IS success model adaptation for Smart Grid*”. Each keyword was searched separately. We found out that in the literature there is no direct study focusing on determining the parameters that directly affect the success of Turkish smart grid transformation. We summarize the most relevant studies below.

ELDER’s Türkiye Smart Grid report discussed future expectations from the Turkish electricity grid. The report emphasizes lowering the carbon footprint of distribution companies by minimizing both technical and non-technical losses, improving grid sustainability and energy quality, enhancing grid resilience, and boosting the distribution companies' situational awareness of the network using sophisticated and near real-time measurement infrastructures (ELDER, 2019).

Keskin offered an overview of the challenges facing Türkiye’s current electric power system while examining the country’s progress toward the smart grid transition to

date. To summarize key smart grid technologies worldwide, he presented a smart grid framework design. Based on this framework, he evaluated Türkiye's past initiatives for power system development from a smart grid perspective and proposed additional steps to achieve a successful transition to a smart grid (Keskin, 2021).

Atasoy examined the modernization efforts in the Turkish electricity distribution sector, which led to processes of liberalization, privatization, and unbundling that have reshaped the sector's landscape. His study offers a comprehensive overview of the Turkish electricity sector, covering aspects such as the regulatory framework, the electricity market value chain, the dynamics of the electricity distribution sector, and its revenue framework (Atasoy, 2020).

Çolak presented an overview of European smart grid projects and provided details of the current infrastructure and smart grid applications of EÜAŞ, TEİAŞ, and TEDAŞ. In his study, he discusses the feasibility of the necessary next steps and offers assessments and recommendations for advancements in smart grid technology more broadly (Colak, 2014).

Elma and Vural reviewed smart grid research in the world and gave an overview of smart grid applications in Türkiye (Elma & Vural, 2014).

There are also related studies in the literature on smart grids in other countries as summarized below.

Bhatt and Shah examined smart grids through the lens of critical applications and parameters. They identified monitoring of the power network, automated metering infrastructure, monitoring and automation of substations, home automation networks, demand response, and integrating solar photovoltaics as 'critical applications'. Additionally, they highlighted security, interoperability, reliability, scalability, congestion, energy efficiency, and latency, as 'critical parameters' in their study (Bhatt & Shah, 2014).

Sæle and Grande shared insights from a pilot study conducted in Norway focusing on households' daily demand response. This study employed smart metering, remote load control, and a pricing model that combined hourly spot prices with a time-of-day network tariff. Customers were also provided with a token to indicate peak hours (Sæle & Grande, 2011).

Boogen and Datta analyzed data from a survey of 30 utility companies in Switzerland to assess the effect of demand-side management activities on residential electricity demand. By examining variations in demand-side management efforts both within and among utilities over time, they determined that the implementation of these programs led to a reduction of approximately 5% in residential electricity consumption per customer (Boogen & Datta, 2017).

Söder and Lund compared various demand-side flexibility approaches for balancing renewable power production. Their study included an analysis of flexibility potentials across seven Northern European countries, as well as an examination of the general challenges faced and the outcomes achieved by each country in relation to the estimation methods employed (Söder & Lund, 2018).

Lampropoulos and Broek proposed exploring opportunities, challenges, and possible solutions for developing flexibility mechanisms via aggregator companies, with an emphasis on market integration. They tested their approach in the Netherlands as a case study, producing a thorough review of electricity market evolution that covers all relevant aspects related to improving the market integration of aggregator companies in the Dutch system, in line with the new European grid codes (Lampropoulos & Broek, 2018).

Korsnes and Throndsen examined how smart energy technologies impact users in Norway and the degree to which users can shape the role of these technologies in their daily lives. Their findings revealed a gap between the intended goals and the actual effects of the implemented technologies. For example, smart technologies were found to influence how individuals structured their daily routines, requiring more effort from participants (Korsnes & Throndsen, 2021).

Norouzi and Hoppe studied the developments in smart grid innovation systems. Their primary research question focused on identifying the systemic and transformational failures that occurred in the development of smart grid innovations in the Netherlands between 2001 and 2021 (Norouzi & Hoppe, 2023).

Nazir and Sharifi used a mixed-methods approach, including a literature review and expert surveys through the Delphi method, to identify the main obstacles to smart grid implementation in Pakistan and their interrelations. They highlighted the following barriers: state monopoly, low public awareness, inadequate regulations and policies, organizational hurdles, financial limitations, market unpredictability, a lack of skilled technical workforce, outdated grid infrastructure, and challenges in data management (Nazir & Sharifi, 2024).

Akkad and Wills examined the requirements and controls for cybersecurity related to the bidirectional data flow in IoT-enabled smart grids within the Saudi energy sector. Their focus was specifically on ensuring the cybersecurity of information flow by implementing technical security measures to combat internet-based threats in IoT-enabled smart grids (Akkad & Wills, 2023).

CHAPTER 3

ACTORS & STAKEHOLDERS IN TURKISH ELECTRICITY GRID

In the Turkish electricity grid, there are different kinds of actors, stakeholders, and institutions whose responsibilities include generation, transmission, and distribution of electricity as well as its regulation, operation, and management. These actors and stakeholders also produce, collect, share, and use data related with electricity. The data flow structure among these actors is a significant part of the Turkish smart grid establishment, development, and future smart grid management. The views, priorities and needs of these actors are game changers to determine the critical parameters that directly affect the success of smart grid transformation in Türkiye. These actors, stakeholders and institutions are EÜAŞ (Electricity Generation Company), TEİAŞ (Turkish Electricity Transmission Company), TEDAŞ (Turkish Electricity Distribution Company), EPİAŞ (Energy Exchange Company), EPDK (Energy Market Regulatory Authority) and Ministry of Energy and Natural Resources. Below we discuss and assess the responsibilities and operations of these players in detail.

3.1. EÜAŞ (Public Electricity Generation Company)

Electrical energy production is carried out by both public and private companies in Türkiye. EÜAŞ (Public Electricity Generation Company), considering public interest, within the framework of profitability and efficiency principles, is a government organization established to generate and distribute electrical energy that is reliable, uninterrupted, high-quality, efficient, cost-effective, and environmentally sustainable. It has only thermal and hydroelectric power plants. Due to the privatized power plants, the share of EÜAŞ in production is decreasing every year.

3.2. TEİAŞ (Turkish Electricity Transmission Company)

The electric transmission network is the backbone of an electric system and carries electric power at a high voltage over long distances. The transmission of electric power at a high voltage reduces the electricity losses allowing large volumes of power to be transported over long distances in an efficient manner. Transmission networks are often likened to a ‘highway system’ that facilitates the long-distance transmission of electricity to individual large users or for onward carriage via more localized electric distribution systems (Rubino, 2021). The transmission network is also a critical

infrastructure required for the integration of distributed energy resources. At the bulk transmission level, high-capacity green energy corridors are planned and implemented.

TEİAŞ in Türkiye is responsible for the critical activity of transmission of electricity from production to the distribution networks. The energy produced in power plants is transmitted to substations in cities via high voltage lines. Since it is necessary to keep the frequency at 50 Hz, the National Load Dispatch Center within TEİAŞ works to keep production and consumption in balance in real time. Under the "Transmission License" granted by the Energy Market Regulatory Authority (EMRA) on March 13, 2003, and in line with the new market structure, TEİAŞ operates through central and nationwide units that manage projects, installation, operations, maintenance, and load dispatch. Since September 18, 2010, the Turkish electricity system has been running in synchronized parallel mode with the European Network of Transmission System Operators for Electricity (ENTSO-E) (TEİAŞ, 2022).

3.3. TEDAŞ (Turkish Electricity Distribution Company)

Distribution is the transmission of electrical energy over lines with a voltage level of 36.000 volts and below. Distribution networks carry power the last few miles from transmission or sub-transmission to consumers, and they are distinguished from transmission networks by their voltage level and topology (A. Papalexopoulos, 2013).

Distribution companies are responsible for the distribution of electricity with medium /low voltage lines, for the reading/maintenance of the meters in the distribution region, smart metering, forecasting the demand and general lighting. Electricity distribution activities have been divided into 21 different regions in Türkiye and the operating rights of these companies have been transferred to the private sector, with the ownership belonging to TEDAŞ. Therefore, TEDAŞ is also responsible for the supervision of these 21 distribution companies (TEDAŞ, 2022).

The main responsibilities of TEDAŞ includes (TEDAŞ, 2022):

- Carrying out operations related to auditing the operational network and investment activities of distribution companies in terms of necessity, priority, and characteristics
- Performing electricity distribution activities domestically and/or abroad when necessary and/or when assigned
- Conducting the necessary R&D studies to improve service quality and customer satisfaction and establishing new performance criteria
- Performing project control and approval, provisional and final acceptance procedures
- Establishing laboratory and training facilities
- Preparing specifications for materials and equipment to be used in the distribution network

- Carrying out the certification process for the conformity assessment of materials or equipment to be used in the network and performing the related documentation/certification procedures
- Development and digitalization of the current distribution grid

3.4. Electricity DSOs (Distribution System Operators) in Türkiye

Electricity distribution networks were initially designed as passive systems, which provided one-way links between the transmission network and electricity end users. The introduction of distributed generation resulted in many distribution networks becoming energy harvesting systems, with much more variability and bi-directional power flows where there are high penetrations of distributed generation (Gharehpetian & Agah, 2017).

Electricity distribution has been evolving from its traditional passive structure to an active form with the increasing penetration of distributed energy resources, distributed energy transition (e.g., wind, solar) and transition to the smart grid. Electricity consumers linked to the distribution network are also more active now, as they consume, produce and store energy in smart grids (Abdelmotteleb &Avila, 2019).

Companies responsible for electricity distribution in a specified region are called distribution companies. In Türkiye there are 21 electricity distribution companies. These companies are presented in Figure 2 and in Table 2. The responsibilities of these distribution companies include:

- Operation, maintenance, repair, expansion, improvement of distribution lines and keeping them running
- Ensuring that the distribution network is operational by performing planned maintenance activities, establishing remote reading systems (eg. smart meters) and energizing newly introduced consumption points
- Facilities and investments, cutting/binding operations
- Meter reading, notifying the elecricity meter consumption data to consumers
- Sharing the consumption data of free consumers to EPİAŞ monthly
- Research and development activities of the distribution network



Figure 2: Türkiye Distribution System Operators Map

Table 2: Distribution System Operators in Türkiye and Their Regions

DISTRIBUTION COMPANY	**REGION**
1)AKDENİZ ELEKTRİK DAĞITIM AŞ	Antalya, Burdur, Isparta
2)AKEDAŞ ELEKTRİK DAĞITIM	Adıyaman, Kahramanmaraş
3)ANADOLU YAKASI ELEKTRİK DAĞITIM AŞ (AYEDAŞ)	İstanbul - Anadolu Yakası
4)ARAS ELEKTRİK DAĞITIM AŞ	Ağrı, Ardahan, Bayburt, Erzincan, Erzurum, Iğdır, Kars
5)AYDEM ELEKTRİK DAĞITIM AŞ	Aydın, Denizli, Muğla
6)BAŞKENT ELEKTRİK DAĞITIM A.Ş.	Ankara, Bartın, Çankırı, Karabük, Kastamonu, Kırıkkale, Zonguldak
7)BOĞAZİÇİ ELEKTRİK DAĞITIM AŞ	İstanbul - Avrupa Yakası
8)ÇAMLIBEL ELEKTRİK DAĞITIM AŞ	Sivas, Tokat, Yozgat
9)ÇORUH ELEKTRİK DAĞITIM AŞ	Artvin, Giresun, Gümüşhane, Rize, Trabzon

Table 2: Distribution System Operators in Türkiye and Their Regions (Continued)

10)DİCLE ELEKTRİK DAĞITIM AŞ	Batman, Diyarbakır, Mardin, Siirt, Şanlıurfa, Şırnak
11)FIRAT ELEKTRİK DAĞITIM AŞ	Bingöl, Elazığ, Malatya, Tunceli
12)GEDİZ ELEKTRİK DAĞITIM AŞ	İzmir, Manisa
13)KAYSERİ VE CİVARI ELEKTRİK TÜRK AŞ	Kayseri
14)MERAM ELEKTRİK DAĞITIM AŞ	Aksaray, Karaman, Kırşehir, Konya, Nevşehir, Niğde
15)OSMANGAZİ ELEKTRİK DAĞITIM AŞ	Afyonkarahisar, Bilecik, Eskişehir, Kütahya, Uşak
16)SAKARYA ELEKTRİK DAĞITIM AŞ	Bolu, Düzce, Kocaeli, Sakarya
17)TOROSLAR ELEKTRİK DAĞITIM AŞ	Adana, Gaziantep, Hatay, Kilis, Mersin, Osmaniye
18)TRAKYA ELEKTRİK DAĞITIM AŞ	Edirne, Kırklareli, Tekirdağ
19)ULUDAĞ ELEKTRİK DAĞITIM AŞ	Balıkesir, Bursa, Çanakkale, Yalova
20)VANGÖLÜ ELEKTRİK DAĞITIM AŞ	Bitlis, Hakkari, Muş, Van
21)YEŞİLIRMAK ELEKTRİK DAĞITIM AŞ	Amasya, Çorum, Ordu, Samsun, Sinop

3.5. EPİAŞ (Energy Exchange Istanbul)

Energy Exchange Istanbul (EXIST), or Enerji Piyasaları İşletme A.Ş. (EPİAŞ) in Turkish, is an energy exchange company established on March 18, 2015. EXIST operates under the Turkish Electricity Market Law and has the Energy Markets Operation License granted by the Energy Markets Regulatory Authority (EMRA) of Türkiye. EXIST oversees the management and operation of energy markets, covering both electricity and gas commodities. By offering central counterparty services, EXIST guarantees transparent, reliable, and credible market conditions (EPİAŞ, 2022).

EXIST, which operates Day-Ahead and Intraday Spot Electricity Market, Spot Natural Gas Market, Power Futures Market, Natural Gas Futures Market and Renewable

Energy Guarantees of Origin System & Organized YEK-G Market, also performs financial transactions such as settlement, collateral and invoicing in these markets, settlement activities regarding the Balancing Power Market (BPM), operation of the Renewable Energy Resources Support Mechanism (YEKDEM), and carries out eligible customer transactions (EPİAŞ, 2022).

3.6. Turkish Republic Ministry of Energy and Natural Resources

Duties and authorities of the Ministry of Energy and Natural Resources in Türkiye are as follows (Ministry of Energy, 2022):

- Determining the country's short-term and long-term needs for energy and natural resources, developing policies, and making plans
- Researching, operating, developing, evaluating, and controlling general policy principles, making necessary programs, planning, and preparing projects
- Exploration, establishment, operation, and utilization of these resources to grant, transfer and revoke rights when necessary,
- Undertaking mortgage, expropriation and establishing other restrictive rights, keeping, and maintaining their records
- Ensuring security and benefit from energy and natural resources in line with public needs; energy production, transmission, distribution, survey, establishment, operation, and maintenance services of its facilities
- Production, transmission, distribution and consumption of underground and surface energy and natural resources and their products; determining the pricing policy and determining the prices when necessary
- Examining and approving the business and investment programs of the affiliated and related institutions of the Ministry; monitoring and evaluating its activities according to annual programs
- Examination, investigation, and inspection of all the activities and transactions of the institutions affiliated with the Ministry and related to the Ministry
- Evaluation of renewable energy sources and increasing energy efficiency

3.7. EPDK (Energy Market Regulatory Authority)

Smart grid business models are influenced by different factors such as electricity market regulation mechanisms, power system characteristics and infrastructure (Behrangrad, 2015). Therefore, the Energy Market Regulatory Authority (EMRA), which is an independent public institution, is significant and critical for smart grid transition in Türkiye. The independence of the institution is an indispensable element for the impartial management of energy markets. The EMRA Board consists of the presidency and service units. The Authority uses its power through the energy market regulatory board, which is the representative and decision body of the institution, while performing its duties. With the privatization of energy markets, the responsibilities of this institution have also increased. The main duties of EMRA are as follows (EPDK, 2024):

- Monitoring the performance of the companies in the market
- Establishing standards for the performance measures to be applied
- Preparing regulations on matters falling under the service area and performing inspections to ensure compliance with regulations
- Dealing with pricing issues and keeping prices updated based on inflation data
- Preparing the necessary regulations for consumers to receive quality, low-cost, reliable, and uninterrupted electricity service
- Approving wholesale tariff, transmission, distribution and retail sales tariffs and determination of pricing principles
- Determining the discount made in the free consumer limit in January every year and publishing the new limit
- Determining the financial reporting standards of companies operating in the market with production, distribution and sales licenses and monitoring the compliance of these companies with the determined equality and transparency requirements
- Encouraging the use of renewable and domestic energy resources

3.8. Installed Power Structure of Turkish Electricity Grid

The installed power structure of the Turkish electricity grid has changed significantly in recent years. The ratio of the renewables (solar and wind) in electricity generation is rapidly increasing. Between 2019 and 2024 the wind power ratio increased from 8.35% to 11.02% and the solar power ratio increased from 0.1 % to 13.32%. In 2019, the installed solar power in Türkiye was 81.66 MW, whereas this number increased to 14640.24 MW just in 5 years, which is more than 179 times. The total installed renewable power increased from 37382 MW to 62701 MW in the same period, which means a 67.73 % increase. As wind and solar power are intermittent sources, smart grid transformation is inevitable and urgent in Türkiye. The installed power configurations of Türkiye for the period 2019-2024 is presented in Figure 3 and detailed in Table 3 (EPDK, 2024).

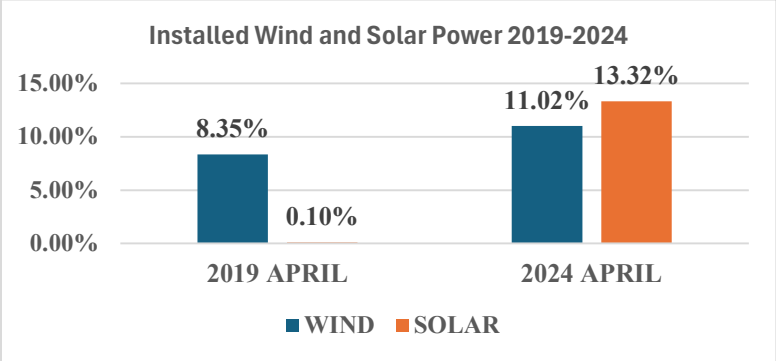


Figure 3: Installed Wind & Solar Power in Türkiye 2019-2024

Table 3: Installed Power of Turkish Electricity Grid (2019-2024)

TYPE	TÜRKİYE INSTALLED POWER (MW)				
	2019 APRIL	PERCENT (%)	2024 APRIL	PERCENT (%)	CHANGE (%)
HYDRO	28392.2	33.79%	32180.42	29.29%	13.34%
WIND	7015.56	8.35%	12102.56	11.02%	**72.51%**
SOLAR	81.66	0.10%	14640.24	13.32%	**17828.29%**
BIOMASS	590.92	0.70%	2087.02	1.90%	253.18%
GEOTHERMAL	1302.52	1.55%	1691.34	1.54%	29.85%
RENEWABLE	**37382.86**	**44.49%**	**62701.58**	**57.07%**	**67.73%**
NATURAL GAS	26119.29	31.08%	25083.95	22.83%	-3.96%
IMPORT COAL	8938.85	10.64%	10373.8	9.44%	16.05%
LIGNITE	9853.08	11.73%	10206.59	9.29%	3.59%
COAL	616.15	0.73%	840.77	0.77%	36.46%
ASPHALTITE	405	0.48%	405	0.37%	0.00%
FUEL OİL	709.21	0.84%	251.93	0.23%	-64.48%
NAFTA	4.74	0.01%	4.74	0.00%	0.00%
LNG	1.95	0.00%	1.95	0.00%	0.00%
DIESEL	1.04	0.00%	1.04	0.00%	0.00%
FOSSIL FUELS	**46649.31**	**55.51%**	**47169.77**	**42.93%**	1.12%
TOTAL	**84032.17**	**100.00%**	**109871.35**	**100.00%**	

CHAPTER 4

ANALYSIS TECHNIQUES & RESEARCH METHODS

This section provides an overview of potential research methods to be used for determining and analyzing the parameters affecting smart grid transformation success in Türkiye.

4.1. Qualitative and Quantitative Analysis Methods

Research methods comprising both data collection and analysis are mainly classified as qualitative or quantitative methods in the literature (Powell, 1999). Quantitative research, in contrast to qualitative research, deals with data that are numerical or that can be converted into numbers (Sheard, 2018). Qualitative research studies typically seek to answer questions about the 'what', 'how' and 'why' of phenomena, which is in contrast to the questions of 'how many' or 'how much' that are answered by quantitative research. Quantitative research involves gathering and analyzing numerical data to describe, explain, predict, or manage variables and phenomena of interest (Gay, Mills & Airasian, 2009).

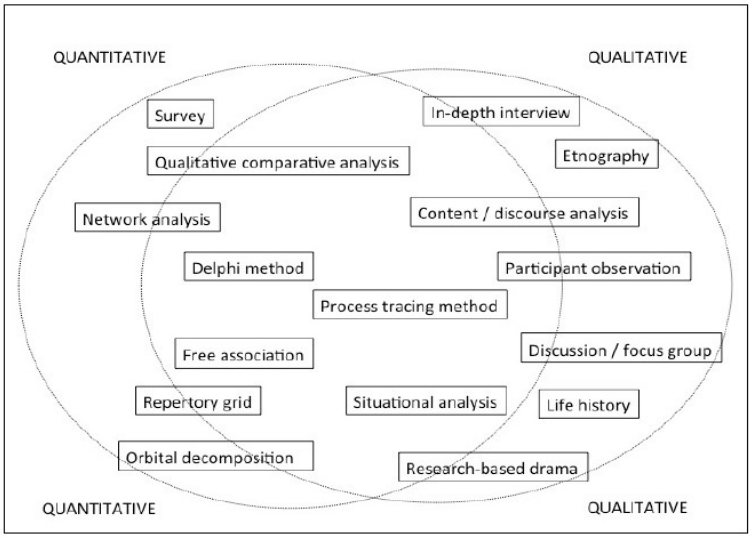


Figure 4: Research Techniques and Types of Research Methods (Cardenas, 2019)

According to Cardenas, research is a process of asking questions and answering them by collecting and analyzing data. Data can be converted into numbers, words or images. When data are numbers or the information collected is transformed into numerical scale, this research is performed with quantitative data and is called quantitative analysis (Cardenas, 2019). Research techniques and types of research methods are presented in Figure 4.

4.2. Types of Quantitative Analysis

To decide the most appropriate method for our problem, we investigated quantitative research methods in the literature. Brief overviews of the six quantitative research methods commonly used in the literature are provided below.

4.2.1. Historical Quantitative Research

Historical quantitative research is the construction of a physical, conceptual or mathematical model that searches the existence and the direction of a relation dependent on the same variable affecting the same group at different times (Armstrong & Shapiro, 1974).

4.2.2. Descriptive Quantitative Research

Descriptive research aims to find the answers to the *Who, What, Where, When, How, How many* and *How much* questions. In descriptive research, the researcher should have a clear idea of what is needed and look for answers to more clearly defined questions. Descriptive studies might tell the size, the structure, developments over time and attitudes of particular groups of people (Sloman, 2010).

4.2.3. Correlational Quantitative Research

Correlational research is used to discover and then possibly measure relationships between two or more variables. From a research perspective, the word relationship means that an individual's status on one variable tends to reflect the status on another variable (Vogt, 2011).

The correlational method focuses on identifying connections between variables and is defined by quantification, as it requires determining the magnitude of those variables. Data can be gathered using various approaches, including observation, interviews, online surveys, questionnaires, or measurements (MacKenzie, 2013).

4.2.4. Experimental Quantitative Research

According to Armstrong and Shapiro, experimental quantitative research is a physical, conceptual, or mathematical model that searches for the existence and the direction of a relation dependent on the same variable affecting two or more groups (Armstrong & Shapiro, 1974). Experimental research involves the differentiation of two basic conditions: exposure and non-exposure to the independent variable. The experimental group is the group exposed to the condition, while the control group is not. Observations are recorded for each group and the groups are then compared, with differences in the experimental group assumed to be attributable to the application of the condition (Tanner, 2002).

4.2.5. Survey Research

The survey method is used as a research strategy that encompasses any measurement procedures that involve asking questions to the respondents concerning the status of the subject under study **(**Powell & Connaway, 2010). Survey research may incorporate quantitative methods, such as using questionnaires with numerically rated items, and employs sampling strategies to gather a sufficient, representative sample of the target population. Since it is typically impractical to collect data from the entire population, a sample or subset is used to estimate the overall population's responses (Ponto, 2015). Table 4 lists the sources of error in survey research.

Table 4: Sources of Error in Survey Research

Type of error	**Source of error**	**Strategies to reduce error**
Coverage error	Unknown or zero chance of individuals in the population being included in the sample	Multimode design
Sampling error	Individuals included in the sample do not represent the characteristics of the population	Clearly identified population of interest; diverse participant recruitment strategies; large, random sample
Measurement error	Questions/instruments do not accurately reflect the topic of interest; questionnaires/ interviews do not evoke truthful answers	Valid, reliable instruments; pretest questions; user-friendly graphics, visual characteristics
Nonresponse error	Lack of response from all individuals in sample	User-friendly survey design; follow-up procedures for nonresponders

4.2.6. Causal Comparative Research

The goal of causal research is to offer explanations, which is why it is often referred to as explanatory research. For instance, it can be employed to determine why individuals prefer brand A over brand B or why some support capital punishment while others do not. This type of research can also help eliminate competing explanations and conclusions (Bertomeu & Beyer & Taylor, 2016).

As a result of our investigation of quantitative research methods, we decided to use both correlational research and survey research for this study. The correlational model best fits our study because the focus and contribution of our study is to determine and analyze the parameters affecting smart grid transformation success in Türkiye. We also use survey research techniques to collect data from stakeholders in the energy sector, such as employees at electricity distribution system operators, transmission system operators, regulatory bodies, electricity generation entities and academicians.

To use the correlational research model in our study, it is required to define independent and dependent variables. In a formal cause-effect relationship, dependent variables are used as the effects and independent variables are used as the causes.

4.3. DeLone & McLean Information System Success Model

The dependent variable of this study is smart grid transformation success in Türkiye. To differentiate subcomponents of the dependent variable from independent variables, we take DeLone's and McLean's studies "Information Systems Success: The Quest for the Dependent Variable-1992" (Delone & McLean, 1992) and "The DeLone and McLean Model of Information Systems Success: A Ten-Year Update-2003" (Delone & Mclean, 2003) as reference. DeLone and McLean proposed the Information Systems Success model as a framework for measuring the complex dependent variable in information systems research and differentiating subcomponents of the dependent variable from independent variables.

Rai and Welker conducted a goodness-of-fit test on the full DeLone & McLean Information Success Model, using survey data from 274 users of a university's student information system. The results showed that while some goodness-of-fit indicators were significant, others were not. Nevertheless, all path coefficients between the success dimensions of the DeLone & McLean Information Success Model were found to be significant (Rai &Welker, 2002).

According to DeLone & McLean's newer study in 2003, subcomponents of the dependent variable include information quality, system quality, service quality, intention to use (use), user satisfaction and net benefits. DeLone & McLean's newer study is presented below.

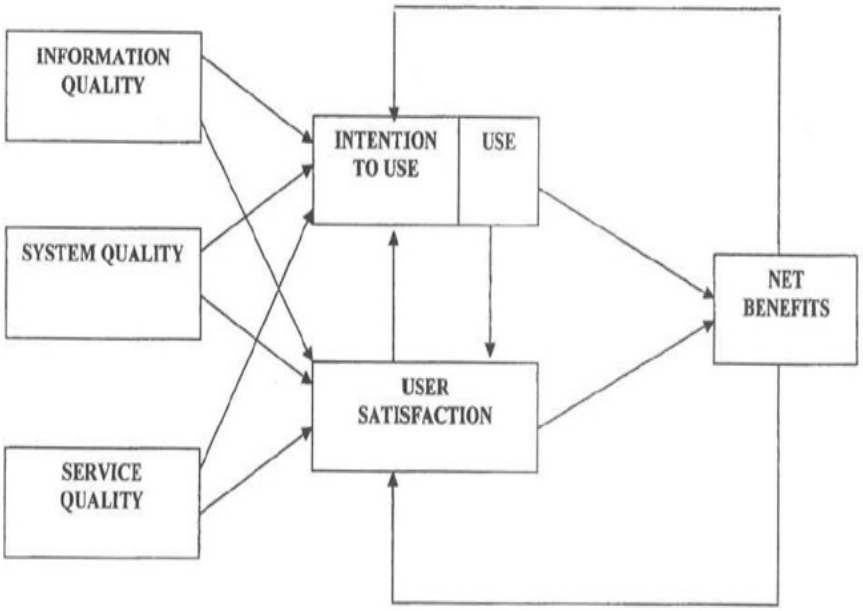


Figure 5: DeLone and McLean IS Success Model (DeLone & Mclean, 2003)

DeLone & McLean provided an example study for e-commerce success to illustrate the dependent variable's subcomponents. The subcomponents of the dependent variable for e-commerce success are as follows:

- System quality: adaptability, availability, reliability, response time, usability
- Service quality: assurance, empathy, responsiveness
- Information quality: completeness, ease of understanding, personalization, relevance, security
- Use: nature of use, navigation patterns, number of site visits, number of transactions executed
- User satisfaction: repeat purchases, repeat visits, user surveys
- Net benefits: cost savings, expanded markets, incremental additional sales, reduced search costs, time savings

For our study, we changed some subcomponents of the dependent variable of DeLone and McLean's example to match smart grid transformation success, by consulting electricity sector experts. We also added *electricity interruption duration* to the service

quality part and removed *reduced search costs,* which is not a suitable subcomponent for smart grid transformation. Experts' explanations about the modification of each subcomponent are given below.

Responsiveness to *self healing:* Responsiveness means giving immediate reaction to incidences in e-commerce. Immediate reaction achieved with self healing is critical and urgent in case of power outages in electricity grids. Therefore, the responsiveness variable was modified as self healing for the smart grid.

Navigation patterns to *load profile:* In e-commerce most of the actions and road maps are determined according to navigation patterns of the users. Likewise in the electricity grid, load profiles of the consumers determine the required actions plans and investments. Hence, the navigation patterns variable was modified as load profile for the smart grid.

Number of site visits to *number of load shiftings:* In e-commerce, the number of site visits is one of the success indicators of that site. For smart grids, load shifting corresponds to a similar indicator.

Number of transactions executed to *shifted electricity used in Kwh:* In e-commerce, the number of transactions executed affects the financial effectiveness of that site. For the smart grid, shifted electricity usage in Kwh determines a similar financial outcome for the system.

Repeat purchases to *repeat load shiftings:* Encouraging a customer to make repeated purchases is one of the targets of an e-commerce site. To encourage the customer/subscriber to participate in load shiftings many times is a similar target for the smart grid. Hence, the repeat purchases variable was modified as repeat load shiftings.

Repeat visits to *repeat shifted electricity usage in off-peak times:* In e-commerce, repeating customer visits increases user satisfaction. In the smart grid, repeating the shifted electricity usage in off-peak times increases user profit, because of the low electricity prices in off-peak times, which in turn increases user satisfaction. Hence, repeat visits was modified as repeat shifted electricity usage in off-peak times for smart grids.

Expanded markets to *expanded distributed energy resources:* E-commerce enables markets to be expanded for new regions and countries. Similarly, smart grid transformation enables energy sources to be expanded to include resources like wind and solar energy. Hence, the expended markets variable was modified as expanded distributed energy sources for smart grids.

Incremental additional sales to *incremental additional electricity sales in off-peak times:* Encouraging customer to make extra purchases is one of the targets of e-

commerce. Encouraging the customer/subscriber to use additional electricity in off-peak times is one of the similar targets of the smart grid. Therefore, the incremental additional sales variable was modified as incremental additional electricity sales in off-peak times for smart grids.

Electricity interruption duration: In electricity grids outage durations are critical parameters for calculating the service quality. Hence, electricity interruption duration was added to the subcomponents list.

Having determined the subcomponents of the dependent variable for smart grid transformation success, below we list and define the 25 subcomponents of the dependent variable.

System quality (5):

Adaptability: Capability of the services received from the smart grid to meet different requirements that will arise over time

Availability: Continuity and uninterruptibility of all services provided by the smart grid

Reliability: The ability of the smart grid to provide trustworthy and trusted functions and services to the users

Response Time: Instant action time for events like technical failures, power outages, price changes, cyber attacks

Usability: Ease of use for smart grid enabled functions and services

Service quality (4):

Assurance: Monitoring and recording of grid safety performance, as well as evaluating safety management processes and practices

Empathy: Designing smart grid services and functions from the users' perspective for enhanced service quality

Self healing: The ability of the smart grid to repair itself or resolve the fault in case of failure

Electricity interruption duration: Power outage periods/durations of the smart grid

Information quality (5):

Completeness: Inclusion of the complete provision of all promised network parameters to the electricity consumers of the smart grid

Ease of understanding: Ease of understandability of the data/information presented to subscribers/users with smart grid transformation

Personalization: Tailoring smart grid services to accommodate subscribers/ consumers (subscriber specific electricity usage tariff, etc.)

Relevance: Information provided to the subscriber/user being related to the user's demands

Security: Transmitting and processing the smart grid data/information through cyber-secure channels and keeping the entire smart grid system secure against cyber security threats

Use (4):

Nature of use: Using the opportunities brought by the smart grid in many different areas

Load profile/pattern: Creating the electricity usage profile/pattern of each user/ subscriber with smart grid transformation

Number of load shiftings: Enabling the electricity consumption to be shifted many times during peak times of electricity demand

Shifted electricity ussage in Kwh: Measuring and recording the shifted electrical energy (Kwh) used by the subscribers/users

User satisfaction (3):

Accepted or demanded load shifting repeats: Evaluating the use of shifted electrical energy accepted/requested by the user/subscriber for customer satisfaction

Accepted or demanded repeats of shifted electricity usage in off-peak times: Showing electricity subscribers/users both the financial and environmental benefit/contribution of the electricity they consume in the off-peak period

User surveys: Conducting surveys to understand the satisfaction of electricity users

Net benefits (4):

Cost savings: Reducing the costs required to operate the electricity grid with the help of smart grid transformation

Expanded distribution of energy resources: Enabling distributed energy resources (wind, solar) to become widespread

Incremental additional electricity sales in off-peak times: Enabling increased electricity sales during non-peak periods of electricity consumption

Time savings: Reducing the total operational time spent in operating the electricity system

A similar DeLone & Mclean information systems success model and its adjustment approach was also used in a study on e-government transformation success in Türkiye by Gökhan İskender and Sevgi Özkan in 2013 (İskender & Özkan, 2013).

4.4. Smart Grid Transformation Success Independent Variables

For determining the independent variables, we performed an extensive search in the sciencedirect.com, researchgate.net, escholarship.org, openresearch.surrey.ac.uk, cadmus.eui.eu, semanticscholar.org databases with the keywords "smart grid", "demand response", "demand side flexibility", "demand side management", and "integration of renewables", which resulted in 196 studies. We determined 24 possible independent variables by reviewing these 196 studies. The list of the studies reviewed, and the independent variables obtained from these studies are shown in Appendix A Table 12.

The 24 possible independent variables affecting smart grid transformation determined by our comprehensive literature review are given below. These independent variables were selected according to their frequency of mention in the studies reviewed. Their frequencies in the studies are also given in parantheses with each independent variable.

1. Remote Controlling (14)
2. Smart Metering (53)
3. Consumer Participation (35)
4. Integration of Renewables (55)
5. Data Management Support (49)
6. Security (41)
7. Distributed Energy Trans. (45)
8. Return of Investment (12)
9. EV Charging (34)
10. Reliability (15)
11. Smart Appliances Usage (14)
12. Aggregator Support (27)
13. Regulatory Framework (41)
14. Incentives (11)
15. Interoperability (IOP) (16)
16. Institutional Change (11)
17. Organizational Change (8)
18. Dynamic Pricing (31)
19. Self Healing of The Grid (9)
20. Communication Support (57)
21. Artifical Intelligence (20)
22. Internet of Things Support (35)
23. Political Support (18)
24. Electric Storage (30)

Some of the items also exist among the subcomponents of the dependent variable. These items are security, reliability, and self-healing. According to the DeLone and McLean information systems success model, these items are among the main subcomponents of the model. Security is a subcomponent of the information quality part; reliability is a subcomponent of the system quality part; self-healing is a subcomponent of the service quality part. Information quality, system quality and service quality are among the main components of the DeLone and McLean model. As it is not possible for a variable to exist both as the dependent variable's subcomponent and independent variable, these items were left in the subcomponent part and removed from the independent variables list, leaving 21 independent variables.

Definitions of the independent variables are given below.

Remote controlling: Use of remote control and online monitoring techniques to control/use grid equipments

Smart metering: Use of smart meters and online measurement techniques in grid power measurement

Consumer participation: Active participation of electricity subscribers /consumers in demand side management and demand response

Integration of renewables: Integration of renewable energy sources like solar and wind power into the electricity grid

Data management support: Establishing data centers, data management and analysis mechanisms for the processing of grid data

Distributed energy transition: Establishing the necessary infrastructure and mechanisms for distributed energy transition

Return of invesment: The payback period and amount for smart grid investment of infrastructure, equipments and human resources

EV charging: Integrating the electric vehicle charging infrastructure and equipments into the smart grid
Smart appliances usage: Usage of smart home appliances that can communicate with both the electrical grid and the Internet

Aggregator support: Establishing the aggregator structure that will mediate between electricity users and electricity suppliers

Regulatory Framework: Establishing and publishing smart grid specific legislations and laws

Incentives: Establishing financial support systems and mechanisms for the smart grid

Interoperability (IOP): Data sharing and collaboration of the smart grid and its equipments with other systems

Institutional change: Establishing responsible institutions or institutes dedicated to smart grid transformation

Organizational change: Making organizational changes in existing structures or institutions for smart grid transformation

Dynamic pricing: Creating a dynamic pricing structure for electricity tariffs among stakeholders for smart grid transformation

Communication support: Using fast, reliable, two-way communication infrastructures and protocols for the smart grid

Artifical intelligence: Using artificial intelligence techniques, applications and approaches in smart grid operations

Internet of Things support: Using Internet-connected devices and equipments in the smart grid infrastructure

Political support: Support of political authorities and the goverment for smart grid transformation

Electric storage: Storage of electrical energy obtained from distributed and renewable energy sources

CHAPTER 5

DELPHI ANALYSIS TO VALIDATE THE VARIABLES

To validate the subcomponents of the dependent variable and the independent variables, we used Delphi Analysis. Delphi Analysis is a formal, in-depth systematic methodology first studied in 1950 by a team at the RAND Corporation. The aim of Delphi Analysis is to narrow down the range of differing opinions within a small group, leading them towards a shared consensus. This method involves a series of iterative cycles that include rounds of questions, responses, and analysis, which are then fed back to the subject matter experts (Dell'Olio & De Oña, 2017).

The Delphi Analysis method has the following characteristics and features:

- **Anonymity of experts**, assuring free expression of opinions by the experts. This method helps prevent the influence of social pressure from dominant or dogmatic individuals, as well as from majorities or minorities.

- **Iteration**— Experts are free to revise their opinions or judgments at any point without the concern of facing public criticism.

- **Controlled feedback**— Experts are made aware of the opinions of other experts involved in the study.

- **Some form of statistical aggregation** permits a quantitative analysis. Hence, although qualitative, the Delphi method can be used for obtaining quantitative results (Profillidis & Botzoris, 2019**)**.

In our study, the email-based Delphi consultation method was used to enhance the relevance of the results for stakeholders. It is suggested that this approach allows for the involvement of a wide variety of stakeholders in a time- and cost-effective way (Northcote & Lee, 2008).

We applied the Delphi Analysis method for the twenty-five subcomponents of the dependent variable and its twenty-one independent variables. According to Hallowell and Gambatese, at least eight participants are needed to conduct a Delphi Analysis (Hallowell & Gambatese, 2010). Accordingly, seventeen experts participated in our Delphi study. Four of them are academicians who have research experience in power systems and smart grids. The other thirteen are from the energy sector. Demographic properties of the participants are given in Table 5. All experts were aware that they were participating in a Delphi Analysis. None of the Delphi group members knew each other and they did not have any information about each other's personal information

because of the Delphi method requirements. The e-mail accounts of the Delphi participants were used to communicate with the Delphi group members.

Table 5: Demographic Properties of the Delphi Participants

Expert No	Gender	Education	Years of Experience	Responsibility
Expert 1	Male	Undergraduate	25 years	IoT Manager
Expert 2	Male	Doctorate	22 years	Academician
Expert 3	Male	Master's Degree	19 years	Electricity Transmission Expert
Expert 4	Male	Undergraduate	32 years	Electricity Distribution Expert
Expert 5	Male	Undergraduate	16 years	Electricity Distribution Expert
Expert 6	Female	Master's Degree	17 years	IoT Expert
Expert 7	Male	Master's Degree	15 years	Smart Appliance Expert
Expert 8	Male	Doctorate	27 years	Academician
Expert 9	Male	Doctorate	23 years	Academician
Expert 10	Male	Doctorate	17 years	Academician
Expert 11	Male	Master's Degree	19 years	Cybersecurity Expert
Expert 12	Male	Undergraduate	23 years	Electricity Generation Expert
Expert 13	Female	Master's Degree	14 years	Electricity Distribution Expert
Expert 14	Male	Master's Degree	16 years	Electricity Regulation Expert
Expert 15	Male	Master's Degree	28 years	Electricity Regulation Expert
Expert 16	Male	Master's Degree	15 years	Electricity Transmission Expert
Expert 17	Male	Master's Degree	21 years	Electricity Generation Expert

5.1. Delphi Analysis Process

The Delphi study was completed in three iterations over two months. At any iteration point, experts could change their opinions or judgments without fear of being exposed to public criticism. All the personal information about the participants were deleted from the e-mails and the experts were informed about the views of other experts.

The Delphi survey was prepared on Google Forms. Definitions for each variable were provided during the Delphi study to ensure that all participants had the same understanding of the variables. In the first round, we sent the Delphi analysis questions to the 17 experts via sharing the Google Forms link. The experts were expected to evaluate whether the determined independent variables and subcomponents of the dependent variable are the right ones for smart grid transformation. We collected the results from 17 experts in three weeks time. Immediately, the results for each independent variable and subcomponents of the dependent variable were shared with the participants in percentage and pie chart form. Then we requested the second-round evaluation. Again, the Delphi participants sent their responses in three weeks time and the second-round results were shared with the participants in percentage and pie chart form. We requested a third and final round of evaluation. The Delphi analysis results

were gathered and analyzed. In the third round, the Delphi participants ultimately reached varying levels of consensus on the dependent variable's subcomponents and the independent variables as shown in Table 6 and Table 7. After the participants had a common decision on the subcomponents of the dependent variable (smart grid transformation success in Türkiye) and its independent variables, they decided to remove three subcomponents of the dependent variable and one independent variable. Accordingly, "usability", "completeness" and "user surveys" were removed from the subcomponents list of the dependent variable. Delphi participants also decided to remove one independent variable, which is "return of investment duration". Round 1 and Round 2 results are also given in Appendix B. As most Delphi studies in the literature accept a consensus level between 50%-97%, to have highly reliable results we take the consensus level as 75% for this study.

For Table 6 and Table 7 the column definitions are given below.

#Accept: Number of participants, who accepted that item as a dependent variable's subcomponent/independent variable of smart grid transformation success.

%Accept: Percentage of participants, who accepted that item as a dependent variable's subcomponent /independent variable of smart grid transformation success.

#Reject: Number of participants who rejected that item as a dependent variable's subcomponent /independent variable of smart grid transformation success.

%Reject: Percentage of participants who rejected that item as a dependent variable's subcomponent /independent variable of smart grid transformation success.

#No idea: Number of participants who had no idea about whether that item is a dependent variable's subcomponent/independent variable of smart grid transformation success.

%No idea: Percentage of participants who had no idea about whether that item is a dependent variable's subcomponent/independent variable of smart grid transformation success.

#Opinion: #Accept+#Reject

%Accept without No Idea: Percentage of participants, who accepted that item as a dependent variable's subcomponent/independent variable of smart grid transformation success, excluding the participants who had no idea.

Table 6: Delphi Analysis Results for Subcomponents of the Dependent Variable

	ROUND 3								
Subcomponents of the Dependent Variable	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	%ACCEPT without No idea	RESULT
ADAPTABILITY	15	100%	0	0%	0	0%	15	100%	CONSENSUS
AVAILABILITY	14	88%	2	13%	0	0%	16	88%	CONSENSUS
RELIABILITY	16	100%	0	0%	0	0%	16	100%	CONSENSUS
RESPONSE TIME	16	100%	0	0%	0	0%	16	100%	CONSENSUS
USABILITY	8	50%	7	44%	1	6%	15	**53%****	**NON-CONSENSUS**
ASSURANCE	16	100%	0	0%	0	0%	16	100%	CONSENSUS
EMPHATY	13	81%	2	13%	1	6%	15	87%	CONSENSUS
SELF HEALING OF THE GRID	9	56%	3	19%	4	25%	12	75%	CONSENSUS
ELECTRICITY INTERRUPTION DURATION	15	100%	0	0%	0	0%	15	100%	CONSENSUS
COMPLETENESS	8	53%	3	19%	4	25%	11	**73%****	**NON-CONSENSUS**
EASE OF UNDERSTANDING	12	80%	1	7%	2	1%	13	92%	CONSENSUS
PERSONALIZATION	16	100%	0	0%	0	0%	16	100%	CONSENSUS
RELEVANCE	12	75%	1	6%	3	19%	13	92%	CONSENSUS
SECURITY	16	100%	0	0%	0	0%	16	100%	CONSENSUS
NATURE OF USE	11	69%	3	19%	2	13%	14	79%	CONSENSUS
LOAD PROFILE /LOAD PATTERN	15	94%	1	6%	0	0%	16	94%	CONSENSUS
NUMBER OF LOAD SHIFTINGS	16	100%	0	0%	0	0%	16	100%	CONSENSUS
SHIFTED ELECTRICITY USAGE IN KWH	16	100%	0	0%	0	0%	16	100%	CONSENSUS
ACCEPTED OR DEMANDED LOAD SHIFTING REPEATS	11	69%	0	0%	5	31%	11	100%	CONSENSUS
ACCEPTED OR DEMANDED REPEATS OF SHIFTED ELECTRICITY USAGE IN OFF-PEAK TIMES	16	100%	0	0%	0	0%	16	100%	CONSENSUS
USER SURVEYS	6	38%	6	38%	4	25%	12	**50%****	**NON-CONSENSUS**
COST SAVINGS	15	94%	0	0%	1	6%	15	100%	CONSENSUS
EXPANDED DISTRIBUTION OF ENERGY RESOURCES	16	100%	0	0%	0	0%	16	100%	CONSENSUS
INCREMENTAL ADDITIONAL ELECTRICITY SALES IN OFF PEAK TIMES.	15	94%	0	0%	1	6%	15	100%	CONSENSUS
TIME SAVINGS	16	100%	0	0%	0	0%	16	100%	CONSENSUS

Table 7: Delphi Analysis Results for Independent Variables

Independent Variables	ROUND 3								
	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	%ACCEPT without No idea	RESULT
REMOTE CONTROLLING	16	100%	0	0%	0	0%	16	100%	CONSENSUS
SMART METERING	16	100%	0	0%	0	0%	16	100%	CONSENSUS
CONSUMER PARTICIPATION	14	88%	0	0%	2	13%	14	100%	CONSENSUS
INTEGRATION OF RENEWABLES	15	94%	1	6%	0	0%	16	94%	CONSENSUS
DATA MANAGEMENT SUPPORT	16	100%	0	0%	0	0%	16	100%	CONSENSUS
DISTRIBUTED ENERGY TRANSITION	16	100%	0	0%	0	0%	16	100%	CONSENSUS
RETURN OF INVESTMENT DURATION	6	38%	4	25%	6	38%	10	**60%****	**NON-CONSENSUS**
ELECTRIC VEHICLE INTEGRATION	15	94%	0	0%	1	6%	15	100%	CONSENSUS
SMART APPLIANCE USAGE	16	100%	0	0%	0	0%	16	100%	CONSENSUS
AGGREGATOR SUPPORT	12	75%	0	0%	4	25%	12	100%	CONSENSUS
REGULATORY FRAMEWORK	16	100%	0	0%	0	0%	16	100%	CONSENSUS
INCENTIVES	16	100%	0	0%	0	0%	16	100%	CONSENSUS
INTEROPERABILITY(IOP)	15	100%	0	0%	0	0%	15	100%	CONSENSUS
INSTITUTIONAL CHANGE	14	88%	0	0%	2	13%	14	100%	CONSENSUS
ORGANIZATIONAL CHANGE	11	69%	0	0%	5	31%	11	100%	CONSENSUS
DYNAMIC PRICING	16	100%	0	0%	0	0%	16	100%	CONSENSUS
COMMUNICATION SUPPORT	16	100%	0	0%	0	0%	16	100%	CONSENSUS
AI (ARTIFICIAL INTELLIGENCE) SUPPORT	15	94%	0	0%	1	6%	15	100%	CONSENSUS
IOT (INTERNET OF THINGS) SUPPORT	16	100%	0	0%	0	0%	16	100%	CONSENSUS
POLITICAL SUPPORT	16	100%	0	0%	0	0%	16	100%	CONSENSUS
ELECTRIC STORAGE	16	100%	0	0%	0	0%	16	100%	CONSENSUS

After the application of the Delphi Analysis, the remaining 22 subcomponents of the dependent variable were determined as follows:

System quality (4): Adaptability, Availability, Reliability, Response Time

Service quality (4): Assurance, Empathy, Self Healing, Electricity Interruption Duration

Information quality (4): Ease of Understanding, Personalization, Relevance, Security

Use (4): Nature of use, Load Profile/Load Pattern, Number of Load Shiftings, Shifted electricity used in Kwh

User satisfaction (2): Accepted or Demanded Load Shifting Repeats, Accepted or Demanded Repeat of shifted electricity usage in off-peak times

Net benefits (4): Cost savings, Expanded distributed energy resources, Incremental Additional Electricity Sales in Off-Peak Times, Time savings

After the application of the Delphi Analysis, the remaining 20 independent variables are as follows:

1. Remote Controlling
2. Smart Metering
3. Consumer participation
4. Integration of Renewables
5. Data Management Support
6. Distributed Energy Transition
7. EV Charging
8. Smart Appliances Usage
9. Aggregator support
10. Regulatory Framework
11. Incentives
12. Interoperability (IOP)
13. Institutional Change
14. Organizational Change
15. Dynamic Pricing
16. Communication Support
17. Artificial Intelligence Support
18. Internet of things Support
19. Political Support
20. Electric Storage

CHAPTER 6

SURVEY STATEMENTS FOR VARIABLES

A survey was prepared and conducted to find out Turkish electricity experts' views on the parameters affecting the smart grid transformation success in Türkiye. The main objective of the survey was to find answers to the research questions of this study. The respondents of the survey were selected from the experts of electricity generation, transmission, distribution, regulation bodies, institutions, and companies of Türkiye. The survey questions were prepared to find answers to the five research questions below.

- RQ-1) Do the independent variables have positive correlation with smart grid transformation success?
- RQ-2) Is there a statistically significant difference between the effects of the independent variables of smart grid transformation success?
- RQ-3) Is there a statistically significant difference between the effects of the independent variables of smart grid transformation success with respect to different regions of Türkiye?
- RQ-4) Is there a statistically significant difference between the time periods required to achieve the independent variables of the smart grid transformation success?
- RQ-5) Is there a statistically significant difference between the time periods required to achieve the independent variables of the smart grid transformation success with respect to different regions of Türkiye?

6.1. Survey Statements for Dependent Variable's Subcomponents and Independent Variables

After determination of the dependent variable and its subcomponents, we defined the related statements to gather scores for the subcomponents of the dependent variable, as given in the below subsections. As the statements were presented to Turkish respondents, the statements are also given in Turkish in parentheses.

6.1.1. Survey Statements for the System Quality Part

Adaptability: The services to be received from smart grids must be able to meet different requirements that will arise over time. (Akıllı şebekelerden alınacak servisler zaman içinde oluşacak farklı gereksinimleri karşılayabilmelidir.)

Availability: All services provided by smart grids should be continuous and uninterrupted. **(**Akıllı şebekelerin sağlayacağı tüm hizmetler sürekli ve kesintisiz olmalıdır.)

Reliability: Smart grids should be more reliable than traditional grids. (Akıllı şebekeler geleneksel şebekelerden daha güvenilir olmalıdır.)

Response time: In smart grids, response time to events (failure, outage, price change, usage amount…) should be faster than in traditional networks. (Akıllı şebekelerde olaylara (arıza, kesinti, fiyat değişikliği, kullanım miktarı…) karşı tepki süresi geleneksel şebekelere göre daha hızlı olmalıdır.)

6.1.2. Survey Statements for the Service Quality Part

Assurance: Smart grids are safer than classical grids. **(**Akıllı şebekeler klasik şebekelere göre daha güvenlidir.)

Empathy: Smart grid services should be designed from the user perspective for service quality. **(**Akıllı şebeke hizmetleri servis kalitesi için kullanıcı bakış açısıyla tasarlanmalıdır.)

Self healing of the grid: The smart grid should be able to repair itself/resolve the fault in case of failure**. (**Akıllı şebeke arıza durumunda kendi kendini onarmalı /arızayı giderebilmelidir.)

Electricity interruption duration: In smart grids, power outage periods should be less than in traditional networks or there should be no outages. (Akıllı şebekelerde elektrik kesinti süreleri geleneksel şebekelere göre daha az olmalı, hatta kesinti olmamalıdır.)

6.1.3. Survey Statements for the Information Quality Part

Ease of understanding: The data/information to be presented to subscribers/users with smart grid transformation should be easily understandable. **(**Akıllı şebeke dönüşümü ile abonelere/kullanıcılara sunulacak veriler/bilgiler kolayca anlaşılır olmalıdır.)

Personalization: The smart grid must offer subscribers/consumers the opportunity to personalize the service provided (subscriber-specific electricity usage tariff, etc.) (Akıllı şebekenin abonelere/ tüketicilere verilen hizmeti kişiselleştirebilme (aboneye özel elektrik kullanım tarifesi vb..) imkanı sunması gerekir.)

Relevance: The information provided to the subscriber/user as a result of smart grid transformation should be related to the user's demands. (Akıllı şebeke dönüşümü sonucu aboneye/kullanıcıya sağlanan bilgiler kullanıcının talepleri ile ilgili olmalıdır.)

Security: Information generated by smart grids must be transmitted through cyber-secure channels. **(**Akıllı şebekeler tarafıdan oluşturulan bilgiler siber güvenlikli kanallardan iletilmelidir.)

6.1.4. Survey Statements for Use

Nature of use: The opportunities brought on by smart grids should be usable in many different areas**. (**Akıllı şebekelerin getirdiği imkanlar bir çok farklı alanda kullanılabilmelidir.)

Load profile: With smart grid transformation, the electricity usage profile/pattern of each subscriber/user must be created. (Akıllı şebeke dönüşümü ile birlikte her abonenin/kullanıcının elektrik kullanım profilinin/patterninin çıkarılması gerekir.)

Number of load shiftings: The smart grid must allow electricity consumption to be shifted many times during peak times of electricity demand. (Akıllı şebekenin, elektrik talebinin pik olduğu zamanlarda elektrik tüketiminin bir çok defa ötelenebilmesine imkan sağlaması gerekir.)

Shifted electricity used in Kwh: The smart grid must be able to measure the shifted electrical energy (Kwh) used by the subscriber/user. (Akıllı şebeke abonenin/kullanıcının öteleyerek kullandığı elektrik enerjisini (Kwh) ölçümleyebilmelidir.)

6.1.5. Survey Statements for User Satisfaction

Accepted or demanded load shifting repeats: The use of shifted electrical energy accepted/requested by the subscriber should be evaluated in customer satisfaction. **(**Abonenin kabul/talep ettiği ötelenmiş elektrik enerjisi kullanımının müşteri memnuniyetinde değerlendirilmesi gerekir.)

Accepted/demanded repeats of shifted electricity usage in off-peak times: The smart grid should be able to show electricity subscribers/users both the financial and environmental benefit/contribution of the electricity they consume in the off-peak period. (Akıllı şebeke elektrik abonelerine/kullanıcılarına pik olmayan dönemde tükettikleri elektriğin hem maddi hem de çevresel faydasını/katkısını gösterebilmelidir.)

6.1.6. Survey Statements for Net Benefits

Cost Savings: The smart grid should reduce the costs required to operate the electricity grid. (Akıllı şebeke elektrik şebekesinin işletilmesi için gerekli maliyetleri düşürmelidir.)

Expanded distributed energy resources: The smart grid should allow distributed energy resources (wind, solar) to become widespread. **(**Akıllı şebeke dağıtık enerji kaynaklarının (rüzgar, güneş) yaygınlaşmasına imkan sağlamalıdır.)

Incremental additional electricity sales in off-peak times: The smart grid should enable increased electricity sales during non-peak periods of electricity consumption**.** (Akıllı şebeke elektrik tüketiminde peak olmayan zamanlarda elektrik satışının artmasını sağlamalıdır.)

Time savings: The smart grid should ensure that the total operational time spent in operating the electricity system is reduced. **(**Akıllı Şebeke, elektrik sisteminin işletilmesinde harcanan toplam operasyonel zamanın azaltılmasını sağlamalıdır.)

6.1.7. Survey Statements for the Independent Variables

After Delphi Analysis, we had twenty independent variables, whose effects we would like to evaluate. Below we list the related survey phrases that we asked the survey respondents to score.

1--Remote controlling: Using remote control techniques (Uzaktan kontrol tekniklerinin kullanılması)

2--Smart metering: Use and widespread use of smart meters (Akıllı Sayaçların kullanımı ve yaygınlaşması)

3--Consumer participation: Active participation of electricity subscribers/consumers in demand side management (Elektrik abonelerinin / tüketicilerinin talep tarafı yönetimine aktif katılımı)

4--Integration of renewables: Integration of renewable energy sources (solar, wind, etc.) into the electricity grid (Yenilenebilir enerji kaynaklarının (güneş, rüzgar vb.) elektrik şebekesine entegrasyonu)

5--Data management support: Establishing data management and analysis mechanisms (Veri yönetimi ve analizi mekanizmalarının kurulması)

6--Distributed energy transition: Establishing the necessary infrastructure for distributed energy transition **(**Dağıtık enerji geçişi için gerekli altyapının kurulması)

7--Electric vehicle integration: Integrating electric vehicle infrastructure into the smart grid (Elektrikli araç alt yapısınının akıllı şebekeye entegre edilmesi)

8--Smart appliances usage: Use and widespread use of smart home appliances that can communicate with the electrical grid (Elektrik şebekesiyle konuşabilen akıllı ev eşyalarının kullanımı ve yaygınlaşması)

9--Aggregator support: Establishing the aggregator structure that will mediate between electricity users and electricity suppliers (Elektrik kullanıcıları ile elektrik tedarikçileri arasında arabulucuk yapacak yapının kurulması)

10--Regulatory framework: Establishing legislation and laws for the smart grid (Akıllı şebeke için mevzuatların ve yasaların oluşturulması)

11--Incentives: Having financial incentive systems for the smart grid (Akıllı şebeke için finansal teşvik sistemleri olması)

12--Interoperability: Interoperability of the smart grid with other systems **(**Akıllı şebekenin diğer sistemlerle birlikte çalışabilir olması)

13--Institutional change: Establishing responsible institutions or institutes for smart grid transformation (Akıllı şebeke dönüşümü için sorumlu kurum ya da enstitülerin kurulması)

14--Organizational change: Making organizational changes in existing structures for smart grid transformation (Akıllı şebeke dönüşümü için mevcut yapılarda organizasyonel değişikliklerin yapılması)

15--Dynamic pricing: Creating a dynamic pricing structure and culture among stakeholders for smart grid transformation **(**Akıllı şebeke dönüşümü için paydaşlar arasında dinamik fiyatlandırma yapısının ve kültürünün oluşması)

16--Communication support: Using fast, reliable, two-way communication infrastructures in the smart grid infrastructure **(**Akıllı şebeke alt yapısında hızlı, güvenilir, çift taraflı iletişim alt yapılarının kullanılması)

17--Artificial intelligence support: Use of artificial intelligence in smart grid operations (Akıllı şebeke işletiminde ve operasyonlarında yapay zeka kullanımı)

18--Internet of Things support: The devices and equipment to be used in the smart grid infrastructure must be IoT devices (connectable to the Internet) (Akıllı şebeke alt yapısında kullanıcak cihaz ve ekipmanların IoT cihazı (İnternete bağlanabilen) olması)

19--Political support: Support of political authorities for smart grid transformation **(**Akıllı Şebeke dönüşümü için siyasi otoritenin desteği)

20--Electric storage: Storage of electrical energy obtained from distributed and renewable sources **(**Dağıtık ve yenilenebilir kaynaklardan elde edilen elektrik enerjisinin depolanması)

CHAPTER 7

HYPOTHESES AND SURVEY QUESTIONS

After determining the independent variables of our study, to investigate the relationship between the independent variables on the success of the Turkish smart grid transformation we applied hypothesis testing.

In hypothesis testing, the research question is simplified into two possible hypotheses: the null hypothesis, represented as H0, and the research (or alternative) hypothesis, represented as H1. Usually, it is easier to disprove a false statement (the null hypothesis); hence, we often start by assuming the opposite of what the research question suggests. The goal is to test whether the null hypothesis can be rejected to provide evidence in favor of the research hypothesis. Hypothesis testing does not confirm the research hypothesis as true, but rather indicates that it is plausible (Allua & Thompson, 2009).

The null hypothesis (H0) is often stated as the assumption that there is no difference between two groups or no relationship between two variables. The alternative hypothesis (H1) on the other hand, is the statement that there is a difference or relationship.

Hypothesis testing uses data to decide between the two possibilities (called hypotheses). It can tell us whether the results we witnessed are just coincidence (and could reasonably be due to chance) or are likely to be real (Siegel & Wagner, 2022).

A hypothesis states a presumed relationship between two variables in a way that can be tested with empirical data. It may take the form of a cause-effect statement or an "if x, ... then y" statement. The cause is called the independent variable and the effect is called the dependent variable. Relationships can be of several forms, including linear or non-linear. Linear relationships can be either direct (positive) or inverse (negative) relationships (Saint-Germain, 2002).

After determining the subcomponents of dependent variable and independent variables for smart grid transformation success, we formed five hypotheses for the following five research questions (As the hypotheses here were tested with data based on the results of the surveys including opinions of people in the sector, it is important to note that *effects* are estimated effects and *time periods* are estimated time periods).

- RQ-1) Do the independent variables have positive correlation with the smart grid transformation success?

H0 for each independent variable *x* for this question is formulated as "x and smart grid transformation success in Türkiye are not positively correlated.", whereas H1 is formulated as "x and smart grid transformation success in Türkiye are positively correlated." For example, for the independent variable *remote controlling*, H0 was formulated as "Remote controlling and smart grid transformation success in Türkiye are not positively correlated." And H1 was formulated as "Remote controlling and smart grid transformation success in Türkiye are positively correlated".

- RQ-2) Is there a statistically significant difference between the effects of the independent variables of smart grid transformation success?

  H0 for this question is stated as "There is no statistically significant difference between the effects of independent variables of smart grid transformation success", whereas H1 is stated as "There is a statistically significant difference between the effects of independent variables of smart grid transformation success."

- RQ-3) Is there a statistically significant difference between the effects of the independent variables of smart grid transformation success with respect to different regions of Türkiye?

  H0 for this question is stated as "There is no statistically significant difference between the effects of the independent variables of smart grid transformation success with respect to regions of Türkiye", whereas H1 is stated as "There is a statistically significant difference between the effects of the independent variables of smart grid transformation success with respect to regions of Türkiye".

- RQ-4) Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation?

  H0 for this question is stated as "There is no statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation", whereas H1 is stated as "There is a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation".

- RQ-5) Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation with respect to regions of Türkiye?

  H0 for this question is stated as "There is a statistically significant difference between the time periods required to complete the independent variables of the

smart grid transformation with respect to regions of Türkiye", whereas H1 is stated as "There is a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation with respect to regions of Türkiye".

7.1. Establishing Survey Questions

As the dependent variable's subcomponents and independent variables of smart grid transformation success were determined and then validated by Delphi Analysis with experts, the survey questions are ready to be established on the basis of the dependent variable's subcomponents, independent variables of smart grid transformation success and the hypothesis statements. The survey was prepared on Google Forms. Survey questions are given in Appendix C.

7.2. Sample Size Calculation

In the literature there exist many works on determining the correct sample size for survey studies. Different studies require different methods for sample size calculation. The sample size can be determined by the level of accuracy required or confidence interval at a desired confidence level (Cochran, 1977). According to Liang and Shen if the allowable error is small, the sample size should be bigger. Conversely, if the allowable error is large, a smaller sample size will be sufficient (Liang & Shen, 2012).

After a broad literature review, we saw that a confidence level of 0.95 and confidence interval of 0.05 are the most frequently used in all disciplines for sample size calculation. Accordingly, we chose 0.95 for the confidence level, and we chose the confidence interval as 0.05. As Smart Grid is a newly emerging subject, it is not easy to calculate the total population, therefore we took the population size as unlimited. Taking 0.95 as the confidence level and 0.05 as the confidence interval, we obtained 385 as the required sample size. Accordingly, our target is to reach at least 385 respondents from the Turkish electricity sector in this study. The sample size formula and its calculation are given below.

$$n = (z^2 * p (1- p)) / \mathcal{E}^2$$

$$n = (1.96^2 * 0.50 (1-0.50)/ 0.05^2$$

n: Sample size
z: Z-score is a value that determines how far a measured value is from the population value. Z-scores can be determined from the confidence level using Z-score tables. The Z- score for a 95% confidence level is 1.96.
p: The population proportion is the percentage of the population that has a specific characteristic. This proportion is usually determined from previous studies or research, although, when unsure, using 50% works as an estimate. That is, 50% of the population falls below a specific point and 50% falls above a specific point.

Ɛ: Confidence interval (margin of error) is how much we can expect our results to differ from the population of interest. Measured as a percentage, a smaller margin of error increases the chance that results will be close to that of the population. Both 5% and 10% are commonly used margins of error. However, lower margin of errors will increase sample sizes.

CHAPTER 8

VALIDITY AND RELIABILITY ANALYSES OF THE SURVEY

After the survey questions for the dependent variable's subcomponents, independent variables and hypothesis statements are established, validating the survey is another critical step. In the literature there are different validation techniques for surveys. Among these are construct validity, content validity, internal consistency (reliability), and external validity. Below we discuss how each form of validity has been established for our survey.

8.1. Construct Validity

Construct validity tests if a survey accurately assesses what it is trying to assess. In our study, the research construction was guided by a comprehensive literature review and the data collection process was supervised by experts in the electricity sector to provide construct validity. Moreover, Delphi analysis was performed with 17 experts to examine, add or remove dependent or independent variables to ensure construct validity.

8.2. Content Validity

We check for content validity to understand if the survey questions cover items related to smart grid transformation success. Also with content validity, unrelated questions would be excluded. To establish content validity, inputs from power system experts were collected for each survey question.

To analyze the content validity of the survey statements, we used the Think-Aloud method. The Think-Aloud method asks potential survey respondents to read through a survey and discuss out loud how they interpret the questions and how they would arrive at their responses. This approach can help identify questions that are confusing or misleading to respondents, questions that take too much time and effort to answer and questions that don't seem to be collecting the information originally intended to be captured (Becho, 2019).

To perform the Think-Aloud content validity test, we gave our smart grid transformation survey questions to 23 experts from the Turkish electricity sector, who are from academia, and electricity distribution and/or transmission institutions. All these experts are knowledgeable on the smart grid and its applications. They read the survey questions aloud and shared their opinions on whether the intended survey content was achieved or not. The opinions of each expert for all parts of our survey

were similar and they got the same view and understanding from the questions. The experts also mentioned that the survey questions are basic, clear and to-the-point questions to reach the target data from the survey respondents.

Some views and opinions of the Think-Aloud content validity participants are given below. Participants expressed their opinions in Turkish and then these were translated into English.

Expert 1: “In parallel with the increase in renewable energy and energy storage systems, it is important to quickly implement smart grid studies together with legislative regulations to operate the grid in a more sustainable and reliable manner with all its dynamics. This is clearly given and reflected in the survey questions.”

Expert 2: “When it comes to the smart grid in Türkiye, only smart meters and technological developments at the point of consumption such as kwh and pricing for consumers' consumption are mentioned. However, unless there are transmission and distribution systems that can be operated properly, having a smart meter at the point of consumption will not be of much use in an environment where energy continuity cannot be provided to the consumers. These survey questions prevent against this confusion and misunderstanding.”

Expert 3: “It is obvious that the relevant survey structure and resulting analyses have the potential to provide insight and guidance regarding the future of electricity network in Türkiye. It is important to share the study results with institutions/organizations in the electricity/energy sector and then with the public. Thus, we can benefit from this guidance to direct our current work. We would like to thank everyone who contributed.”

Expert 4: “The electrical network generally consists of many different subcomponents. It is a dynamic system. This diversity is well reflected, and all dimensions are covered in the survey statements.”

Expert 5: “It was a good study; the questions are logical, and the requirements are well expressed. These kinds of studies need to be increased and supported.”

Expert 6: “The concept of Smart Grid is a very broad concept. Small-scale IoT-supported projects are being tried in the public sector, but those working in the transmission and distribution departments need to be more specifically informed about this issue. Cyber security systems began to be partially used in TEİAŞ's download centers. However, cyber security in energy covers a wide range of areas, from GSM lines sending data from the field via APNs, to the security of data centers where data is stored, to isolating SCADA centers from wide area networks. On the distribution side, smart meter specifications have been prepared within TEDAŞ and are planned to be implemented within 2 years. Currently, lighting subscribers come to the TEDAŞ data center with the infrastructure established with the remote reading system (OSOS)

and a headend software is displayed. Data of lighting subscribers (approximately 260 thousand meters) located throughout Türkiye can be monitored live every half hour. It took approximately 6 years to install the required topology and software. We estimate that it will take approximately 10 years to implement the national smart meter installation for all customers. All these important items are included in the survey content."

All participants had the common opinion that the survey covers all related questions about smart grid transformation success in Türkiye. They had a common understanding of the questions, stated that questions do not take too much time and effort to answer and are able to collect the information initially intended to be captured.

8.3. Internal Consistency (Reliability) of the Survey

After the survey questions for the dependent variable's subcomponents and independent variables were established and content validity check was performed with 23 experts, we sent the survey questions to 53 respondents and calculated Cronbach's Alpha values for the variables with the Minitab-18 Program. If the Cronbach Alpha values are higher than 0.7, the reliability of the survey is established.

The responses of the 53 respondents were analyzed with Minitab-18. Cronbach's Alpha for the dependent variable's subcomponents is 0.8981 and for the independent variables it is 0.9026. These are high scores; hence the reliability of the survey is established. We realized that there is no item whose removal increases the Cronbach's Alpha value. Cronbach's Alpha values calculated for each omitted item in the subcomponents of the dependent variable are shown in Table 8 and those calculated for each omitted item in the independent variables are shown in Table 9.

Table 8: Cronbach's Alpha for Subcomponents of the Dependent Variable

Omitted Variable	Mean	StDev	Cronbach's Alpha
Adaptability	4.509	0.576	0.8952
Availability	4.717	0.455	0.8983
Reliability	4.509	0.724	0.8963
Response Time	4.585	0.602	0.8938
Assurance	4.321	0.850	0.8937
Empathy	4.170	0.753	0.8980
Self Healing of the Grid	4.321	0.754	0.8940
Electricity Interruption Duration	4.547	0.667	0.8953
Ease of Understanding	4.208	0.717	0.8943
Personalization	4.340	0.758	0.8913
Relevance	4.113	0.751	0.8935
Security	4.830	0.509	0.8970
Nature of Use	3.811	0.878	0.8937
Load Profile/Load Pattern	3.943	0.770	0.8906
Number of Load Shiftings	4.094	0.883	0.8903
Shifted Electricity Usage in Kwh	4.151	0.864	0.8919
Accepted or demanded load shifthing repeats	3.962	0.784	0.8919
Accepted or demanded repeats of shifted electricity usage in off-peak times	4.132	0.810	0.8927
Cost Savings	4.717	0.533	0.8930
Expanded Distribution Energy Resources	4.547	0.667	0.8954
Incremental additional electricity sales in off peak times	4.000	0.855	0.8907
Time Savings	4.038	0.854	0.8907

Table 9: Cronbach's Alpha for Independent Variables

Omitted Variable	Mean	StDev	Cronbach's Alpha
Remote Controlling	4.321	0.673	0.8983
Smart Metering	4.472	0.696	0.8979
Consumer Participation	4.075	0.829	0.8987
Integration of Renewables	4.340	0.898	0.9002
Data Management Support	4.340	0.783	0.8951
Distributed Energy Transition	4.283	0.885	0.8937
Electrical Vehicle Charging	4.132	0.962	0.9001
Smart Appliance Usage	4.377	0.686	0.8969
Aggregator Support	3.943	0.864	0.9014
Regulatory Framework	4.509	0.697	0.8958
Incentives	4.377	0.657	0.9004
Interoperability (IOP)	4.528	0.608	0.8964
Institutional Change	4.321	0.613	0.8965
Organizational Change	3.887	0.800	0.8966
Dynamic Pricing	4.415	0.692	0.8984
Communication Support	4.434	0.747	0.8990
AI Support	4.019	0.866	0.8993
IoT Support	4.377	0.790	0.8951
Political Support	4.396	0.768	0.9009
Electric Storage	4.283	0.690	0.8985

8.4. External Validity

External validity describes how effectively the findings of a research may be generalized for different people, places or times. The majority of scientific studies aim for results that extend beyond just the individuals who took part in the research. To decrease the risk of not achieving external validity in this study, we systematically determined the sample size. Sample size determination is the mathematical estimation of the number of population units to be included in the study. This must be sufficient to represent the population. The determination should be optimum and must be obtained by a scientific method. We obtained a sample size of 385, corresponding to a confidence level of 95% and margin of error of 5% when there is a large (infinite) population, and included more than 385 participants in our survey to achieve external validity.

CHAPTER 9

DATA COLLECTION

To provide the accuracy and reliability of our survey results and study, our target was to reach at least 385 respondents from the Turkish electricity sector. Our survey was constructed and shared on Google Forms.

Prior to sending the survey to the respondents, the survey was sent to the Middle East Technical University Ethics Council. The ethics council reviewed and approved our survey. The Middle East Technical University Ethics Council Approval is given in Appendix H**.**

We sent and shared the survey to the respondents via e-mail. We contacted electricity distribution system operator companies, public electricity distribution system operators, public transmission system operators, electricity market regulators and IoT smart grid device manufacturers in different regions of Türkiye.

Data collection and survey took 6 months to be completed. In 6 months, we reached 2362 people from the Turkish electricity sector. 535 of them accepted to fill out our survey.

In the survey, 27 respondents declared that they do not have any information and idea about smart grids and another 34 survey respondents filled the survey incompletely, randomly and/or erroneously. Therefore, a total of 61 survey responses were improper. We removed these 61 responses from the survey and finally had 474 complete responses to analyze.

9.1. Data Groups

To process the data obtained from the survey we formed four data groups. To form the data groups, we consulted experts from the energy sector. The experts mentioned that the structure of the Turkish grid and its needs are significantly different in the west from the east. The needs for the eastern regions of Türkiye are commonly related with loss of electricity and illegal usage of electricity. In the western regions there is no significant problem about illegal usage of electricity. In the western regions more high-technology projects such as artificial intelligence usage, demand response and communication support can be implemented. For the central regions of Türkiye they mentioned that the most important problems are about the infrastructure of the grid. Voltage fluctuations and voltage drops are prevalent problems in central regions of

Türkiye. Therefore, the energy experts suggested us to divide Türkiye into 3 groups as western provinces, central provinces and eastern provinces to get reliable results. Accordingly, Data Group-1, Data Group-2 and Data Group-3 are classified according to the provinces of Türkiye. Data Group-1 consists of 25 western provinces, Data Group-2 consists of 30 central provinces and Data Group-3 consists of 26 eastern provinces of Türkiye. Data Group-4 consists of the Electricity Distribution System Operators, Electricity Transmission System Operators, Electricity Generation Bodies & Companies, Electricity Regulation & Market Operation Institutions, and Internet of Things (IoT) Manufacturers. The provinces included in each data group are listed below and shown in Figure 7. The survey questions were asked to the respondents according to the province they work in.

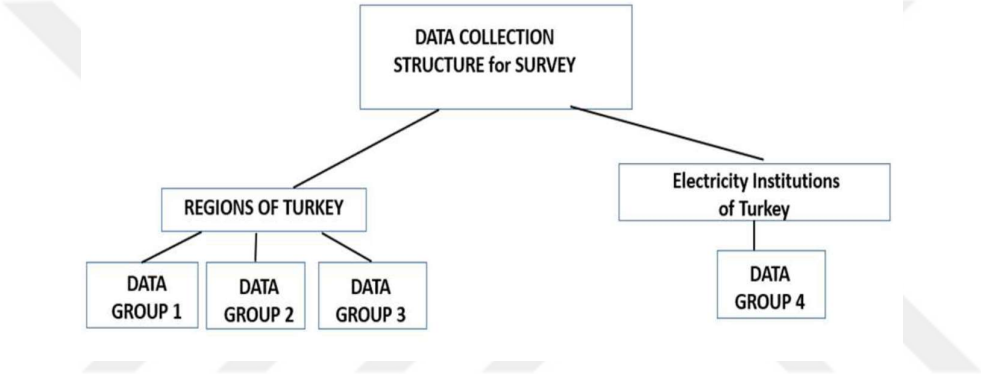


Figure 6: Data Collection Structure for the Smart Grid Survey

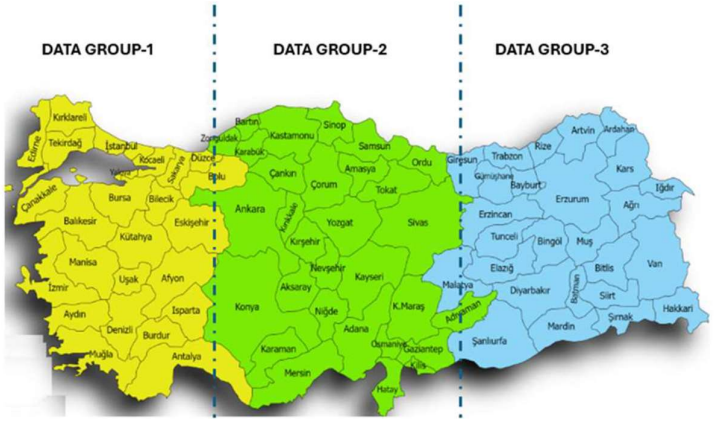


Figure 7: Türkiye Map for Data Groups

DATA GROUP-1 (25 Provinces of Türkiye): Istanbul European Side, Istanbul Anatolian Side, İzmir, Manisa, Bursa, Balıkesir, Çanakkale, Yalova, Antalya, Isparta, Burdur, Aydın, Denizli, Muğla, Kocaeli, Sakarya, Düzce, Bolu, Afyonkarahisar, Bilecik, Eskişehir, Kütahya, Uşak, Tekirdağ, Edirne and Kırklareli.

DATA GROUP-2 (30 Provinces of Türkiye): Ankara, Bartın, Çankırı, Karabük, Kastamonu, Kırıkkale, Zonguldak, Adana, Osmaniye, Gaziantep, Mersin, Kilis, Hatay, Samsun, Amasya, Çorum, Ordu, Sinop, Konya, Aksaray, Niğde, Nevşehir, Karaman, Kırşehir, Sivas, Tokat, Yozgat, Kayseri, Kahramanmaraş and Adıyaman.

DATA GROUP-3 (26 Provinces of Türkiye): Şanlıurfa, Diyarbakır, Mardin, Batman, Siirt, Şırnak, Artvin, Giresun, Gümüşhane, Trabzon, Rize, Erzurum, Ağrı, Ardahan, Bayburt, Iğdır, Kars, Erzincan, Elazığ, Malatya, Bingöl, Tunceli, Van, Bitlis, Muş and Hakkari.

DATA GROUP-4: Electricity Distribution System Operators, Electricity Transmission System Operators, Electricity Generation Bodies and Companies, Electricity Regulation and Market Operation Institutions, Internet of Things (IoT) Manufacturers.

9.2. Demographic Properties of Data Groups

We obtained some demographic properties of the survey respondents. These demographic properties are their education level, work experience and smart grid knowledge. Below we provide the demographic properties of all respondents. The demographic properties for each data group are given separately in Appendix D.

9.2.1. Demographic Properties of All Respondents

As the highest academic degree obtained, 1.12 % of all respondents had a high school diploma, 64.11% had a bachelor's degree, 30.84% had a master's degree and 3.93% had a PhD, as shown in Figure 8.

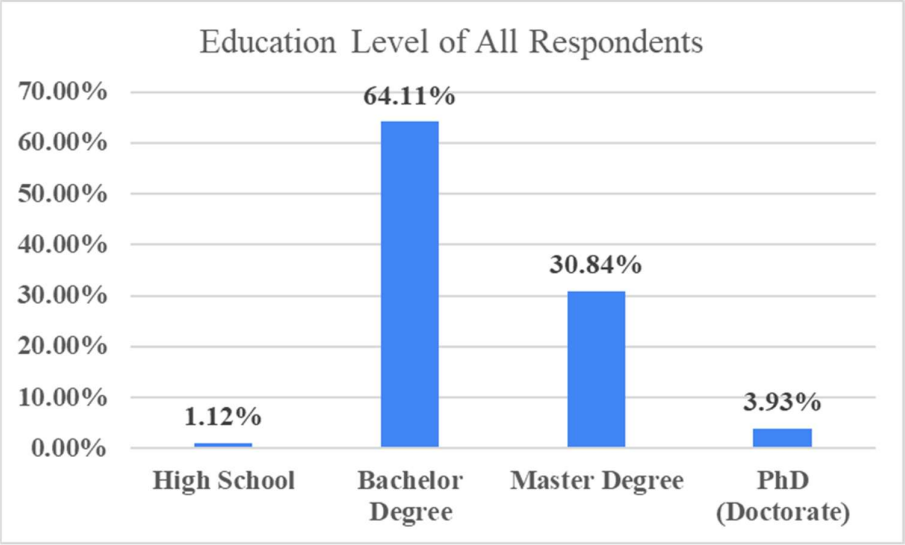


Figure 8: Education Levels of Survey Respondents

2.80% of all respondents had less than 1 year work experience in the electricity sector, 16.26% of them had 1 to 5 years of experience, 24.11% of them had 5 to 10 years of experience, 37.76% of them had 10 to 20 years of experience and 19.07% of them had more than 20 years of experience, as shown in Figure 9.

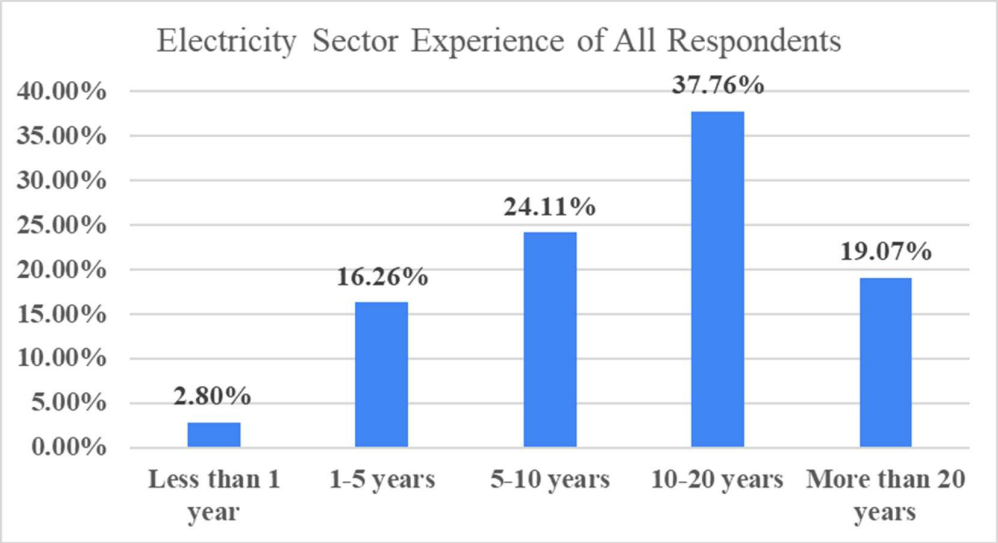


Figure 9: Electricity Sector Experience of Survey Respondents

94.95% of all respondents had knowledge about the smart grid and 5.05% of them had no idea about it.

9.3. Statistical Tools to Analyze Survey Scores

After getting the scores for the subcomponents of the dependent variable and the independent variables from the survey results, we analyzed the scores using appropriate statistical analysis tools. Below we describe the utilized analysis techniques.

9.3.1. Correlation Analysis

Correlation analysis deals with relationships among variables. The correlation coefficient is a measure of association between two variables. Values of the correlation coefficient are always between -1 and +1. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive sense, while a correlation coefficient of -1 indicates that two variables are perfectly related in a negative sense and a correlation coefficient of 0 indicates that there is no relationship between the two variables. Correlation analysis allows the study of only two variables.

9.3.2. ANOVA Analysis

ANOVA is used to compare three or more groups of continuous data when the variances are equal, and the data are independent and follow a normal distribution. It helps determine if there are statistically significant differences between the groups, but it does not specify which specific groups differ from one another. In the ANOVA analysis, an alpha value is determined for hypothesis testing. If the p-value is less than the alpha value, then H1 (alternate hypothesis) is accepted. This means that there is a statistically significant difference between the groups. If the p-value is greater than the alpha value, then H0 (null hypothesis) is accepted. This means there is no statistically significant difference between the groups.

Before applying ANOVA analysis on the data, all ANOVA assumptions were checked. For the homogeneity of the variances, the variances were calculated and the variation within each group being compared was similar for every group. For the independence of the data, the data were collected using statistically valid non-probability sampling method that uses criteria of expert knowledge of the individuals and there were no hidden relationships among observations. For normal distribution, the normality test was applied, and p-values were greater than 0.05. The data was normally distributed.

CHAPTER 10

DATA ANALYSIS

Our purpose in the data analysis is to find answers to the below research questions.

- RQ-1) Do the independent variables have positive correlation with smart grid transformation success?
- RQ-2) Is there a statistically significant difference between the effects of independent variables of smart grid transformation success?
- RQ-3) Is there a statistically significant difference between the effects of independent variables of smart grid transformation success with respect to different regions of Türkiye?
- RQ-4) Is there a statistically significant difference between the time periods required to complete the independent variables of smart grid transformation success?
- RQ-5) Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation success with respect to regions of Türkiye?

Correlation analysis was applied to test the hypotheses created for the first research question. To quantify smart grid transformation success, which is the dependent variable of this study, responses given to subcomponents of the dependent variable were used.

For the dependent variable, 22 subcomponents were determined, and questions were asked to the respondents to rate the importance of these 22 subcomponents in the survey. These 22 subcomponents of the dependent variables were classified into 6 main categories including system quality, service quality, information quality, use, user satisfaction and net benefits. In the survey, the weights of these 6 main categories were also asked to the respondents. Each respondent rated the importance of each subcomponent of the dependent variable and rated the weights of the categories of subcomponents. The weights of the categories are given in Table 10**.**

Table 10: Simple & Weighted Average Coefficients of Subcomponents of DV

WEIGHTS	Systems Quality	Service Quality	Information Quality	Use	User Satisfaction	Net Benefits	TOTAL
DG-1(numeric)	4.41	4.43	4.53	4.06	4.00	4.26	25.69
DG-1 weighted average(%)	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	
DG-1 simple average(%)	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%	
DG-2(numeric)	4.53	4.47	4.46	4.04	3.89	4.42	25.81
DG-2 weighted average(%)	17.55%	17.33%	17.28%	15.66%	15.07%	17.12%	
DG-2 simple average(%)	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%	
DG-3 (numeric)	4.68	4.62	4.67	4.21	4.11	4.42	26.71
DG-3 weighted average(%)	17.53%	17.30%	17.47%	15.77%	15.37%	16.56%	
DG-3 simple average(%)	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%	
DG-4(numeric)	4.43	4.49	4.45	4.07	4.02	4.46	25.93
DG-4 weighted average(%)	17.08%	17.33%	17.17%	15.70%	15.49%	17.22%	
DG-4 simple average(%)	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%	

To quantify smart grid transformation success there are two options for calculation. One is calculating the simple average of the subcomponents, while the second is calculating the weighted average with respect to categories. To select the proper one, we decided to make sample calculations for both and compare the results.

Table 11: Simple Average vs Weighted Average Comparison

	Weighted Average Coefficients						Results		
#Respondent	Systems Quality	Service Quality	Information Quality	Use	User Satisfaction	Net Benefits	**Success Point by Simple Average**	**Success Point by Weighted Average**	**Difference**
1	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.14**	**4.13**	**0.01**
2	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.09**	**4.09**	**0.00**
3	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.36**	**4.37**	**-0.01**
4	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.27**	**4.25**	**0.02**
5	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.91**	**4.91**	**0.00**
6	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.59**	**4.55**	**0.04**
7	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.14**	**4.10**	**0.04**
8	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.45**	**4.45**	**0.01**
9	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.32**	**4.27**	**0.05**
10	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.73**	**4.75**	**-0.02**
11	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.55**	**4.51**	**0.03**
12	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.14**	**4.13**	**0.01**
13	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.09**	**4.09**	**0.00**
14	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**3.45**	**3.39**	**0.07**
15	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**3.59**	**3.51**	**0.08**
16	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.18**	**4.17**	**0.01**
17	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.00**	**3.98**	**0.02**
18	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.45**	**4.45**	**0.00**
19	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**3.36**	**3.34**	**0.02**
20	17.17%	17.25%	17.62%	15.81%	15.57%	16.59%	**4.59**	**4.58**	**0.01**

We applied both calculation methods to the responses of 95 respondents. We saw that the results do not differ much with differences varying between 0.01 and 0.08. The

results for both simple average and weighted average were found to be quite similar. Hence, we decided to apply the simple average.

After calculating the success points for all 474 responses, we applied correlation analysis to all four data groups by using the Minitab-18 Statistical Program to find an answer to the first research question. All correlation analyses results are given below, and the related graphs are given in Appendix E.

For DATA GROUP-1:

Correlation: Remote Controlling; Smart Grid Transformation Success

Pearson correlation **0.066 *Lowest of DG-1**
P-value 0.528

Correlation: Smart Metering; Smart Grid Transformation Success
Pearson correlation **0.252**
P-value 0.014

Correlation: Consumer Participation; Smart Grid Transformation Success
Pearson correlation **0.358**
P-value 0.000

Correlation: Integration of Renewables; Smart Grid Transformation Success
Pearson correlation **0.145**
P-value 0.161

Correlation: Data Management Support; Smart Grid Transformation Success
Pearson correlation **0.339**
P-value 0.001

Correlation: Distributed Energy Transition; Smart Grid Transformation Success
Pearson correlation **0.164**
P-value 0.112

Correlation: Electric Vehicle Charging; Smart Grid Transformation Success
Pearson correlation **0.186**
P-value 0.071

Correlation: Smart Appliance Usage; Smart Grid Transformation Success
Pearson correlation **0.373**
P-value 0.000

Correlation: Aggregator Support; Smart Grid Transformation Success
Pearson correlation **0.386**
P-value 0.000

Correlation: Regulatory Framework; Smart Grid Transformation Success
Pearson correlation **0.217**
P-value 0.035

Correlation: Incentives; Smart Grid Transformation Success
Pearson correlation **0.320**
P-value 0.002

Correlation: Interoperability (IOP); Smart Grid Transformation Success
Pearson correlation **0.292**
P-value 0.004

Correlation: Institutional Change; Smart Grid Transformation Success
Pearson correlation **0.304**
P-value 0.003

Correlation: Organizational Change; Smart Grid Transformation Success
Pearson correlation **0.370**
P-value 0.000

Correlation: Dynamic Pricing; Smart Grid Transformation Success
Pearson correlation **0.451**
P-value 0.000

Correlation: Communication Support; Smart Grid Transformation Success
Pearson correlation **0.455 *Highest of DG-1**
P-value 0.000

Correlation: AI (Artificial Intelligence) Support; Smart Grid Transformation Success
Pearson correlation **0.401**
P-value 0.000

Correlation: IoT (Internet of Things) Support; Smart Grid Transformation Success
Pearson correlation **0.328**
P-value 0.001

Correlation: Political Support; Smart Grid Transformation Success
Pearson correlation **0.286**
P-value 0.005

Correlation: Electric Storage; Smart Grid Transformation Success
Pearson correlation **0.373**
P-value 0.000

For DATA GROUP-2:

Correlation: Remote Controlling; Smart Grid Transformation Success
Pearson correlation **0.374**
P-value 0.001

Correlation: Smart Metering; Smart Grid Transformation Success
Pearson correlation **0.411**
P-value 0.000

Correlation: Consumer Participation; Smart Grid Transformation Success
Pearson correlation **0.348**
P-value 0.003

Correlation: Integration of Renewables; Smart Grid Transformation Success
Pearson correlation **0.558**
P-value 0.000

Correlation: Data Management Support; Smart Grid Transformation Success
Pearson correlation **0.631 *Highest of DG-2**
P-value 0.001

Correlation: Distributed Energy Transition; Smart Grid Transformation Success
Pearson correlation **0.521**
P-value 0.000

Correlation: Electric Vehicle Charging; Smart Grid Transformation Success
Pearson correlation **0.396**
P-value 0.001

Correlation: Smart Appliance Usage; Smart Grid Transformation Success
Pearson correlation **0.436**
P-value 0.000

Correlation: Aggregator Support; Smart Grid Transformation Success
Pearson correlation **0.497**
P-value 0.000

Correlation: Regulatory Framework; Smart Grid Transformation Success
Pearson correlation **0.541**
P-value 0.000

Correlation: Incentives; Smart Grid Transformation Success
Pearson correlation **0.325**
P-value 0.005

Correlation: Interoperability (IOP); Smart Grid Transformation Success
Pearson correlation **0.439**
P-value 0.000

Correlation: Institutional Change; Smart Grid Transformation Success
Pearson correlation **0.499**
P-value 0.000

Correlation: Organizational Change; Smart Grid Transformation Success
Pearson correlation **0.494**
P-value 0.000

Correlation: Dynamic Pricing; Smart Grid Transformation Success
Pearson correlation **0.624**
P-value 0.000

Correlation: Communication Support; Smart Grid Transformation Success
Pearson correlation **0.522**
P-value 0.000

Correlation: AI Support; Smart Grid Transformation Success
Pearson correlation **0.444**
P-value 0,000

Correlation: IoT (Internet of Things) Support; Smart Grid Transformation Success
Pearson correlation **0.598**
P-value 0.001

Correlation: Political Support; Smart Grid Transformation Success
Pearson correlation **0.212 *Lowest of DG-2**
P-value 0.074

Correlation: Electric Storage; Smart Grid Transformation Success
Pearson correlation **0.351**
P-value 0.003

For DATA GROUP-3:

Correlation: Remote Controlling; Smart Grid Transformation Success
Pearson correlation **0.034 * Lowest of DG-3**
P-value 0.788

Correlation: Smart Metering; Smart Grid Transformation Success
Pearson correlation **0.405**
P-value 0.001

Correlation: Consumer Participation; Smart Grid Transformation Success
Pearson correlation **0.451**
P-value 0.000

Correlation: Integration of Renewables; Smart Grid Transformation Success
Pearson correlation **0.106**
P-value 0.399

Correlation: Data Management Support; Smart Grid Transformation Success
Pearson correlation **0.310**
P-value 0.011

Correlation: Distributed Energy Transition; Smart Grid Transformation Success
Pearson correlation **0.280**
P-value 0.023

Correlation: Electric Vehicle Charging; Smart Grid Transformation Success
Pearson correlation **0.301**
P-value 0.014

Correlation: Smart Appliance Usage; Smart Grid Transformation Success
Pearson correlation **0.442**
P-value 0.000

Correlation: Aggregator Support; Smart Grid Transformation Success
Pearson correlation **0.493 *Highest of DG-3**
P-value 0.000

Correlation: Regulatory Framework; Smart Grid Transformation Success
Pearson correlation **0.435**
P-value 0.035

Correlation: Incentives; Smart Grid Transformation Success
Pearson correlation **0.408**
P-value 0.001

Correlation: Interoperability (IOP); Smart Grid Transformation Success
Pearson correlation **0.331**
P-value 0.007

Correlation: Institutional Change; Smart Grid Transformation Success
Pearson correlation **0.236**
P-value 0.057

Correlation: Organizational Change; Smart Grid Transformation Success
Pearson correlation **0.244**
P-value 0.048

Correlation: Dynamic Pricing; Smart Grid Transformation Success
Pearson correlation **0.407**
P-value 0.001

Correlation: Communication Support; Smart Grid Transformation Success
Pearson correlation **0.377**
P-value 0.002

Correlation: AI Support; Smart Grid Transformation Success
Pearson correlation **0.394**
P-value 0.001

Correlation: IoT Support; Smart Grid Transformation Success
Pearson correlation **0.473**
P-value 0.000

Correlation: Political Support; Smart Grid Transformation Success
Pearson correlation **0.236**
P-value 0.057

Correlation: Electric Storage; Smart Grid Transformation Success
Pearson correlation **0.196**
P-value 0.115

For DATA GROUP-4:

Correlation: Remote Controlling; Smart Grid Transformation Success
Pearson correlation **0.273**
P-value 0.000

Correlation: Smart Metering; Smart Grid Transformation Success
Pearson correlation **0.372**
P-value 0.000

Correlation: Consumer Participation; Smart Grid Transformation Success
Pearson correlation **0.373**
P-value 0.000

Correlation: Integration of Renewables; Smart Grid Transformation Success
Pearson correlation **0.328**
P-value 0.000

Correlation: Data Management Support; Smart Grid Transformation Success
Pearson correlation **0.379**
P-value 0.000

Correlation: Distributed Energy Transition; Smart Grid Transformation Success
Pearson correlation **0.335**
P-value 0.000

Correlation: Electric Vehicle Charging; Smart Grid Transformation Success
Pearson correlation **0.283**
P-value 0.000

Correlation: Smart Appliance Usage; Smart Grid Transformation Success
Pearson correlation **0.388**
P-value 0.000

Correlation: Aggregator Support; Smart Grid Transformation Success
Pearson correlation **0.372**
P-value 0.000

Correlation: Regulatory Framework; Smart Grid Transformation Success
Pearson correlation **0.338**
P-value 0.000

Correlation: Incentives; Smart Grid Transformation Success
Pearson correlation **0.346**
P-value 0.000

Correlation: Interoperability (IOP); Smart Grid Transformation Success
Pearson correlation **0.417**
P-value 0.000

Correlation: Institutional Change; Smart Grid Transformation Success
Pearson correlation **0.299**
P-value 0.000

Correlation: Organizational Change; Smart Grid Transformation Success
Pearson correlation **0.371**
P-value 0.000

Correlation: Dynamic Pricing; Smart Grid Transformation Success
Pearson correlation **0.478 *Highest of DG-4**
P-value 0.000

Correlation: Communication Support; Smart Grid Transformation Success
Pearson correlation **0.446**
P-value 0.000

Correlation: AI (Artificial Intelligence) Support; Smart Grid Transformation Success
Pearson correlation **0.403**
P-value 0.000

Correlation: IoT (Internet of Things) Support; Smart Grid Transformation Success
Pearson correlation **0.404**
P-value 0.000

Correlation: Political Support; Smart Grid Transformation Success
Pearson correlation **0.235 * Lowest of DG-4**
P-value 0.000

Correlation: Electric Storage; Smart Grid Transformation Success
Pearson correlation **0.244**
P-value 0.000

In the correlation analyses all Pearson's correlation coefficients were found to be positive, with values varying between 0.034 and 0.631. Hence all independent variables are positively correlated with the smart grid transformation success of Türkiye in each data group. This proves all H1 alternate hypotheses for the first

research question. Therefore, all the 20 independent variables should remain in the independent variables list in the smart grid transformation success models of Türkiye.

For RQ-2, we had twenty independent variables, and we aimed to check for the existence of statistically significant differences between the effects of these variables on smart grid transformation success. For this question, we applied ANOVA analysis using the one-way ANOVA method of the Minitab-18 statistical program. One-way ANOVA analysis results are given in Appendix G.

In the one-way ANOVA analysis, we got a p-value of 0 and f-value of 35.23. As the p-value is less than the alpha value (0.05) and the f-value is quite high, the null hypothesis was rejected, and the alternate hypothesis accepted. It was shown that there is a statistically significant difference between the effects of independent variables on smart grid transformation success.

To answer our third research question, "*Is there a statistically significant difference between the effects of independent variables of smart grid transformation success with respect to regions of Türkiye?",* we applied ANOVA analysis to each independent variable using the one-way ANOVA module. Importance of each independent variable related responses of the survey were classified according to regions of Türkiye.

In the one-way ANOVA analysis for RQ-3, all p-values are greater than the alpha value (0.05), except for consumer participation's p-value. For consumer participation, the p-value is 0.033 and f-value is 3.46. This p-value is less than the alpha value (0.05) and the f-value is high, therefore for the effect of consumer participation on smart grid transformation success there is a statistically significant difference among the regions of Türkiye. The effect of "consumer participation" on smart grid transformation success in eastern regions of Türkiye is significantly different and more important than the western and central regions of Türkiye.

For the effect of the other nineteen independent variables on smart grid transformation success, there is not a statistically significant difference among the regions of Türkiye. For RQ-3, one-way ANOVA analysis results of each independent variable are given in Appendix G.

Respondents from DATA GROUP-1 (Western Provinces of Türkiye) perceive "Remote Controlling" and "Smart Metering" as the most effective independent variables on the success of smart grid transformation, and "Aggregator Support" as the least effective.

Respondents from DATA GROUP-2 (Central Provinces of Türkiye) perceive "Remote Controlling" and "Smart Metering**"** as the most effective independent variables on the success of smart grid transformation, and "Aggregator Support" as the least effective.

Respondents from DATA GROUP-3 (Eastern Provinces of Türkiye) also perceive "Remote Controlling" and "Smart Metering**"** as the most effective independent variables on the success of smart grid transformation, and "Aggregator Support" as the least effective.

For the western, central and eastern provinces of Türkiye, the most effective independent variables are same, which are "Remote Controlling" and "Smart Metering". In addition to this, for all three parts of Türkiye, the least effective independent variable is also the same, which is "Aggregator Support".

To answer RQ-4, "*Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation success?*", we searched for the existence of statistically significant differences between the time periods required to complete the twenty independent variables of smart grid transformation success. For this, once again we applied ANOVA analysis to the survey responses using the one-way ANOVA module of Minitab-18. One-way ANOVA analysis results are given in Appendix G.

In the one-way ANOVA analysis, we got a p-value of 0 and f-value of 25.85. As the p-value is less than the alpha value (0.05) and f-value is quite high, the null hypothesis was rejected, and alternate hypothesis accepted. It was shown that there is a statistically significant difference between the time periods required to complete the independent variables of smart grid transformation success.

To answer RQ-5, "*Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation success with respect to regions of Türkiye?",* we applied ANOVA analysis using the one-way ANOVA module to each independent variable with respect to regions. Survey responses for the time periods of each independent variable were categorized according to regions of Türkiye.

In the one-way ANOVA analysis, all p-values were greater than the alpha value (0.05), except for "smart metering"s p-value. For smart metering the p-value is 0.017 and f-value is 4.17. As the "smart metering" p-value is less than the alpha value (0.05) and the f-value is high, for the time period required for smart metering there is a statistically significant difference among the regions of Türkiye.

For the time period required for the other nineteen independent variables of smart grid transformation success, there is not a statistically significant difference among the regions of Türkiye. The one-way ANOVA analysis results for each independent variable are given in Appendix G.

Respondents from DATA GROUP-1 (Western Provinces of Türkiye) evaluate that the shortest required time is for "Integration of Renewables", which is at least 5.1 years, and the longest required time is for "Smart Appliance Usage", which is at least 9 years.

Respondents from DATA GROUP-2 (Central Provinces of Türkiye) evaluate that the shortest required time is for “Data Management Support”, which is at least 5.76 years, and the longest required time is for “Smart Appliance Usage”, which is at least 9.37 years.

Respondents from DATA GROUP-3 (Eastern Provinces of Türkiye) evaluate that the shortest required time is for “Smart Metering”, which is at least 5.26 years and the longest required time is for “Smart Appliance Usage”, which is at least 8.92 years.

CHAPTER 11

CONCLUSION

In this study, we performed the first systematic study to determine the critical parameters for the successful transformation from the traditional grid to a smart grid in Türkiye. The dependent variable's subcomponents and independent variables of Turkish smart grid transformation success were determined and clarified through a comprehensive literature review and by applying DeLone & Mc Lean's information systems success model, with a 3-round Delphi Analysis and taking experts' views. These parameters and the prepared survey study were validated using the Think-Aloud method and Cronbach Alpha Tests and a broad survey was conducted with the participation of 474 participants from the electricity sector.

Below we summarize the main results of the study, the proposed smart grid transformation success model, additional results obtained from the survey, the major contributions of the study and future work in the field.

11.1. The Main Results

There are five main results of this study. These five results are listed below, and they can guide and form the basis for future research on smart grid studies of Türkiye.

All independent variables have positive correlation on the smart grid transformation success of Türkiye.

There is a statistically significant difference between the effects of independent variables of smart grid transformation success.

For the effect of "consumer participation" on smart grid transformation success, there is a statistically significant difference among the regions of Türkiye. The effect of "consumer participation" on the smart grid transformation success in eastern regions of Türkiye is significantly different and more important than the western and central regions of Türkiye. For the effect of the other nineteen independent variables on smart grid transformation success, there is not a statistically significant difference among the regions of Türkiye.

There is a statistically significant difference between the time periods required to complete the independent variables of smart grid transformation.

For the time period required for "smart metering", there is a statistically significant difference among the regions of Türkiye. For the time period required for the other

nineteen independent variables of the smart grid transformation, there is not a statistically significant difference among the regions of Türkiye.

11.2. The Final Model

Based on the results of our study, we formed a smart grid transformation success model of Türkiye as shown in Figure 10. In this model, the Turkish smart grid transformation success has twenty-two subcomponents and twenty independent variables affecting this success. The region and required time are two important dimensions of this model. Correlations between the success and the independent variables change with respect to regions of Türkiye.

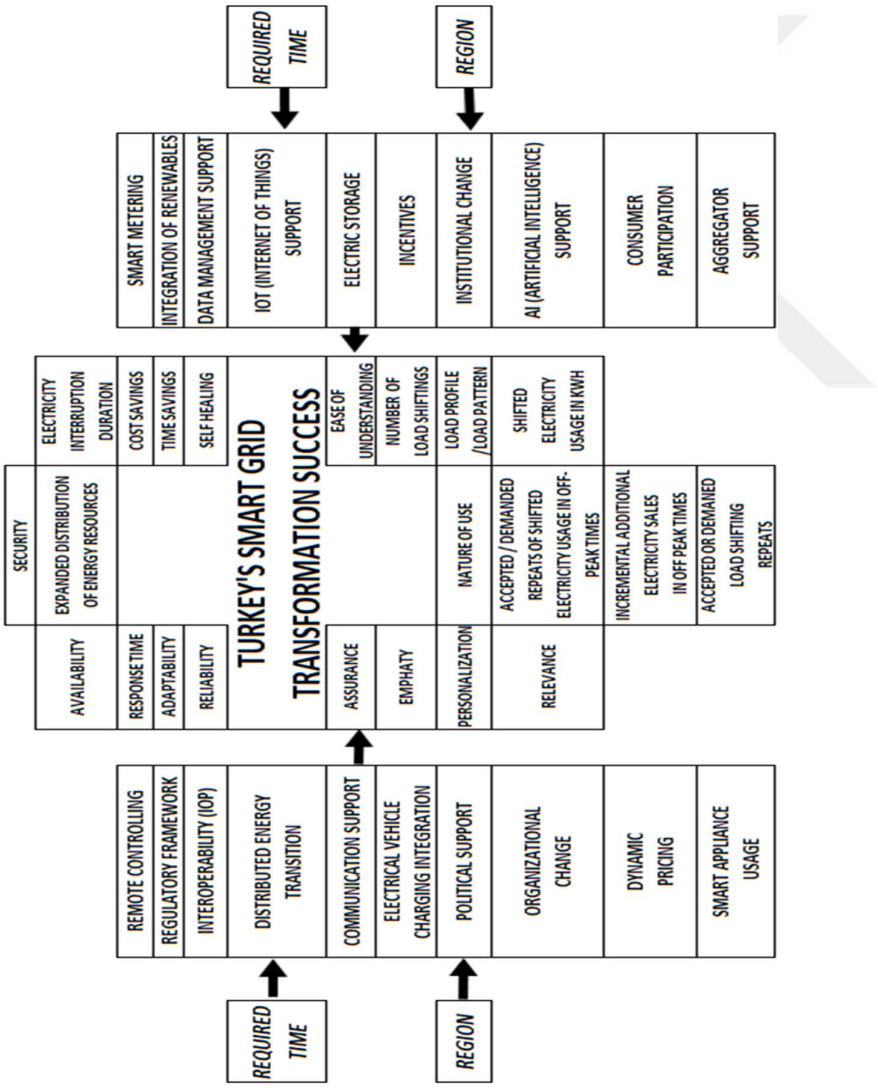


Figure 10: Smart Grid Transformation Success Model of Türkiye

11.3. Additional Results

In addition to the main results, the below findings were also obtained from this research. The comparisons below assess the impact of individual success factors on the smart grid transformation success in Türkiye using the results of statistical analyses.

For Data Group-1 (Western Provinces of Türkiye), the independent variable with the highest correlation with smart grid transformation success is “Communication Support”, whereas the least correlated one is “Remote Controlling”. Pearson correlation for “Communication Support” is 0.455, where Pearson correlation for “Remote Controlling” is 0.066.

For Data Group-2 (Central Provinces of Türkiye), the independent variable with the highest correlation with smart grid transformation success is “Data Management”, whereas least correlated one is “Political Support”. Pearson correlation for “Data Management” is 0.631 and Pearson correlation for “Political Support” is 0.212.

For Data Group-3 (Eastern Provinces of Türkiye), the independent variable with the highest correlation with smart grid transformation success is “Aggregator Support”, whereas the least correlated one is “Remote Controlling”. Pearson correlation for “Aggregator Support” is 0.493 and Pearson correlation for “Remote Controlling” is 0.034.

For Data Group-4 (Institutions of Türkiye), the independent variable with the highest correlation with smart grid transformation success is “Dynamic Pricing”, whereas the least correlated one is “Political Support”. Pearson correlation for “Dynamic Pricing” is 0.478 and Pearson correlation for “Political Support” is 0.235.

Respondents from both central provinces of Türkiye and institutions evaluate that “Political Support” is the least correlated independent variable with smart grid transformation success.

Respondents from both the western and eastern provinces of Türkiye evaluate that “Remote Controlling” is the least correlated independent variable with smart grid transformation success.

“Data Management Support”, “Smart Appliance Usage”, “Aggregator Support”, “Incentives”, “Dynamic Pricing”, “Communication Support”, “Artificial Intelligence Support” and “Internet of Things Support” have high Pearson correlation scores in all four data groups. These Pearson correlations vary between 0.310 and 0.631.

“Political Support” has low Pearson correlation scores in all four data groups. These Pearson correlations vary between 0.212 and 0.286. This is an unexpected result.

“Integration of Renewables” has low Pearson correlation scores for the western and eastern provinces of Türkiye, 0.145 and 0.106 respectively. On the other hand, the Pearson correlation is 0.558 in central provinces.

All respondents from all data groups have the common opinion that “Smart Appliance Usage” will take the longest time in smart grid transformation in Türkiye. This duration will not be less than 9 years.

The times required for “Data Management Support”, “Smart Appliance Usage”, “Aggregator Support”, “Incentives”, “Dynamic Pricing”, “Communication Support”, “Artificial Intelligence Support” and “Internet of Things Support” have high Pearson correlation scores in all four data groups. Respondents evaluate that these eight independent variables will take at least 5 years to complete. Durations for these independent variables vary between 5.34 and 9.37 years.

In the survey respondents also shared their views on smart grid transformation success in Türkiye. All the respondents’ views are given in Appendix F.

For Data Group-1 (Western Provinces of Türkiye), the views of the respondents are mainly about:

- Renewable energy integration
- Smart grid integration of smart devices
- Smart appliance usage
- Importance of experienced technical staff about the smart grid
- Necessity of smart grid legislations
- Requirement of special institutions for smart grid transformation

For Data Group-2 (Central Provinces of Türkiye), the views of the respondents are mainly about:

- Availability and continuity of electricity
- Necessity of smart grid legislations
- Necessity of smart and connected of electricity automation systems
- Integrated single smart grid infrastructure for all of Türkiye

For Data Group-3 (Eastern Provinces of Türkiye), the views of the respondents are mainly about:

- Necessity of smart grid related lectures at universities
- Integrated single smart grid infrastructure for all of Türkiye
- Integration problems of different smart devices and platforms for the smart grid
- Common protocol and common communication technologies requirement
- Necessity of smart grid legislations

- Importance of experienced technical staff about the smart grid and its inadequacy

For Data Group-4 (Institutions of Türkiye), the views of the respondents are mainly about:

- Smart appliance usage at homes
- Importance of back-up systems for the smart grid
- Reliability and cybersecurity of the smart grid
- Common protocol and common communication technologies requirement
- Necessity of smart grid legislations
- Integration of renewables to the smart grid

11.4. Contributions of The Study

The primary and additional findings of this study share the same objective: to evaluate the success of smart grid transformation in Türkiye and the factors that influence it, with unique contributions to the literature.

The contributions of the main findings provide a strong foundation for future research aimed at assessing the existence and strength of the statistical relationships between smart grid transformation success and the influencing factors. This study is among the few that analyze the issue quantitatively and from multiple dimensions. Additionally, the contributions of the supplementary results lay a solid groundwork for future discussions regarding the perspectives of different data groups related to the regions of Türkiye and their impact on smart grid transformation success for the first time. Using this study as a reference, researchers and Turkish electricity grid stakeholders can thoroughly evaluate and improve various aspects of smart grid systems in their future projects, ensuring that these initiatives effectively achieve their objectives and provide substantial benefits to consumers and society. The subcomponents of smart grid transformation success and the independent variables identified in this study will serve as valuable insights for further research in the field.

11.5. Limitations and Future Research

The study does have some limitations, as the main and supplementary findings from the survey are not universally applicable; they are based on data collected from stakeholders in Turkish institutions and experts. However, since the subcomponents of the variables and the independent variables were identified through a global analysis, researchers from other countries or regions can utilize our study and compare their findings with those from Türkiye.

Alternatively, researchers may choose to use our dataset, which is well-organized and free from errors, containing a sufficient number of quantitative evaluations. Interested

researchers can conduct different statistical analyses on our dataset to explore the dynamics of smart grid transformation success in Türkiye from various perspectives.

Another option is to replicate our study with the same sample group using the same methodology after a reasonable interval, allowing for an analysis of trends and changes in the opinions of Turkish electricity stakeholders over time.

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APPENDICES

APPENDIX A: Independent Variables from Reviewed Studies

Table 12: Independent Variables from Reviewed Studies

Year	Authors	Independent Variables from Study	Reference Study Title
2008	J. Han, M.A. Piette	Consumer Participation, Dynamic Pricing, Regulatory Framework	Solutions for Summer Electric Power Shortages: Demand Response and its applications in Air Conditioning and Refrigerating Systems
2008	J. Vasconcelos	Smart Meter Installation, Regulatory Framework, Incentives, Renewable Sources Integration	Survey of Regulatory and Technological Developments Concerning Smart Metering in the European Union Electricity Market
2008	M.H. Albadi, E.F. El-Saadany	Consumer Participation, Dynamic Pricing, Incentives, Reliability	A summary of demand response in electricity markets
2009	J. Torriti, M.G. Hassan, M. Leach	Smart Meter Installation, Regulatory Framework, Incentives, Renewable Sources Integration	Demand response experience in Europe: Policies, programmes and implementation
2009	C. Batlle, P. Rodilla	Incentives, IT support, Smart Meter Installation, Communication Support	Electricity demand response tools: current status and outstanding issue
2010	S. Mohagheghi, J. Stoupis, H. Kazemzadeh	Aggregator Support, Incentives, Distributed Energy Transition, Renewable Sources Integration	Demand Response Architecture: Integration into the Distribution Management System
2010	North American Electric Reliability Corporation	Smart Appliances Usage, Interoperability, Smart Meter Installation, Distributed Energy Transition, Renewable Sources Integration	Reliability Considerations from Integration of Smart Grid
2011	B. Adebisi, A. Treytl, A. Haidine, A. Portnoy, R. Shan, D. Lund	Communication Support, Integration of Renewables, Distributed Energy Transition, Load Management, Demand Response	IP-Centric High-Rate Narrowband PLC for Smart Grid Applications

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2011	P. Palensky, D. Dietrich	Demand Side Management, Dynamic Pricing, Integration of Renewables, Consumer Participation, Data Management Support, Communication Support	Demand Side Management: Demand Response, Intelligent Energy Systems and Smart Loads
2011	L.Peng, G. Yan	Climate Change Risks, Energy Shortage	Clean Energy Grid-Connected Technology Based on Smart Grid
2011	V.S.K.M. Balijepalli, V. Pradhan, S.A. Khaparde, R.M. Shereef	Consumer Participation, Distributed Energy Transition,	Review of Demand Response under Smart Grid Paradigm
2011	G. Xiong, C. Chen, S. Kishore, A. Yener	Smart Meters Installation, Consumer Participation, Communication Support	Smart (in-home) power scheduling for demand response on the smart grid
2011	M. Hashmi	Aggregator Support, Distributed Energy Transition, Demand Response, Regulatory Framework, Dynamic Pricing	Survey of smart grids concepts worldwide
2011	S. Mohagheghi, B. Falahati, F. Yang	Reliability, Consumer Participation, Aggregator Support	Impact of demand response on distribution system reliability
2011	H. Sæle, O.S. Grande	Consumer Participation, Distributed Energy Transition, Renewable Sources Integration, Remote Controlling, Internet of Things Support	Demand Response from Household Customers: Experiences from a Pilot Study in Norway
2011	R. J. Pierce	Regulatory Framework, Political Support, Dynamic Pricing	A Primer on Demand Response and a Critique of FERC Order 745

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2011	W. Wang, Y. Xu, M.Khanna	Communication Support, Regulatory Framework, Distrubuted Energy Resources, Renewable Energy Resources, Customer Participation, Communication Support	A survey on the communication architectures in smart grid
2011	P. Faria, Z. Vale	Consumer participation, Dynamic Pricing, Distributed Energy Transition, Renewable Sources Integration, Load Shifting	Demand response in electrical energy supply: An optimal real time pricing approach
2012	S. Blumsack, A. Fernandez	Dynamic Pricing, Renewable Sources Integration, Political Support, Regulatory Framework	Ready or not, here comes the smart grid!
2012	P. Harper-Slaboszewicz, T. McGregor, S. Sunderhauf	Smart Meter Installation, Consumer Participation, Remote Controlling, Internet of Things Support, Dynamic Pricing, Regulatory Framework, Smart Appliances Usage	Customer View of Smart Grid—Set and Forget?
2012	N. Jenkins, J.B. Ekanayake, K.M. Liyanage, A. Yokoyama, J. Wu	Communication Support, Smart Meter Installation, Security, Regulatory Framework	Smart Grid: Technology and Applications
2012	R.C. Qiu, Z. Hu, Z. Chen, T. Guo, R. Ranganathan	Communication Support, Security, Smart Metering	Cognitive Radio Network for the Smart Grid: Experimental System Architecture, Control Algorithms, Security and Microgrid Testbed
2012	X.Li, X. Liang, R. Lu, X.S. Shen, X. Lin, H. Zhu	Security, Communication Support, Privacy	Securing Smart Grid: Cyber Attacks, Countermeasures and Challenges
2012	F.R. Pazheri, wsN.H. Malik, F. Othman, E.A. Al-Ammar	Renewable Sources Integration	Use of Renewable Energy Sources in Saudi Arabia through Smart Grid

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2012	J. Struker, C. Dinther	Integration of Renewables, Information Systems, Demand Response, Distributed Energy Transition, Electrical Vehicle Integration, Smart Metering, Communication Support, Data Management Support, Aggregator Support	Demand Response in Smart Grids: Research Opportunities for the IS Discipline
2012	C. King, J. Strapp	Data management Support, Smart Meter Installation, Interoperability, IT support	Software Infrastructure and the Smart Grid
2013	K.O. Aduda, T. Labeodan, W. Zeiler, G. Boxem, Y. Zhao	Integration of Renewables, Distributed Energy Transition, Smart Metering, Customer Participation, Dynamic Pricing, Remote Controlling	Demand side flexibility: potentials and building performance implications
2013	T. Blenkinsopp, S.R. Colesi, K. Kirwan	Integration of Renewables, Customer Participation, Political Support, Regulatory Framework,	Renewable energy for rural communities in Maharashtra, India
2013	I. Colak, G. Fulli, S. Vitiello, I. Tekin, R. Bayındır, K. Demirtas	Regulatory Framework, Integration of Renewables, Electrical Vehicle Integration, Availability	Developments of Turkish grid system infrastructure for entegration with Europe
2013	I.G. Hamilton, P.J. Steadman, H.B. Bruhns, A.J. Summerfield, R. Lowe	Data Management Support, Regulatory Framework, Political Support	Energy efficiency in the British housing stock: Energy demand and the Homes Energy Efficiency Database
2013	X. He, N. Keyaerts, I. Azevedo, L. Meeus, L. Hancher, J. Glachant	Political Support, Institutional Change, Organizational Change, Demand Response, Political Support	How to engage consumers in demand response: A contract perspective
2013	E. Kırmızıoğlu	Communication Support, Smart Metering, Data Management, Integration of Renewables, Distributed Energy Transition	Smart Grid Strategies and Projects
2013	N. Phuangporpitak, S. Tia	Distributed Energy Transition, Renewable Sources Integration, Political Support, Regulatory Framework, Climate Change Risks	Opportunities and Challenges of Integrating Renewable Energy in Smart Grid System

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2013	P. Siano	Communication Support, Electrical Vehicle Integration, Smart Meters Installation, Dynamic Pricing, Consumer Participation, Security	Demand response and smart grids—A survey
2013	W. Wang, Z. Lu	Security, Communication Support	Cyber security in the Smart Grid: Survey and challenges
2013	O.M. Ghita, S.D. Grigorescu, C. Cepisca, A. Vintea	Reliability, Data Management Support, Renewable Energy Integration	Power Quality Monitoring Systems for Smart Grid Networks
2013	J.L. Dedrick, Y. Zheng	Data Management Support, Security Support, Privacy, Smart Meter Installation	Information Systems and Smart Grid: New Directions for the IS Community
2014	M. Bilton, M. Aunedi, M. Woolf G. Strbac	Smart Appliances Usage, Dynamic Pricing, Customer Participation, Remote Controlling	Smart appliances for residential demand response
2014	M. El-hawary	Smart Meters Installation, Renewable Sources Integration, Smart Appliances Usage, Electrical Vehicle Usage	The Smart Grid, State-of-the-art and Future Trends
2014	F. Mwasilu, J.J. Justo, E. Kim, T.D. Do, J. Jung	Electrical Vehicle Integration, Renewable Sources Integration, Smart Meters Installation	Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration
2014	L.Gelazanskas, K.A.A. Gamage	Distributed Energy Transition, Renewable Sources Integration, Communication Support, Electrical Vehicle Integration, Smart Meters Installation	Demand side management in smart grid: A review and proposals for future direction
2014	C.S. Kudarihal	Smart Metering, Demand Side Management, Electrical Vehicle Integration, Integration of Renewables, Commnunication Support, Security	Smart metering and Demand Side Integration
2014	M. Kuzlu, M. Pipattanasomporn, S. Rahman	Communication Support, Smart Metering	Communication network requirements for major smart grid applications in HAN, NAN and WAN

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2014	D. Bian, M. Kuzlu, M. Pipattanasomporn, S. Rahman	Communication Support, Data Management Support	Assessment of Communication Technology Alternatives for a Home Energy Management System in Premises Area Network
2014	A. Roos, S. Ottesen, T.F. Bolkesjo	Aggregator Support, Electric Storage, Integration of Renewables, Regulatory Framework	Modeling consumer flexibility of an aggregator participating in the wholesale power market and the regulation capacity market
2014	S. Jain, M. Pradish, A. Paventhan, N. Pahuja, R. Sutaria	Smart Metering, Interoperability, Regulatory Framework, Internet of Things Support, Communication Support, Demand Response	Smart metering worldwide deployment scenarios and IoT based approach for India
2015	M. Behrangrad	Demand Side Management, Integration of Renewables, Regulatory Framework	A review of demand side management business models in the electricity market
2015	P.D. Lund, J. Lindgren, J. Mikkola, J. Salpakari	Integration of Renewables, Demand Side Management, Electrical Vehicle Integration, Electric Storage, Demand Side Flexibility	Review of energy system flexibility measures to enable high levels of variable renewable electricity
2015	J. Ma, A. Elkasrawy, D. Yu	Customer Participation, Renewable Sources Integration, Demand Response, Load Shifting, Aggregation, Dynamic Pricing, Cost Savings	Demand response literature review
2015	D.F. Ramirez, S. Cespedes	Communication Support, Integration of Renewables, Smart Metering, Security	Routing in Neighborhood Area Networks: A Survey in the Context of AMI Communications
2015	G. Ryckebusch	Consumer participation, Dynamic Pricing, Distributed Energy Transition, Renewable Sources Integration	Analysis of Demand-Response Participation Strategies for Congestion Management

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2015	Q. Wang, C. Zhang, Y. Ding, G. Xydis, J. Wang, J. Ostergaard	Distributed Energy Transition, Integration of Renewables, Demand Response, Dynamic Pricing, Electrical Vehicle Integration, Aggregator Support, Consumer Participation	Review of real-time electricity markets for integrating Distributed Energy Resources and Demand Response
2015	Q. Wang	Integration of Renewables, Communication Support, Distributed Energy Transition, Electrical Vehicle Integration, Remote Controlling, Distributed Energy Transition, Data Management Support	Renewable Energy and the Smart Grid: Architecture Modelling, Communication Technologies and Electric Vehicles Integration
2016	S.S. Reka, V. Ramesh	Consumer participation, AI Support, Demand Response, Load Shifting, Smart Metering	A demand response modeling for residential consumers in smart grid environment using game theory based energy scheduling algorithm
2016	P. Zancanella, P. Bertoldi, K. Benigna	Demand Response, Customer Participation, Aggregator Support, Data Management Support, Political Support, Distributed Energy Transition, Regulatory Framework, Integration of Renewables	Demand Response status in EU Member States
2016	I. Çolak, S. Sağıroğlu, G. Fulli, M. Yeşilbudak, C.F. Covrig	Communication Support, Electric Storage, Data Management Support, Smart Metering, Return of Investment Duration, Demand Side Management	A survey on the critical issues in smart grid technologies
2016	C. Eid, P. Codani, Y. Perez, J. Renesesi, R. Hakvoort	Distributed Energy Transition, Demand Side Management, Demand Response, Smart Metering, Electrical Vehicle Integration, Electric Storage, Aggregator Support, Dynamic Pricing	Managing electric flexibility from Distributed EnergyResources: A review of incentives for market design

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2016	M.S. Hossain, N.A. Madlool, N.A. Rahim, J. Selvaraj, A.K. Pandey	Integration of Renewable Sources	Role of smart grid in renewable energy: An overview
2016	D.Javor, A. Janjic	Demand Side Management, Customer Participation	Application of Demand Side Management Techniques in Successive Optimization Procedures
2017	S. Alam, M.F. Sohail, S.A. Ghauri, I.M. Qureshi, N. Aqdas	Communication Support	Cognitive radio based Smart Grid Communication Network
2017	N. Boogen, S. Datta, M. Filippini	Demand Side Management	Demand-side management by electric utilities in Switzerland: Analyzing its impact on residential electricity demand
2017	S. Burger, J.P. Chaves-Avila, C. Batlle, I.J. Perez-Arriaga	Aggregator Support, Distributed Energy Transition, Demand Response, Regulatory Framework, Political Support, Communication Support, Electrical Vehicle Integration, Electric Storage, Consumer Participation, Smart Metering	A review of the value of aggregators in electricity systems
2017	A.M. Carreiro, H.M. Jorge, C.H. Antunes	Aggregator Support, Consumer Participation, Dynamic Pricing, Demand Response, Integration of Renewables, Distributed Energy Transition, Smart Appliances Usage, Communication Support, Internet of Things Support	Energy management systems aggregators: A literature survey
2017	H. Daki, A.E. Hannani, A. Aqqal, A. Dahbi	Data Management Support	Big Data management in smart grid: concepts, requirements, and implementation

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2017	R. Smale, B. Vliet, G. Spaargaren	Smart Appliances Usage, Energy Storage Capacities, Renewable Sources Integration, Smart Meters Installation	When social practices meet smart grids: Flexibility, grid management and domestic consumption in The Netherlands
2017	B. AL- Madani, H. Ali	Data Management, Communication Support	Data Distribution Service (DDS) based implementation of Smart grid devices using ANSI C12.19 standard
2017	H. Lund, P.A. Ostergaard, D. Connoly & B.V. Mathiesen	Renewable Sources Integration	Smart energy and smart energy systems
2017	J. Naus	Consumer Participation, Smart Metering, Internet of Things Support	The Social Dynamics of Smart Grids: on Households, Information flows & Sustainable energy transitions
2017	C. Li	Distributed Energy Transition, Cybersecurity, Communication Support, Smart Metering, Dynamic Pricing, Demand Side Management	Distributed Optimisation of Energy Management in Smart Grids
2017	P. Alstone, J. Potter, M.A. Piette, M.A. Berger, L.N. Dunn	Smart Meter Installation, Regulatory Framework, Incentives, Renewable Sources Integration, Political Support, Consumer Participation, Distributed Energy Transition, Remote Controlling, Internet of Things Support	2025 California Demand Response Potential Study – Charting California's Demand Response Future: Final Report on Phase 2 Results
2018	C. Brandauer, F. P. Andren, T.I. Strasser, J.G. Resch, B. Schuiki	Distributed Energy Transition, Communication Support, Cybersecurity, Demand Response	On Fostering Smart Grid Systems Development and Validation with a Model-Based Engineering and Support Framework

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2018	R. Kappagantu, S.A. Daniel	Political Support, Regulatory Framework, Consumer Participation, Renewables Integration, Electric Storage, Data Management Support, Communication Support, Smart Metering, Dynamic Pricing, Electrical Vehicle Integration, Internet of Things Support	Challenges and issues of smart grid implementation: A case of Indian scenario
2018	I. Lampropoulos, M.Broek, E. Hoofd, K. Hommes, W. Sark	Aggregator Support, Demand Side Management, Integration of Renewables, Regulatory Framework, Consumer Participation	A system perspective to the deployment of flexibility through aggregator companies in the Netherlands
2018	A.O. Otuoze, M.W. Mustafa, R.M. Larik	Cybersecurity, Data Manegement, Artifical Intelligence Support	Smart grids security challenges: Classification by sources of threats
2018	T.M. Skjølsvold, W. Throndsen, M. Ryghaug, I.F. Fjellså, G.H. Koksvik	Distributed Energy Transition, Renewable Sources Integration, Political Support, Regulatory Framework, Consumer Participation, Distributed Energy Transition	Orchestrating households as collectives of participation in the distributed energy transition: New empirical and conceptual insights
2018	L. Söder, P.D. Lund, H. Koduvere, T.F. Bolkesjø, G.H. Rossebø, E. Rosenlund-Soysal, K. Skytte, J. Katz, D. Blumberga	Demand Side Management, Integration of Renewables	Review of demand side flexibility potential in Northern Europe
2018	X. Yan, Y. Ozturk, Z. Hu, Y. Song	Demand Response, Dynamic Pricing, Integration of Renewables, Smart Metering, Data Management Support, Incentives, Consumer Participation, Political Support	A review on price-driven residential demand response

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2018	L.A. Arias, E. Rivas, F. Santamaria, V. Hernandez	Dynamic Pricing, Smart Meter Installation, Smart Appliances Usage, Distributed Energy Transition, Renewable Sources Integration	A Review and Analysis of Trends Related to Demand Response
2018	A. Shahid	Integration of Renewables, Communication Support, Distributed Energy Transition	Smart Grid Integration of Renewable Energy Systems
2018	Z. Soufiane, E. Abdeslam, B. Slimane	Communication Support, Smart Metering, Distributed Energy Resourses, Demand Response, Smart Appliance Usage, Electrical Vehicle Inregration, Regulatory Framework, Interoperability	New Communication Architecture Model for Smart Grid
2018	BEUC The European Consumer Organisation	Aggregator Support, Demand Response, Integration of Renewables, Demand Side Management, Consumer Participation, Regulatory Framework, Smart Metering, Electrical Vehicle Integration	Electricity Aggregators: Starting off on the Right Foot with Consumers
2019	Y. Wang, L. Liu, R. Wennersten, Q. Sun	Integration of Renewables, Demand Response	Peak Shaving and Valley Filling potential of Energy Management System in High Rise Residential Building
2019	J.R. Vazquez-Cantel, Z. Nagy	Renewable Sources Integration, Electrical Vehicle Integration, AI Support, Dynamic Pricing	Reinforcement learning for demand response: A review of algorithms and modeling techniques
2019	D. Baldissin, G. Himeno, H. Kagan, G. Travassos, R. Padilha, M. Pelegrini, D. Duarte	Communication Support, Distributed Energy Transition, Cost Savings, Integration of Renewables	A Combined Planning and Simulation Approach for Smart Grid Reliability Analysis

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2019	G. Dileep	Smart Metering, Communication Support, Data Management Support, Electrical Vehicle Integration, Distributed Energy Transition, Demand Response, Regulatory Framework, Customer Participation, Aggregator Support	A survey on smart grid technologies and applications
2019	ELDER	Distributed Energy Integration, Communication Support, Smart Metering, Electrical Vehicle Integration, Data Management Support, Integration of Renewables, Electric Storage, Regulatory Framework, Organizational Change, Institunal Change, Incentives, AI Support, Interoperability, Internet of Things Support	Türkiye Smart Grid 2023 Vision and Strategy Roadmap Summary Report
2019	T. Serrenho, P. Bertoldi, European Commission	Smart Appliances Usage, Communication Support, Smart Metering, Demand Response, Regulatory Framework, Internet of Things Support	Smart home and appliances: State of the art
2019	F. Fumiatti, V. Giordano, P. Mandatova, European Commission	Aggregator Support, Data Management Support, Electrical Vehicle Integration, Customer Participation, Smart Metering, Integration of Renewables, Regulatory Framework, Data Management Support, Dynamic Pricing, Inter of Things Support, AI Support	Assessment and roadmap for the digital transformation of the energy sector towards an innovative internal energy market
2019	C. Alaton, F. Tounquet, European Commission	Interoperability, Smart Meter Installation, Renewable Sources Integration	Benchmarking smart metering deployment in the EU-28
2019	L. Daniele, W. Strabbing, B. Roelofsen, A. Aalberts,	Interoperability, Demand Response, Consumer Participation, Smart Metering, Smart Appliaces Usage, Communication Support, Integration of Renewables, Electric Storage, Remote Controlling	Study on ensuring interoperability for enabling Demand Side Flexibility

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2019	K. Kimani, V. Oduol, K. Langat	Internet of Things Support, Cybersecurity, Interoperability, Communication Support, Self Healing, Smart Metering, Smart Appliances Usage	Cyber security challenges for IoT-based smart grid networks
2019	Z. Ma, L. Friedrichsen, M. Thomsen, B.N. Jorgensen	Demand Response, Consumer Participation, Aggregator Support	Universities' Implicit Demand Response Participation
2019	R.S. Martín-Loeches, F. Iov, D.V. Pombo, M.S. Kemal, R.L. Olsen	Smart Metering, Integration of Renewables, Communication Support, Data Management Support	Enabling Smart Grid Fetaures by Enhanced Utilization of Actual Advanced Metering Infrastructure
2019	A. Ortner, G. Totschnig	Renewable Integration, Distributed Energy Transition	The future relevance of electricity balancing markets in Europe - A 2030 case study
2019	J. Sakhnini, H. Karimipour, A. Dehghantanha, R. Parizi, G. Srivastava	Internet of Things Support, Cyberseucrity, Smart Metering, Communication Support, Artificial Intelligence Support	Security aspects of Internet of Things aided smart grids: A bibliometric survey
2019	Z. Wang, J. Wang	Communication Support, Regulatory Framework, Electrical Vehicle Integration, Distributed Energy Resources Integration	A delay-adaptive control scheme for enhancing smart grid stability and resilience
2020	O.M. Babatunde, J.L. Munda, Y. Hamam	Integration of Renewables, Electric Storage, Electrical Vehicle Intagration	Power system flexibility: A review
2020	L. Das, S. Munikoti, B. Natarajan, B. Srinivasan	Renewable Sources Integration, Dynamic Pricing, Self Healing of the grid	Measuring smart grid resilience: Methods, challenges and opportunities
2020	M.Z. Gunduz, R. Das	Internet of Things Support, Cybersecurity, Interoperability, Communication Support, Distributed Energy Transition, Political Support, Incentives	Cyber-security on smart grid: Threats and potential solutions

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2020	S. Impram, S.V. Neşe, B. Oral	Integration of Renewables, Demand Side Management	Challenges of renewable energy penetration on power system flexibility: A survey
2020	O. M. Butt, M. Zulqarnain, T.M. Butt	Reliability, Security, Communication Support, Self Healing, Consumer Participation, Internet of Things Support, Electrical Vehicle Integration, Data Management Support, Cloud Computing Support	Recent advancement in smart grid technology: Future prospects in the electrical power network
2020	A. Immonen, J. Kiljandera, M. Aro	Consumer Participation, Internet of Things Support, Renewable Sources Integration	Consumer viewpoint on a new kind of energy market
2020	M. Obi, T. Slay, R. Bass	Distributed Energy Transition, Aggregator Support, Regulatory Framework, Communication Support, Integration of Renewables, Electric Storage, Demand Side Management	Distributed energy resource aggregation using customer-owned equipment: A review of literature and standards
2020	G. Schweiger, L.V. Eckerstorfer, I. Haffner, A. Fleischhacker, J. Radl, B. Glock, M. Wastian, M. Rößler, G. Lettner, N. Popper, K. Corcoran	Consumer Participation, Aggregator Support, Electrical Vehicle Integration, Data Management Support	Active consumer participation in smart energy systems
2020	D. Azuatalam, W. Lee, F. Jijs, A. Liebman	Renewable Sources Integration, AI support	Reinforcement learning for whole-building HVAC control and demand
2020	S.M. Sirin, B.N. Yilmaz	Distributed Energy Transition, Renewable Sources Integration, Electrical Vehicle Integration,	Variable renewable energy technologies in the Turkish electricity market: Quantile regression analysis of the merit-order effect
2020	J. Stede, K. Arnold, C. Dufter, G. Holtz, S. Roon, J. Richstein	Aggregator Support, Demand Response, Integration of Renewables, Demand Response, Demand Side Management, Consumer Participation	The role of aggregators in facilitating industrial demand response: Evidence from Germany

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2020	S.J. Darby	Customer Participation, Renewable Sources Integration, Demand Response, Load Shifting, Aggregation, Dynamic Pricing, Communication Support	Demand response and smart technology in theory and practice: Customer experiences and system actors
2020	Y. Wang, A.O. Rousis, G. Strbac	Data Management Support, Remote Controlling	On microgrids and resilience: A comprehensive review on modeling and operational strategies
2021	M.Z. Degefa, I.B. Sperstad, H. Saale	Demand Response, Distributed Energy Transition, Integration of Renewables	Comprehensive classifications and characterizations of power system flexibility resources
2021	O.S. Neffati, S. Sengan, K.D. Thangavelu, S.D. Kumar, R. Setiawan, M. Elangovan, D. Mani, P. Velayutham	Renewable Sources Integration, Infrastructure, Cyber Security, Privacy, Community Education, Smart Meters Installation	Migrating from traditional grid to smart grid in smart cities promoted in developing country
2021	F. Rohde, S. Hielscher	Institutional Change, Organizational Change	Smart grids and institutional change: Emerging contestations between organisations over smart energy transitions
2021	L. Saarinen, K. Tokimatsu	Integration of Renewables, Demand Side Management, Electric Storage, Data Management Support, Regulatory Framework	Flexibility metrics for analysis of power system transition - A case study of Japan and Sweden
2021	D.Sadhukhan, S. Ray, M.S. Obaidat, M. Dasgupta	Communication Support, Cyber Security	A secure and privacy preserving lightweight authentication scheme for smart-grid communication using elliptic curve cryptography
2021	Y. Ding, M. Mao, L.Chang	Electricity Reliability	Conservative power theory and its applications in modern smart grid: Review and prospect

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2021	S. Saxena, H.E.Z. Farag, N. El-Taweel	Communication Support, Internet of Things Support	A distributed communication framework for smart Grid control applications based on data distribution service
2021	D. Fan, Y. Ren, Q. Feng, Y. Liu, Z. Wang, J. Lin	Communication Support, Reliability	Restoration of smart grids: Current status, challenges and opportunities
2021	T. Chen, X. Yin, G. Wang	Communication Support, Security, Privacy Support	Securing communications between smart grids and real users providing a methodology based on user authentication
2021	I.F. Fjellså, A. Silvast, T.M. Skjølsvold	Smart Meters Installation, Smart Appliances Usage, Dynamic Pricing, Consumer Participation	Justice aspects of flexible household electricity consumption in future smart energy systems
2021	M. Kubli, P. Canzi	Aggregator Support, Incentives, Distributed Energy Transition, Renewable Sources Integration, Load Shifting, Regulatory Framework, Consumer Participation	Business strategies for flexibility aggregators to steer clear of being “too small to bid
2021	M.Korsnes, W. Throndsen	Consumer Participation, Aggregator Support, Climate Change Risk	Smart energy prosumers in Norway: Critical reflections on implications for participation and everyday life
2021	O. Okur, P. Heijnen, Z. Lukszo	Electric Storage, Renewables Integration, Distributed Energy Transition, Demand Response, Aggregator Support, Customer Participation Interoperability, Dynamic Pricing, Regulatory Framework, Electrical Vehicle Integration, Internet of Things Support	Aggregator’s business models in residential and service sectors: A review of operational and financial aspects

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2021	British Standards Institution	Smart Meter Installation, Consumer Participation, Remote Controlling, Internet of Things Support, Regulatory Framework, Smart Appliances Usage, Interoperability	British Standards Institution PAS-1878
2021	British Standards Institution	Consumer Participation, Remote Controlling, Regulatory Framework, Smart Appliances Usage, Interoperability	British Standards Institution PAS-1879
2021	M. Papadimitrakis, N. Giamarelos, M. Stogiannos, E.N. Zois, N.A. Livanos, A. Alexandridis	Data Management Support, Demand Side Management, Electric Storage	Metaheuristic search in smart grid: A review with emphasis on planning, Scheduling and power flow optimization applications
2021	M.Rana, M.F. Romlie, M.F. Abdullah, M. Uddin, R. Sarkar	Load Shifting, Load Shaving, Data Management Support, Cost Savings, Electrical Vehicle Integration	A novel peak load shaving algorithm for isolated microgrid
2021	T. Schittekatte, V. Deschamps, L. Meeus	Regulatory Framework, Demand Response, Aggregator Support	The regulatory framework for independent aggregators
2021	S. Sharda, M. Singh, K. Sharma	Load Shifting, Demand Response, Demand Side Management, Smart Appaliances Usage, Smart Metering, Cost Saving, Remote Controlling, Integration of Renewables, Load Profiles, Consumer Participation	Demand side management through load shifting in IoT based HEMS: Overview, challenges and opportunities
2022	E. Azizi, R. Ahmadiahangar, A. Rosin, S. Bolouki	Remote Controlling, Data Management, Elecrical Vehicle Integration, Smart Appliances Usage, Demand Response, Aggregator Support, Electric Storage	Characterizing energy flexibility of buildings with electric vehicles and shiftable appliances on single building level and aggregated level
2022	T. Freire-Barcelo, F. Martín-Martínez, A. Sanchez-Miralles	Aggregator Support, Demand Response, Distributed Energy Transition, Integration of Renewables, Interoperability	A literature review of Explicit Demand Flexibility providing energy services

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2022	M.A. Judge, A. Khan, A. Manzoor, H.A. Khattak	Demand Response, Integration of Renewables, Distributed Energy Transtion, Load Shifting, Smart Metering	Overview of smart grid implementation: Frameworks, impact, performance and challenges
2022	S. Kerscher, P. Arboleya	Aggregator Support, Regulatory Framework, Distributed Energy Transition, Integration of Renewables, Electrical Vehicle Integration, Demand Response, Communication Support, Data Management Support, Consumer Participation, Privacy	The key role of aggregators in the energy transition under the latest European regulatory framework
2022	S. Mohanty, S. Panda, S. Parida, P.R. Rout, B.K. Sahu, M. Bajaj, H.M. Zawbaa, N.M. Kumar, S. Kamel	Electrical Vehicle Integration, Demand Response, Demand Side Management, Consumer Participation, Dynamic Pricing, Smart Metering, Communication Support	Demand side management of electric vehicles in smart grids: A survey on strategies, challenges, modeling and optimization
2022	S.B. Slama	Artifical Intelligence Support, Cloud Computing Support	Prosumer in smart grids based on intelligent edge computing: A review on Artificial Intelligence Scheduling Techniques
2022	Akkad, Wills & Rezazadeh	Internt of Things Support, Cybersecurity, Data Management Support	An information security model for an IoT-enabled Smart Grid in the Saudi energy sector
2022	R. Feng, Y. Xue, W. Wang, M. Xiao	Load Management, Political Support, Data Management	Saturated load forecasting based on clustering and logistic iterative regression
2022	S. Panda, S. Mohanty, P.K. Rout, B.K. Sahu, M.B. Bajaj, H.M. Zawbaa, S. Kamel	Demand Response, Integration of Renewables, Distributed Energy Transtion, Load Shifting, Communication Support, Electric Storage, Internet of Things Support, Smart Metering	Residential Demand Side Management model, optimization and future perspective: A review

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2022	F. Plaum, R. Ahmadiahangar, A. Rosin, J. Kilter	Aggregator Support, Integration of Renewables, Smart Appliances Usage, Demand Response, Electric Storage, Electrical Vehicle Integration, Distributed Energy Transition	Aggregated demand-side energy flexibility: A comprehensive review on characterization, forecasting and market prospects
2022	D.K. Sharma, G.K. Rapaka, A.P. Pasupulla, S. Jaiswal, K. Abadar, H. Kaur,	Communication Support, Smart Metering, Data Management	A review on smart grid telecommunication system
2022	J. Stekli, L. Bai, U. Cali, U. Halden, M.F., Dynge	Distributed Energy Transition, Aggregator Support, Communication Support	Distributed energy resource participation in electricity markets: A review of approaches, modeling and enabling information and communication technologies
2022	UK Department for Business, Energy & Industrial Strategy	Electric Storage, Demand Response, Internet of Things Support, Regulatory Framework, Electric Vhicle Integration, Cybersecurity, Demand Side Response, Instituonal Change, Organizational Change, Dynamic Response	Delivering a smart and secure electricity system
2023	S. Akkara, I. Selvakumar	Cost Savings, Demand Side Management, Smart Metering, Communication Support	Review on optimization techniques used for smart grid
2023	M.A. Alomar	Internet of Things Support, Communication Support, Data Management Support, Artificial Intelligence Support, Self Healing of the Grid, Remote Controlling, Electrical Vehicle Integration, Cybersecurity, Smart Metering	An IOT based smart grid system for advanced cooperative transmission and communication
2023	Y. Chang, J.Li, W. Li	Data Management Support, Cybersecurity, AI Support, Data Privacy	2D2PS: A demand-driven privacy-preserving scheme for anonymous data sharing in smart grids

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2023	T. Chen, C. Liu	Security, Communication Support, Data Management Support, AI Support	Soft computing based smart grid fault detection using computerised data analysis with fuzzy machine learning model
2023	S. Jebri, A.B. Amor, S. Zidi	Smart Metering, Privacy, Cybersecurity, Cost Savings, Internet of Things Support	Reliable low-cost data transmission in smart grid system
2023	M. Rana, M. Uddin, R. Sarkar S.T. Meraj, G.M. Shafiullah, S.M. Muyeen, A. Islam, T. Jamal	Electric Storage, Renewables Integration, Distributed Energy Transition	Applications of energy storage systems in power grids with and without renewable energy integration
2023	K. Abdulsalam, J. Adebisi, M. Emezirinwune, O. Babatunde	Cybersecurity, Regulatory Framework, Electric Storage, Power Systems, Communication Technologies	An overview and multicriteria analysis of communication technologies for smart grid applications
2023	M. Fotopoulou, D. Rakopoulos, S. Petridis, P. Drosatos	Artificial Intelligence Support, Integration of Renewables, Interoperability	Assessment of smart grid operation under emergency situations
2023	J.P. Leon, C.L.D. Santos, A.M. Mezher, J.C. Barrera, J. Meng, E.C. Guerra	Communication Support, Smart Metering	Exploring the potential, limitations and future directions of wireless technologies in smart grid networks: A comparative analysis
2023	O. Qays, I. Ahmad, A. Abu-Siada, L. Hossain, F. Yasmin	Cybersecurity, Interoperability, Internet of Things Support, Communication Support	Key communication technologies, applications, protocols and future guides for IoT-assisted smart grid systems: A review

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2023	Z. Ullah, A.U. Rehman, S. Wang, H.M. Hassanien, P. Luo, M.R. Elkadeem &M.A. Abido	Renewables Integration, Electric Vehicles, Artifical Intelligence, Load Management, Data Management, IOT applications	IoT-based monitoring and control of substations and smart grids with renewables and electric vehicles integration
2023	L. Zhu, F. Jiang, M.Luo, Q. Li	Cybersecurity, Data Management, Data Security, Communication Support, Dynamic Pricing, Load Management, Smart Metering, Smart Appliances	An efficient identity-based signature protocol over lattices for the smart grid
2023	T. Kataray, B. Nitesh, B. Yarram, S. Sinha, E. Cuce, S. Shaik, P. Vigneshwaran, A. Roy	Renewable Integration, Electricity Storage, Demand Side Management, Communication Support, Security, Regulatory Framework, Reliability, Self Healing, Load Shifting, Smart Metering, Cybersecurity, Cost Savings	Integration of smart grid with renewable energy sources: Opportunities and challenges A comprehensive review
2023	H. Lin, W. Wang, Y. Zou, H. Chen	Artifical Intelligence Support, Electrical Vehicle Integration, Data Management, Demand Management, Electric Storage, Distributed Energy Transition	An evaluation model for smart grids in support of smart cities based on the Hierarchy of Needs Theory
2023	K. Liu, C. Wang, X. Zhou	Data Management, Cybersecurity, Smart Metering, Privacy	Decentralizing access control system for data sharing in smart grid
2023	A. Zahoor, K. Mahmood, S. Shamshad, M.A. Saleem, M.F. Ayub, M. Conti, A.K. Das	Internet of Things Support, Cybersecurit, Smart Metering	An access control scheme in IoT-enabled Smart-Grid systems using blockchain and PUF
2023	H.M.S. Badar, K. Mahmood, W. Akram, Z. Ghaffar, M. Umar, A.K. Das	IOT Support, Cybersecurity	Secure authentication protocol for home area network in smart grid-based smart cities

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2023	F. Norouzi, T. Hoppe, L.M. Kamp, C. Manktelow, P. Bauer	Renewables Integration, Distributed Energy Resources, Cybersecurity, Electric Storage, Electrical Vehicles, Smart Metering, Demand Side Management, Political Support, Customer Participation	Diagnosis of the implementation of smart grid innovation in The Netherlands and corrective actions
2023	K.A. Khan, M. Quamar, F. H. Al-Qahtani,	Integration of Renewables, Communication Support, Smart Metering, Data Management Support	Smart grid infrastructure and renewable energy deployment: A conceptual review of Saudi Arabia
2024	M. Aurangzeb, Y. Wang, S. Iqbal, A. Naveed, M. Ahmed, M. Alenezi	Cybersecurity, Privacy	Enhancing cybersecurity in smart grids: Deep black box adversarial attacks and quantum voting ensemble models for blockchain privacy-preserving storage
2024	C.P. Ohanu, S.A. Rufai, U.C. Oluchi	Renewables Integration, Distributed Energy Resources, Electrical Vehicle Integration, Smart Metering, Electric Storage	A comprehensive review of recent developments in smart grid through renewable energy resources integration
2024	H. Zheng	Renewables Integration, Distributed Energy Resources, IoT Support, Data Management Support, Political Support	Research on low-carbon development path of new energy industry under the background of smart grid
2024	M.Khalid	Renewables Integration, Electric Storage, IoT support	Smart grids and renewable energy systems: Perspectives and grid integration challenges
2024	Y. Duan, Y. Zhang	Security, Smart Metering, Data Management, Integration of Renewables, Distributed Energy Transition, AI support	Enhancing smart grid security: A novel approach for efficient attack detection using SMART framework

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2024	V.Bolgouras, T. Ioannidis, I. Politis, A. Zarras, C. Xenakis	Security, Smart Metering, IoT support, Electric Storage, Distributed Energy Transition, Integration of Renewables, Dynamic Pricing	RETINA: Distributed and secure trust management for smart grid applications and energy trading
2024	M.A. Mochinski, M Biczkowsk, I.J. Chueiri, E. Jamhour	Communication Support	Developing an Intelligent Decision Support System for large-scale smart grid communication network planning
2024	Z. Yang	Integration of Renewables, Artificial Intelligence Support, Cyber Security, Internet of Things Support	Renewable energy management in smart grid with cloud security analysis using multi agent machine learning model
2024	S. Mitra, B. Chakraborty, P. Mitra	Smart Metering, Integration of Renewables, Data Management Support, Security, Dynamic Pricing, Consumer Participation, Internet of Things Support	Smart meter data analytics applications for secure, reliable and robust grid system: Survey and future directions
2024	M.H. Alsharif, A. Jahid, R. Kannadasan, M. Kim	Communuciation Support, Data Management, Security, Distributed Energy Transition, Integration of Renewables, Electric Storage, Consumer Participation, Internet of Things Support, Artificial Intelligence Support	Unleashing the potential of sixth generation (6G) wireless networks in smart energy grid management: A comprehensive review
2024	S. Balavignesh, C. Kumar, R. Sripriya, T. Senjyu	Data Management, Internet of Things Support, Dynamic Pricing, Smart Metering	An enhanced optimization algorithm for optimizing energy management in smart grids for home appliances
2024	Z. Allal, H.N. Noura, O. Salman, K. Chahine	Artificial Intelligence Support, Integration of Renewables, Internet of Things Support, Distributed Energy Transition, Communication Support, Electric Storage, Data Management Support	Leveraging the power of machine learning and data balancing techniques to evaluate stability in smart grids

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2024	J. Powell, A. McCafferty-Leroux, W. Hilal, S. A. Gadsden	Cybersecurity, Integration of Renewables, Internet of Things Support, Electric Storage, Artificial Intelligence Support, Interoperability	Smart grids: A comprehensive survey of challenges, industry applications and future trends
2024	D. Lee, Y. Chiang, Y. Chen, H. Tsai	Electric Storage	Impacts of battery energy storage system on power grid smartness: Case study of Taiwan Power Company
2024	M. Mussi, L. Pellegrin, O.F. Pindaro, M. Restelli, F. Trovò	Artificial Intelligence Support, Customer Participation	A Reinforcement Learning controller optimizing costs and battery State of Health in smart grids
2024	A. Bagheri	Electric Storage, Integration of Renewables	Energy storage system coordinated with phase-shifting transformer and dynamic rating equipment for optimal operation of wind-rich smart power networks
2024	B. Wang, S. Evergreen, J. Forest	Integration of Renewables	Game Theory in Smart Grids: Strategic decision-making for renewable energy integration
2024	A. Baz, J. Logeshwaran, Y. Natarajan, S. K. Patel	Artificial Intelligence Support, Smart Metering, Internet of Things Support	Deep fuzzy nets approach for energy efficiency optimization in smart grids
2024	C. N. Priyanka, N. Ramachandran	Cybersecurity	An Efficient Neighbor Nodes Trust Tagging Model for Optimized Route Detection in Smart Grids with Secure Data Transmission
2024	S.M.S. Mohammadabadi, M. Entezami, A K. Moghaddam, M. Orangian, S. Nejadshamsi	Artificial Intelligence Support, Communication Support	Generative Artificial Intelligence for Distributed Learning to Enhance Smart Grid Communication

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2024	Z. Liao, J. Kally, S. Ru,	Integration of Renewables, Artificial Intelligence Support	Probabilistic modeling of renewable energy sources in smart grids: A stochastic optimization perspective
2024	Z. Zhao, N. Holland, J. Nelson	Integration of Renewables	Optimizing smart grid performance: A stochastic approach to renewable energy integration
2024	N. Rodriguez-Perez, J. Matanza, G. Lopez, R. Cossent, J. Pablo	Integration of Renewables, Smart Metering, Distributed Energy Transition, Remote Controlling	Measuring the digitalisation of electricity distribution systems in Europe: Towards the smart grid
2024	O. Munoz, A. Ruelas, P. F. Rosales-Escobedo	Artificial Intelligence Support, Smart Metering, Internet of Things Support	Development of an IoT smart energy meter with power quality features for a smart grid architecture
2024	H. Taherdoost	Data Management Support, Artificial Intelligence Support	A systematic review of big data innovations in smart grids
2024	Q. Hassan, C. Hsu, K. Mounich, S. Algburi, M. Jaszczur, A.A. Telba	Integration of Renewables, Smart Metering, Distributed Energy Transition	Enhancing smart grid integrated renewable distributed generation capacities: Implications for sustainable energy transformation
2024	L. Nazir, A. Sharifi	Integration of Renewables, Political Support, Regulatory Framework	An analysis of barriers to the implementation of smart grid technology in Pakistan
2024	A.R. Al-Ali, R. Gupta, I. Zualkernan, S.K. Das,	Internet of Things Support, Data Management Support, Communication Support, Smart Metering, Electrical Vehicle Integration	Role of IoT technologies in big data management systems: A review and Smart Grid case study
2024	P. Boopathy, M. Liyanage, N. Deepa, M. Velavali, S. Reddy	Artificial Intelligence Support, Data Management Support, Internet of Things Support	Deep learning for intelligent demand response and smart grids: A comprehensive survey

Table 12: Independent Variables from Reviewed Studies (Continued)

Year	Author	Independent Variables from study	Reference Study Title
2024	Z. Wang, F. Zhang, A. Zhang, J. Chang	Data Management Support	LFTDA: A lightweight and fault-tolerant data aggregation scheme with privacy-enhanced property in fog-assisted smart grid
2024	J. Zhao, S. Zeng, P. Luo, B. Zhao, Z. Chen, X. Du, Z. Wang	Internet of Things Support, Communication Support, Cyber Security	A lightweight multi sensor concurrent identity authentication protocol for smart grids
2024	R. Yuan, S. A. Pourmousavi, W. L. Soong, A. J. Black	Data Management Support, Smart Metering	Unleashing the benefits of smart grids by overcoming the challenges associated with low-resolution data
2024	V. Verma, V. Sorathiya, G. Sonowal, M. S. Reddy	Integration of Renewables, Distributed Energy Transition, Electric Storage	Hybrid optimization for integration of renewable energy systems into smart grids
2024	M. Wadi, A. Shobole, W. Elmasry, I. Kucuk	Artificial Intelligence Support, Integration of Renewables, Electrical Vehicle Integration, Cyber Security	Load frequency control in smart grids: A review of recent developments

APPENDIX B: Delphi Analysis Results

Table 13: Round 1 Delphi Analysis Results for Subcomponents of the Dependent Variable

		1.ROUND								
	Subcomponents of Dependent Variable	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	**%ACCEPT without No idea**	**RESULT**
SYSTEMS QUALITY (5)	ADAPTABILITY	17	100%	0	0%	0	0%	17	**100%**	**CONSENSUS**
	AVAILABILITY	14	82%	2	12%	1	6%	16	**88%**	**CONSENSUS**
	RELIABILITY	15	88%	1	6%	1	6%	16	**94%**	**CONSENSUS**
	RESPONSE TIME	15	88%	1	6%	1	6%	16	**94%**	**CONSENSUS**
	USABILITY	12	71%	4	24%	1	6%	16	**75%**	**CONSENSUS**
SERVICE QUALITY (4)	ASSURANCE	16	94%	1	6%	0	0%	17	**94%**	**CONSENSUS**
	EMPHATY	12	71%	4	24%	1	6%	16	**75%**	**CONSENSUS**
	SELF HEALING OF THE GRID	12	71%	2	12%	3	18%	14	**86%**	**CONSENSUS**
	ELECTRICITY INTERRUPTION DURATION	14	82%	2	12%	1	6%	16	**88%**	**CONSENSUS**
INFORMATION QUALITY (5)	COMPLETENESS	13	76%	2	12%	2	12%	15	**87%**	**CONSENSUS**
	EASE OF UNDERSTANDING	12	71%	4	24%	1	6%	16	**75%**	**CONSENSUS**
	PERSONALIZATION	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
	RELEVANCE	12	71%	3	18%	2	12%	15	**80%**	**CONSENSUS**
	SECURITY	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
USE (4)	****NATURE OF USE**	10	59%	4	24%	3	18%	14	**71%**	****NON-CONSENSUS**
	LOAD PROFILE /LOAD PATTERN	14	82%	2	12%	1	6%	16	**88%**	**CONSENSUS**
	NUMBER OF LOAD SHIFTINGS	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
	SHIFTED ELECTRICITY USAGE IN KWH	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
USER SATISFACTION (3)	ACCEPTED OR DEMANDED LOAD SHIFTING REPEATS	15	88%	0	0%	2	12%	15	**100%**	**CONSENSUS**
	ACCEPTED OR DEMANDED REPEATS OF SHIFTED ELECTRICITY USAGE IN OFF-PEAK TIMES	15	88%	0	0%	2	12%	15	**100%**	**CONSENSUS**
	USER SURVEYS	12	71%	2	12%	3	18%	14	**86%**	**CONSENSUS**
NET BENEFITS (4)	COST SAVINGS	16	94%	1	6%	0	0%	17	**94%**	**CONSENSUS**
	EXPANDED DISTRIBUTION OF ENERGY RESOURCES	13	76%	4	24%	0	0%	17	**76%**	**CONSENSUS**
	INCREMENTAL ADDITIONAL ELECTRICITY SALES IN OFF PEAK TIMES.	14	82%	1	6%	2	12%	15	**93%**	**CONSENSUS**
	TIME SAVINGS	14	82%	0	0%	3	18%	14	**100%**	**CONSENSUS**

Table 14: Round 2 Delphi Analysis Results for Subcomponents of the Dependent Variable

		2.ROUND								
	Subcomponents of Dependent Variable	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	**%ACCEPT without No idea**	**RESULT**
SYSTEMS QUALITY (5)	ADAPTABILITY	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
	AVAILABILITY	14	88%	1	6%	1	6%	15	**93%**	**CONSENSUS**
	RELIABILITY	15	94%	1	6%	0	0%	16	**94%**	**CONSENSUS**
	RESPONSE TIME	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
	****USABILITY**	9	56%	5	31%	2	13%	14	**64%**	****NON-CONSENSUS**
SERVICE QUALITY (4)	ASSURANCE	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
	EMPHATY	14	88%	2	13%	0	0%	16	**88%**	**CONSENSUS**
	SELF HEALING OF THE GRID	10	63%	3	19%	3	19%	13	**77%**	**CONSENSUS**
	ELECTRICITY INTERRUPTION DURATION	14	88%	1	6%	1	6%	15	**93%**	**CONSENSUS**
INFORMATION QUALITY (5)	COMPLETENESS	11	69%	2	13%	3	19%	13	**85%**	**CONSENSUS**
	EASE OF UNDERSTANDING	13	81%	2	13%	1	6%	15	**87%**	**CONSENSUS**
	PERSONALIZATION	15	94%	1	6%	0	0%	16	**94%**	**CONSENSUS**
	RELEVANCE	12	75%	2	13%	2	13%	14	**86%**	**CONSENSUS**
	SECURITY	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
USE (4)	NATURE OF USE	12	75%	1	6%	3	19%	13	**92%**	**CONSENSUS**
	LOAD PROFILE /LOAD PATTERN	14	93%	1	7%	0	0%	15	**93%**	**CONSENSUS**
	NUMBER OF LOAD SHIFTINGS	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
	SHIFTED ELECTRICITY USAGE IN KWH	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
USER SATISFACTION (3)	ACCEPTED OR DEMANDED LOAD SHIFTING REPEATS	14	88%	0	0%	2	13%	14	**100%**	**CONSENSUS**
	ACCEPTED OR DEMANDED REPEATS OF SHIFTED ELECTRICITY USAGE IN OFF-PEAK TIMES	13	87%	0	0%	2	13%	13	**100%**	**CONSENSUS**
	****USER SURVEYS**	9	56%	4	25%	3	19%	13	**69%**	****NON-CONSENSUS**
NET BENEFITS (4)	COST SAVINGS	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
	EXPANDED DISTRIBUTION OF ENERGY RESOURCES	15	94%	1	6%	0	0%	16	**94%**	**CONSENSUS**
	INCREMENTAL ADDITIONAL ELECTRICITY SALES IN OFF PEAK TIMES.	13	81%	1	6%	2	13%	14	**93%**	**CONSENSUS**
	TIME SAVINGS	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**

Table 15: Round 1 Delphi Analysis Results for Independent Variables

Independent Variables	1.ROUND								
	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	%ACCEPT without No idea	RESULT
REMOTE CONTROLLING	16	94%	1	6%	0	0%	17	**94%**	**CONSENSUS**
SMART METERING	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
CONSUMER PARTICIPATION	15	88%	1	6%	1	6%	16	**94%**	**CONSENSUS**
INTEGRATION OF RENEWABLES	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
DATA MANAGEMENT SUPPORT	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
DISTRIBUTED ENERGY TRANSITION	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
RETURN OF INVESTMENT DURATION	11	65%	2	12%	4	24%	13	**85%**	**CONSENSUS**
ELECTRICAL VEHICLE INTEGRATION	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
SMART APPLIANCE USAGE	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
AGGREGATOR SUPPORT	12	71%	1	6%	4	24%	13	**92%**	**CONSENSUS**
REGULATORY FRAMEWORK	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
INCENTIVES	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
INTEROPERABILITY(IOP)	15	94%	0	0%	1	6%	15	**100%**	**CONSENSUS**
INSTITUTIONAL CHANGE	14	88%	0	0%	2	13%	14	**100%**	**CONSENSUS**
ORGANIZATIONAL CHANGE	13	76%	1	6%	3	18%	14	**93%**	**CONSENSUS**
DYNAMIC PRICING	14	82%	0	0%	2	12%	14	**100%**	**CONSENSUS**
COMMUNICATION SUPPORT	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
AI (ARTIFICIAL INTELLIGENCE) SUPPORT	14	82%	0	0%	3	18%	14	**100%**	**CONSENSUS**
IOT (INTERNET OF THINGS) SUPPORT	17	100 %	0	0%	0	0%	17	**100%**	**CONSENSUS**
POLITICAL SUPPORT	16	94%	0	0%	1	6%	16	**100%**	**CONSENSUS**
ELECTRIC STORAGE	15	88%	0	0%	2	12%	15	**100%**	**CONSENSUS**

Table 16: Round 2 Delphi Analysis Results for Independent Variables

Independent Variables	2.ROUND								
	#ACCEPT	%ACCEPT	#REJECT	%REJECT	#NO IDEA	%NO IDEA	#OPINION	%ACCEPT without No idea	RESULT
REMOTE CONTROLLING	15	100%	0	0%	0	0%	15	**100%**	**CONSENSUS**
SMART METERING	14	93%	0	0%	1	7%	14	**100%**	**CONSENSUS**
CONSUMER PARTICIPATION	15	94%	0	0%	1	6%	15	**100%**	**CONSENSUS**
INTEGRATION OF RENEWABLES	15	94%	1	6%	0	0%	16	**94%**	**CONSENSUS**
DATA MANAGEMENT SUPPORT	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
DISTRIBUTED ENERGY TRANSITION	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
RETURN OF INVESTMENT DURATION	8	50%	2	13%	6	38%	10	**80%**	**CONSENSUS**
ELECTRICAL VEHICLE INTEGRATION	15	94%	0	0%	1	6%	15	**100%**	**CONSENSUS**
SMART APPLIANCE USAGE	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
AGGREGATOR SUPPORT	12	75%	0	0%	4	25%	12	**100%**	**CONSENSUS**
REGULATORY FRAMEWORK	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
INCENTIVES	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
INTEROPERABILITY(IOP)	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
INSTITUTIONAL CHANGE	15	94%	0	0%	1	6%	15	**100%**	**CONSENSUS**
ORGANIZATIONAL CHANGE	11	69%	1	6%	4	25%	12	**92%**	**CONSENSUS**
DYNAMIC PRICING	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
COMMUNICATION SUPPORT	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
AI (ARTIFICIAL INTELLIGENCE) SUPPORT	14	88%	0	0%	2	13%	14	**100%**	**CONSENSUS**
IOT (INTERNET OF THINGS) SUPPORT	15	94%	0	0%	1	6%	15	**100%**	**CONSENSUS**
POLITICAL SUPPORT	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**
ELECTRIC STORAGE	16	100%	0	0%	0	0%	16	**100%**	**CONSENSUS**

APPENDIX C: Survey Questions

AKILLI ŞEBEKE (SMART GRID) ANKETİ

Türkiye'de elektrik üretiminde, iletiminde ve dağıtımında akıllı elektrik şebekesi dönüşümünü etkileyen parametreler

Orta Doğu Teknik Üniversitesi Enformatik Enstitüsü'nde Doç. Dr. Pelin Angın danışmanlığında Türkiye'de akıllı elektrik şebeke dönüşümünü etkileyen parametreler üzerine bir tez hazırlanmaktadır. Bu çalışmanın amacı Türkiye'de geleneksel elektrik şebekesinden akıllı elektrik şebekesine dönüşümdeki başarının etkenlerini analiz etmek ve bu etkenler arasındaki ilişkileri ortaya çıkarmaktır.

Bu anket yukarıda açıklanan konuda veri toplamak için tasarlanmıştır. Anketin tamamlanması için öngörülen süre 10-15 dakikadır. Elektrik şebekesi hakkında bilginiz var veya elektrik şebekesi ile ilgili bir kurumda çalıştıysanız/çalışıyorsanız bu anketi doldurabilirsiniz.Araştırmaya katılım tamamen gönüllülük esasına dayanmakta olup, sizden herhangi bir kişisel bilgi talep edilmeyecektir. Cevaplarınız tamamen gizli tutulacak ve yalnızca araştırmacı tarafından değerlendirilecektir. Araştırma sonuçları yalnızca bilimsel araştırmalar için kullanılacaktır. Katılım sırasında sorulardan veya başka bir sebepten dolayı kendinizi rahatsız hissederseniz, cevaplama sürecini sonlandırıp ayrılmakta özgürsünüz. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Katılımınız, Türkiye'de akıllı elektrik şebekesine dönüşümdeki başarının etkenlerinin analiz edilmesinde ve bu etkenler arasındaki ilişkilerin ortaya çıkarılmasında önemli katkı sağlayacaktır.

Yukarıdaki açıklama metnini okudum. Bu çalışmaya tamamen gönüllü olarak katılıyorum. Verdiğim bilgilerin bilimsel yayınlarda kullanılmasını kabul ediyorum. İstersem anketi doldurmayı istediğim zaman bırakabileceğimi biliyorum.

Onaylıyorum.

1) Akıllı Elektrik Şebekesi (Smart Grid) kavramı hakkında bilginiz var mı/daha önce bu konuyu duydunuz mu? (Akıllı Elektrik şebekesi kavramını duymadıysanız lütfen ankete devam etmeyiniz, anket sayfasını kapatınız)

- o Evet, Akıllı Elektrik Şebekesi (Smart Grid) kavramını duydum, konu ile bilgim var.
- o Hayır, Akıllı Elektrik Şebekesi (Smart Grid) hakkında hiçbir bilgim yok.

2) Elektrik sektörü ya da ilgili bir alanda mı çalışıyorsunuz veya daha önce çalıştınız mı?

- o Evet
- o Hayır

3) Elektrik sektörü ile ilgili çalıştığınız ya da çalışıyor olduğunuz alan

- o Elektrik Üretimi
- o Elektrik İletimi
- o Elektrik Dağıtımı
- o Elektrik Piyasası Düzenleme
- o Elektrik Piyasası İşletme
- o Üniversite/Akademi
- o Elektrik Şebeke Ekipman Üretimi
- o IoT (Internet of Things) Cihaz üretimi
- o Diğer:

4) Eğitim Düzeyiniz

- o Orta Öğretim
- o Lisans
- o Yüksek Lisans
- o Doktora

5) Toplam çalışma/tecrübe süreniz

- o 1 yıldan az
- o 1-5 yıl
- o 5-10 yıl
- o 10 -20 yıl
- o 20 yıldan fazla

Türkiye'de Akıllı Elektrik Şebekesi (Smart Grid) dönüşümünde yer alan aşağıdaki konuların önemini 1(Bir) ile 5(Beş) arasında puan vererek derecelendiriniz.

1–Kesinlikle Önemsiz 2- Önemsiz 3-Kısmen Önemli 4-Önemli 5-Kesinlikle Önemli

1) Adaptability (Akıllı şebeke sistemlerinin zaman içinde oluşacak farklı gereksinimleri karşılayabilmesi)

1	2	3	4	5

2) Availability (Akıllı şebeke dönüşümü ile birlikte sunulacak hizmetlerin sürekli ve kesintisiz olması)

1	2	3	4	5

3) Reliability (Akıllı şebeke dönüşümü ile birlikte sunulacak hizmetlerin geleneksel şebekelere göre daha güvenilir olması)

1	2	3	4	5

4) Response time (Akıllı şebekede arıza, fiyat değişikliği, kullanım miktarı gibi olaylara karşı tepki süresinin klasik şebekelere göre daha hızlı olması)

1	2	3	4	5

5) Assurance (Akıllı şebekenin klasik şebekeye göre daha fazla güven vermesi)

1	2	3	4	5

6) Empathy (Akıllı şebeke hizmetlerinin servis kalitesi için kullanıcı bakış açısıyla tasarlanması)

1	2	3	4	5

7) Self healing of the grid (Akıllı şebekenin arıza durumunda kendi kendini onarması /arızayı giderebilmesi)

1	2	3	4	5

8) Electricity interruption duration (Akıllı şebekelerde geleneksel şebekelere göre elektrik kesintilerinin çok daha az olması, hatta hiç olmaması)

1	2	3	4	5

9) Ease of understanding (Akıllı şebeke dönüşümü ile abonelere/kullanıcılara sunulacak verilerin/bilgilerin kolayca anlaşılır olması)

1	2	3	4	5

10) Personalization (Akıllı şebekenin abonelere/ tüketicilere verilen hizmeti kişiselleştirebilme (aboneye özel elektrik kullanım tarifesi vb..) imkanı sunması)

1	2	3	4	5

11) Relevance (Akıllı şebeke dönüşümü sonucu aboneye/kullanıcıya sağlanan bilgilerin kullanıcının talepleri ile ilgili olması)

1	2	3	4	5

12) Security (Akıllı elektrik şebekesinin siber güvenliği)

1	2	3	4	5

13) Nature of use (Akıllı şebeke dönüşümü ile getirilen imkanların birçok farklı alanda da kullanılabilmesi)

1	2	3	4	5

14) Load profile/load pattern (Akıllı şebeke dönüşümü ile birlikte her abonenin/kullanıcının elektrik kullanım profilinin/patterninin çıkarılması)

1	2	3	4	5

15) Number of load shiftings (Akıllı şebekenin, elektrik talebinin pik olduğu zamanlarda elektrik tüketiminin bir çok defa ötelenebilmesine imkan sağlaması)

1	2	3	4	5

16) Shifted electricity usage in Kwh (Akıllı şebekenin abonenin/kullanıcının öteleyerek kullandığı elektrik enerjisini (Kwh) ölçümleyebilmesi)

1	2	3	4	5

17) Accepted or demanded load shifting repeats (Abonenin kabul/talep ettiği ötelenmiş elektrik enerjisi kullanımının müşteri memnuniyetinde değerlendirilmesi)

1	2	3	4	5

18) Accepted or demanded repeats of shifted electricity usage in off-peak times (Akıllı şebekenin elektrik abonelerine/kullanıcılarına pik olmayan dönemde tükettikleri elektriğin hem maddi hem de çevresel faydasını/katkısını göstermesi)

1	2	3	4	5

19) Cost savings (Akıllı şebekenin elektrik üretim, işletim ve hizmet maliyetlerini düşürmesi)

1	2	3	4	5

20) Expanded distribution energy resources (Akıllı şebekenin dağıtık enerji kaynaklarının (güneş, rüzgar, vb.) yaygınlaşmasına imkan sağlaması)

1	2	3	4	5

21) Incremantal additonal electricity sales in off peak times (Akıllı şebekenin pik olmayan zamanlarda elektrik satışının artmasını sağlaması)

1	2	3	4	5

22) Time savings (Akıllı şebekenin elektrik şebekesinin işletilmesinde harcanan operasyonel süreleri azaltması)

1	2	3	4	5

Türkiye'de Akıllı Elektrik Şebekesi (Smart Grid) dönüşümündeki başarının yükselmesinde aşağıdaki maddelerin etkisini 1(Bir) ile 5(Beş) arasında puan vererek değerlendiriniz.

1–Etkisizdir 2- Çok Az Etkilidir 3-Kısmen Etkilidir 4-Etkilidir 5-Çok Etkilidir

1) Remote controlling (Uzaktan kontrol tekniklerinin kullanımı)

1	2	3	4	5

2) Smart metering (Akıllı Sayaçların kullanımı ve yaygınlaşması)

1	2	3	4	5

3) Consumer participation (Elektrik abonelerinin/tüketicilerinin talep tarafı yönetimine aktif katılımı)

1	2	3	4	5

4) Integration of renewables (Yenilenebilir enerji kaynaklarının (güneş, rüzgar vb.) elektrik şebekesine entegrasyonu)

1	2	3	4	5

5) Data management support (Veri yönetimi ve analizi mekanizmalarının kurulması)

1	2	3	4	5

6) Distributed energy transition infrastructure (Dağıtık enerjiye geçiş için gerekli alt yapının kurulması)

1	2	3	4	5

7) Electrical vehicle charging integration (Elektrikli araç şarj alt yapısınının akıllı şebekeye entegre edilmesi)

1	2	3	4	5

8) Smart appliance usage (Elektrik şebekesiyle konuşabilen akıllı ev cihazlarının kullanımı ve yaygınlaşması)

1	2	3	4	5

9)Aggregator support (Elektrik aboneleri/tüketicileri ile elektrik tedarikçileri arasında arabulucuk yapacak yapının kurulması)

1	2	3	4	5

10) Regulatory framework (Akıllı şebeke için gerekli mevzuatların ve yasaların oluşturulması)

1	2	3	4	5

11) Incentives (Finansal teşvik mekanizmalarının oluşturulması)

1	2	3	4	5

12) Interoperability (IOP) (Akıllı şebekenin diğer sistemlerle birlikte ve uyumlu çalışabilir olması)

1	2	3	4	5

13) Institutional change (Akıllı şebeke dönüşümü için sorumlu kurum yada enstitülerin kurulması)

1	2	3	4	5

14) Organizational change (Akıllı şebeke dönüşümü için mevcut yapılarda organizyonel değişikliklerin yapılması)

1	2	3	4	5

15) Dynamic pricing (Dinamik fiyatlandırma sisteminin kurulması)

1	2	3	4	5

16) Communication support (Hızlı, güvenilir ve çift taraflı iletişim alt yapıları)

1	2	3	4	5

17) AI (Artificial Intelligence) support (Akıllı şebeke uygulamalarında yapay zeka kullanımı)

1	2	3	4	5

18) IoT (Internet of Things) support (Akıllı şebeke alt yapısında kullanıcak cihaz ve ekipmanların IoT (internete bağlanabilen) cihazı olması)

1	2	3	4	5

19) Political support (Siyasi otoritenin desteği)

1	2	3	4	5

20) Electric storage (Dağıtık ve yenilenebilir kaynaklardan elde edilen elektrik enerjisinin depolanması)

1	2	3	4	5

Türkiye'de Akıllı Elektrik Şebekesi (Smart Grid) dönüşümünde aşağıdaki maddelerin tamamlanması için ne kadar süre gereklidir?

1) 1-3 yıl 2) 4-6 yıl 3) 7-10 yıl 4) 11-15 yıl 5) 15 yıldan fazla

1) Remote controlling (Uzaktan kontrol tekniklerinin kullanımı)

1	2	3	4	5

2) Smart metering (Akıllı sayaçların kullanımı ve yaygınlaşması)

1	2	3	4	5

3) Consumer participation (Elektrik abonelerinin/tüketicilerinin talep tarafı yönetimine aktif katılımı)

1	2	3	4	5

4) Integration of renewables (Yenilenebilir enerji kaynaklarının (güneş, rüzgar vb.) elektrik şebekesine entegrasyonu)

1	2	3	4	5

5) Data management support (Veri yönetimi ve analizi mekanizmalarının kurulması)

1	2	3	4	5

6) Distributed energy transition infrastructure (Dağıtık enerjiye geçiş için gerekli alt yapının kurulması)

1	2	3	4	5

7) Electrical vehicle charging integration (Elektrikli araç şarj alt yapısınının akıllı şebekeye entegre edilmesi)

1	2	3	4	5

8) Smart appliance usage (Elektrik şebekesiyle konuşabilen akıllı ev cihazlarının kullanımı ve yaygınlaşması)

1	2	3	4	5

9) Aggregator support (Elektrik aboneleri/tüketicileri ile elektrik tedarikçileri arasında arabulucuk yapacak yapının kurulması)

1	2	3	4	5

10) Regulatory framework (Akıllı şebeke için gerekli mevzuatların ve yasaların oluşturulması)

1	2	3	4	5

11) Incentives (Finansal teşvik mekanizmalarının oluşturulması)

1	2	3	4	5

12) Interoperability (IOP) (Akıllı şebekenin diğer sistemlerle birlikte ve uyumlu çalışabilir olması)

1	2	3	4	5

13) Institutional change (Akıllı şebeke dönüşümü için sorumlu kurum yada enstitülerin kurulması)

1	2	3	4	5

14) Organizational change (Akıllı şebeke dönüşümü için mevcut yapılarda organizyonel değişikliklerin yapılması)

1	2	3	4	5

15) Dynamic pricing (Dinamik fiyatlandırma sisteminin kurulması)

1	2	3	4	5

16) Communicaiton support (Hızlı, güvenilir ve çift taraflı iletişim alt yapıları)

1	2	3	4	5

17) AI (Artificial Intelligence) support (Akıllı şebeke uygulamalarında yapay zeka kullanımı)

1	2	3	4	5

18) IoT (Internet of Things) support (Akıllı şebeke alt yapısında kullanıcak cihaz ve ekipmanların IoT (internete bağlanabilen) cihazı olması)

1	2	3	4	5

19) Political support (Siyasi otoritenin desteği)

1	2	3	4	5

20) Electric storage (Dağıtık ve yenilenebilir kaynaklardan elde edilen elektrik enerjisinin depolanması)

1	2	3	4	5

Türkiye'de Akıllı Elektrik Şebekesi (Smart Grid) dönüşümünün başarılı olmasında aşağıdaki konular ne ağırlıkta önemlidir? 1 (Bir) ile 5 (Beş) arasında puan vererek değerlendiriniz.

1-Önemsiz 2-Az Önemli 3-Kısmen Önemli 4-Önemli 5-Çok Önemli

1) Akıllı şebeke dönüşümünün farklı gereksinimleri karşılayabilmesi, ulaşılabilir ve güvenilir olması, hızlı reaksiyon verebilmesi

1	2	3	4	5

2) Akıllı şebekenin güven vermesi, kullanıcı bakışıyla tasarlanması, kendi kendini onarması ve kesintilerin olmaması

1	2	3	4	5

3) Akıllı şebekenin sağladığı bilgilerin kolayca anlaşılması, kişiselleştirilebilmesi, talep edilen ilgili bilgileri sağlaması ve siber güvenli olması

1	2	3	4	5

4) Akıllı şebekenin sağladığı imkanların farklı alanlarda kullanılması, her abonenin elektrik tüketim profilini çıkarması, elektrik tüketiminde ötelenme imkanı vermesi ve ötelenen miktarı ölçümlemesi

1	2	3	4	5

5) Akıllı şebekenin ötelenerek kullanılan elektriğin maddi katkısını raporlaması

1	2	3	4	5

6) Akıllı şebekenin maliyetleri düşürmesi, zamandan kazanç sağlaması, yenilenebilir enerjinin yaygınlaşmasını ve pik olmayan zamanlarda elektrik satışının artmasını sağlaması

1	2	3	4	5

Eklemek istediğiniz görüş ve düşünceleriniz varsa bu bölüme yazabilirsiniz
…….

APPENDIX D: Demographic Properties of Each Data Group

Demographic Properties of Data Group-1

Data Group-1 is for 25 western provinces of Türkiye. 0.90% of the respondents in this group have a high school diploma, 72.07% of them have a bachelor's degree, 25.23% of them have a master's degree and 1.80% of them have a doctorate.

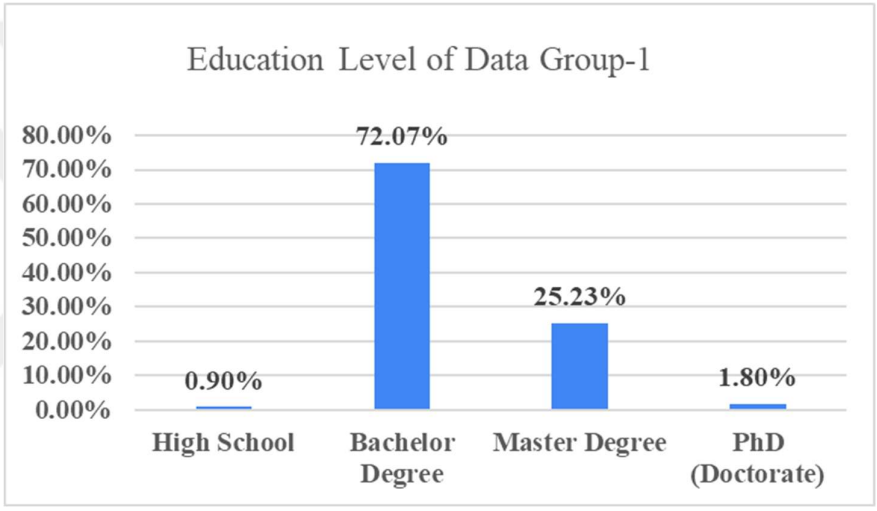


Figure 11: Education Level of Data Group-1

In Data Group-1, 4.50% of the respondents have less than 1 year of work experience in the electricity sector, 21.62 % of them have 1 to 5 years of work experience, 25.23% of them have 5 to 10 years of work experience, 37.84% of them have 10 to 20 years of work experience and 10.81% of them have more than 20 years of work experience.

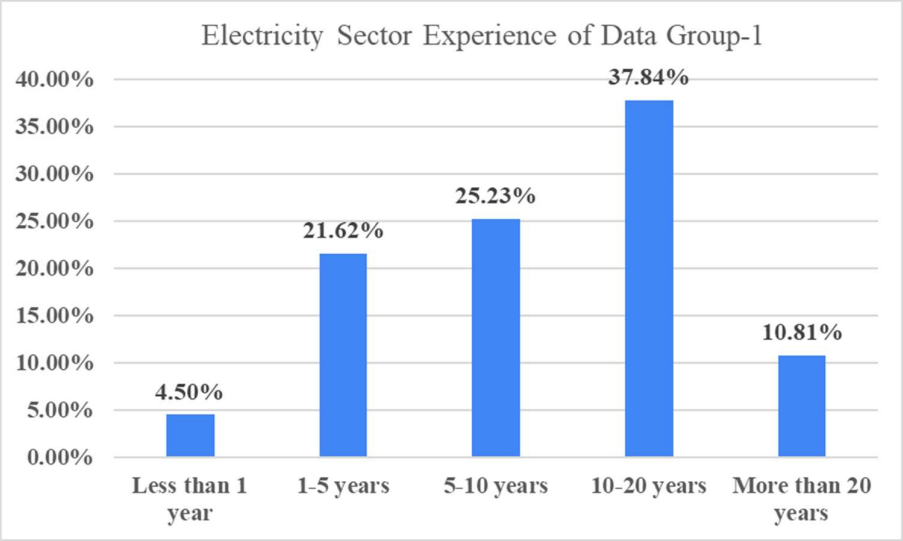


Figure 12: Electricity Sector Experience of Data Group-1

In Data Group-1, 91.89 % of the respondents have knowledge about the smart grid and 8.11% of them have no idea about the smart grid.

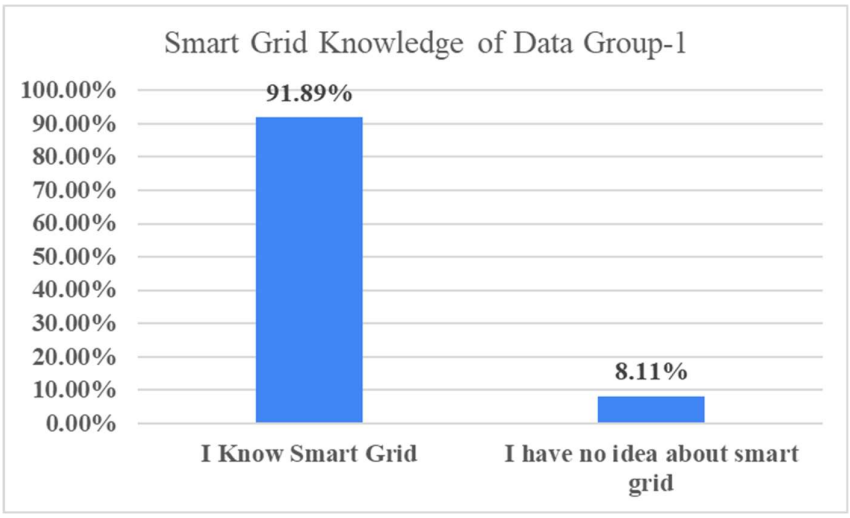


Figure 13: Smart Grid Knowledge of Data Group-1

Demographic Properties of Data Group-2

Data Group-2 is for the 30 central provinces of Türkiye. 1.20% of the respondents in this group have high a school diploma, 65.06% of them have a bachelor's degree, 32.53% of them have a master's degree and 1.20 % of them have a doctorate.

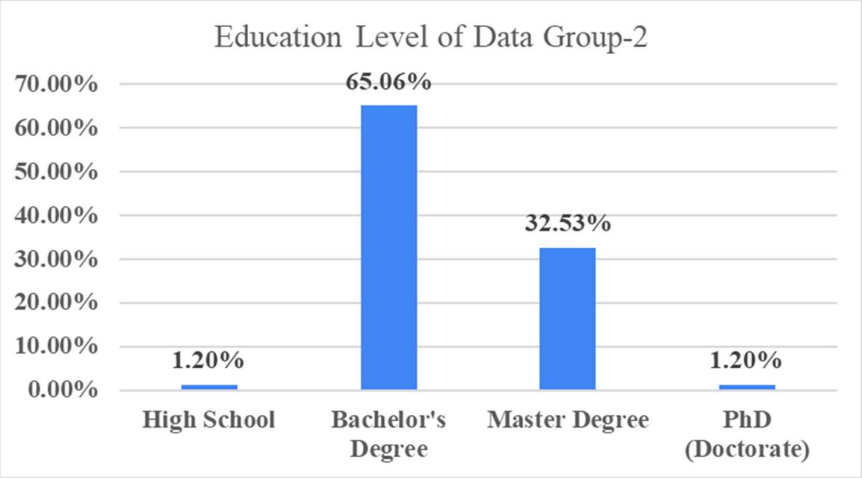


Figure 14: Education Level of Data Group-2

In Data Group-2, 1.20% of the respondents have less than 1 year of work experience in the electricity sector, 27.71% of them have 1 to 5 years of work experience, 31.33% of them have 5 to 10 years of work experience, 32.53% of them have 10 to 20 years of work experience and 7.23% of them have more than 20 years of work experience.

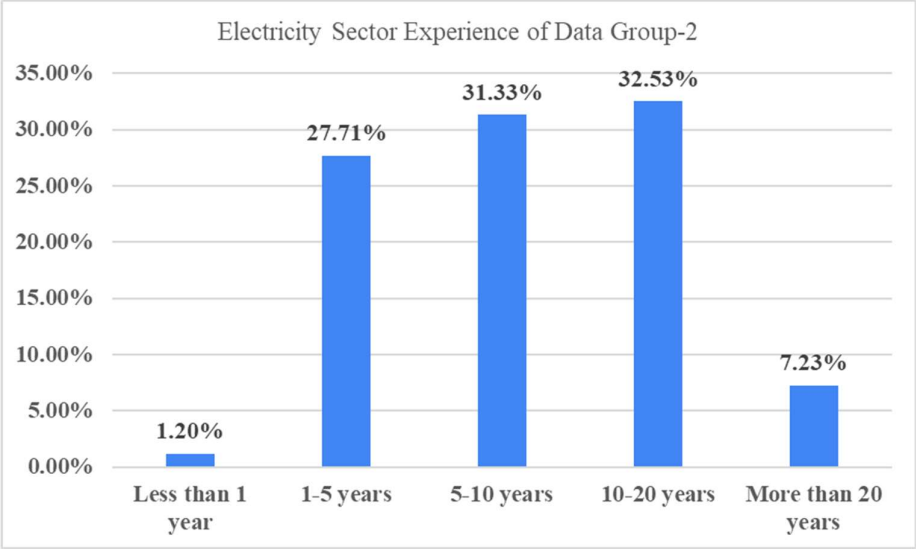


Figure 15: Electricity Sector Experience of Data Group-2

In Data Group-2, 96.39% of the respondents have knowledge about the smart grid and 3.61% of them have no idea about the smart grid.

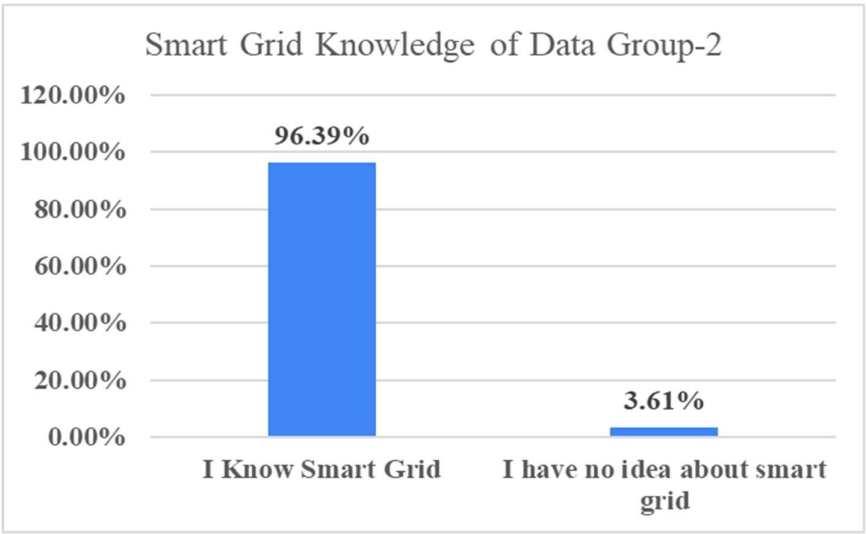


Figure 16: Smart Grid Knowledge of Data Group-2

Demographic Properties of Data Group-3

Data Group-3 is for the 30 eastern provinces of Türkiye. In this group, 1.37% of the respondents have a high school diploma, 69.86% of them have a bachelor's degree, 28.77% of them have a master's degree and none of them has a doctorate.

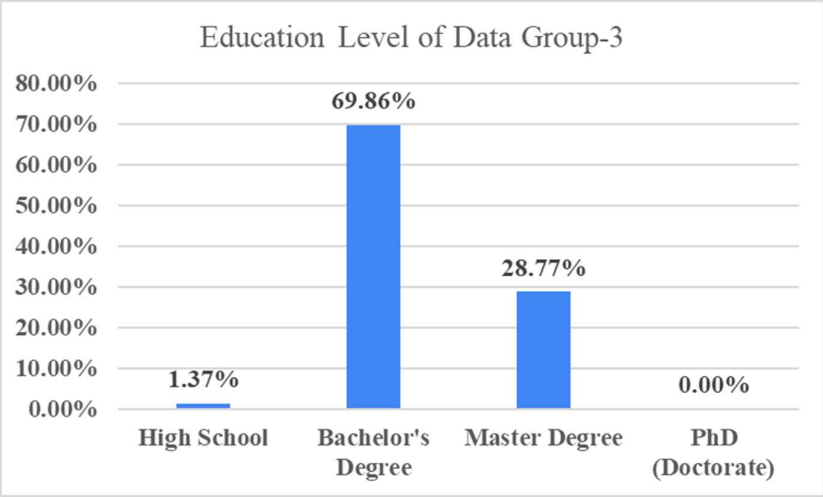


Figure 17: Education Level of Data Group-3

In Data Group-3, 6.85% of the respondents have less than 1 year of work experience in the electricity sector, 31.51% of them have 1 to 5 years of work experience, 21.92% of them have 5 to 10 years of work experience, 30.14% of them have 10 to 20 years of work experience and 9.59% of them have more than 20 years of work experience.

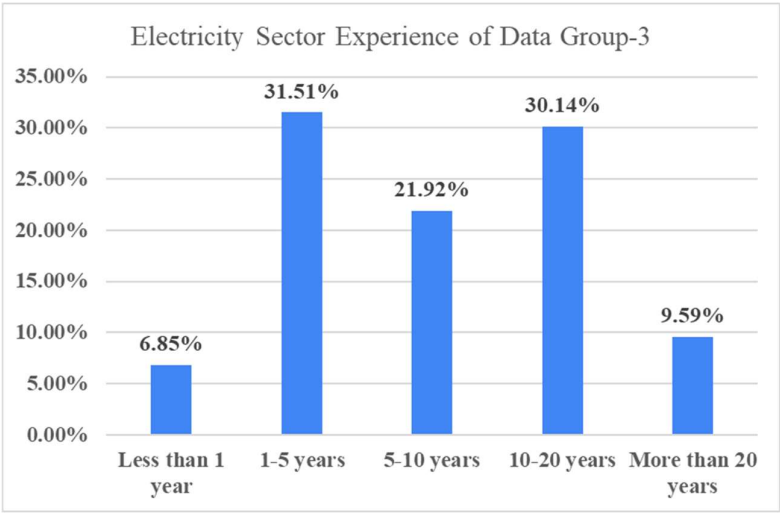


Figure 18: Electricity Sector Experience of Data Group-3

In Data Group-3, 97.26% of the respondents have knowledge about the smart grid and 2.74% of them have no idea about the smart grid.

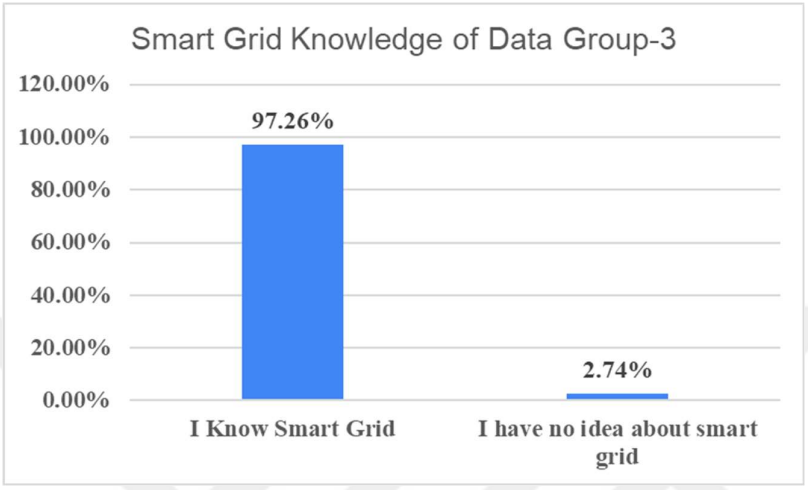


Figure 19: Smart Grid Knowledge of Data Group-3

Demographic Properties of Data Group-4

Data Group-4 is for electricity entities of Türkiye. In this group, 1.12% of the respondents have high a school diploma, 58.96% of them have a bachelor's degree, 33.21% of them have a master's degree and 6.72% of them have a doctorate.

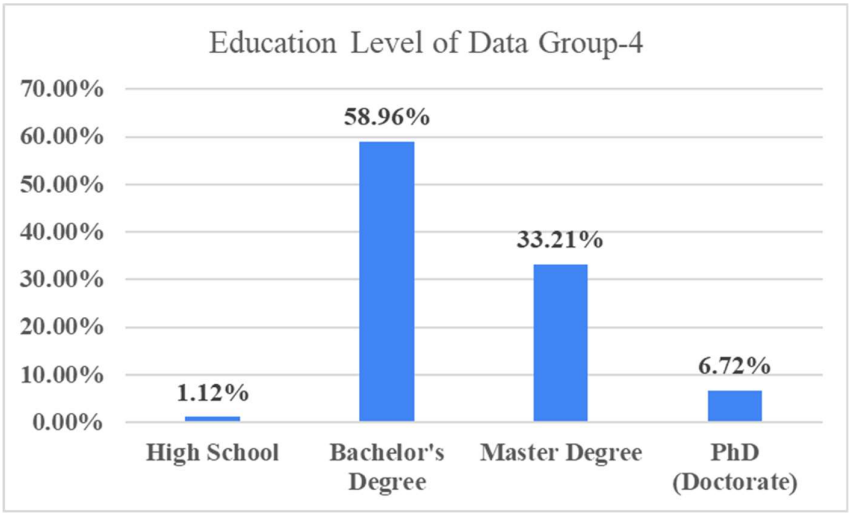


Figure 20: Education Level of Data Group-4

In Data Group-4, 1.49% of the respondents have less than 1 year of work experience in the electricity sector, 6.34% of them have 1 to 5 years of work experience, 22.01% of them have 5 to 10 years of work experience, 41.42% of them have 10 to 20 years of work experience and 28.73% of them have more than 20 years of work experience.

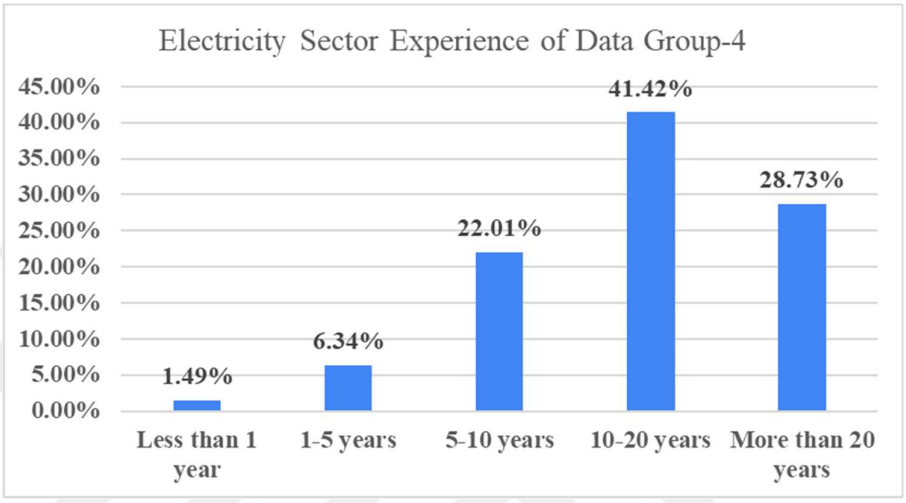


Figure 21: Electricity Sector Experience of Data Group-4

In Data Group-4, 95.15% of the respondents have knowledge about the smart grid and 4.85% of them have no idea about the smart grid.

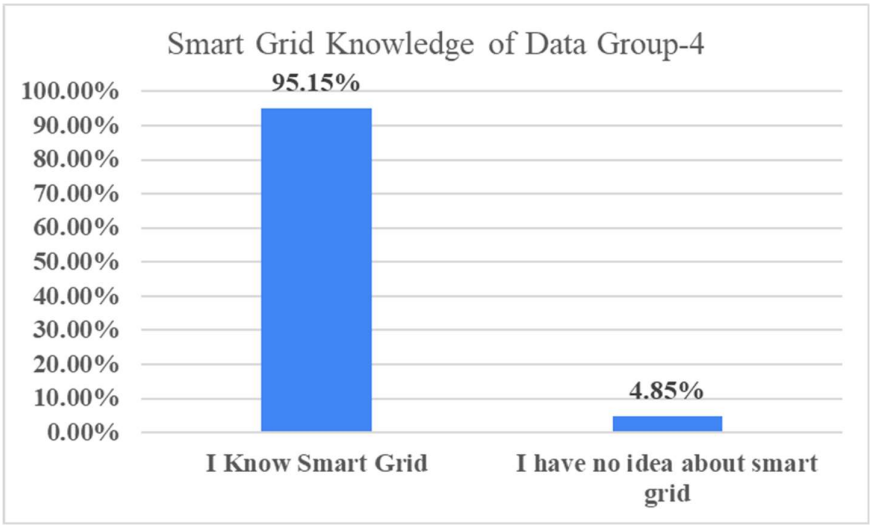


Figure 22: Smart Grid Knowledge of Data Group-4

APPENDIX E: Correlation Analysis

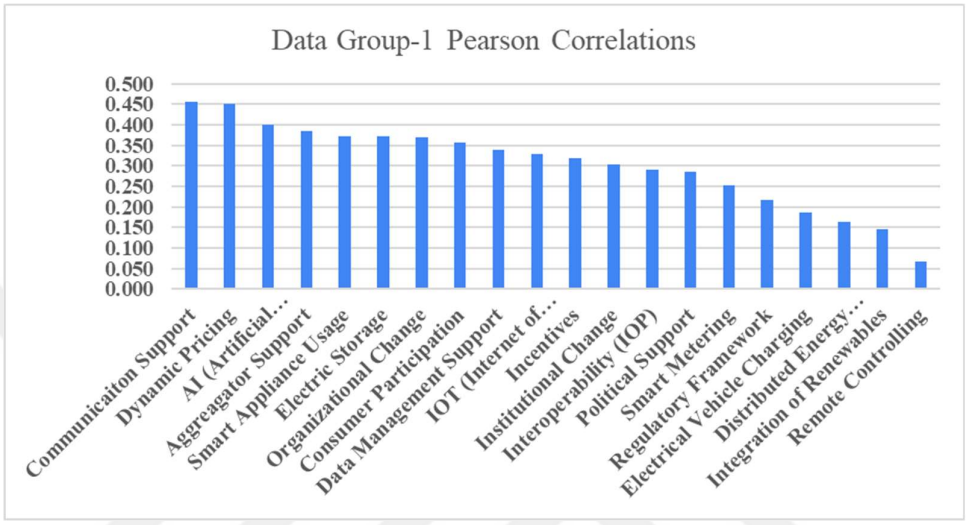


Figure 23: Data Group-1 Pearson Correlations

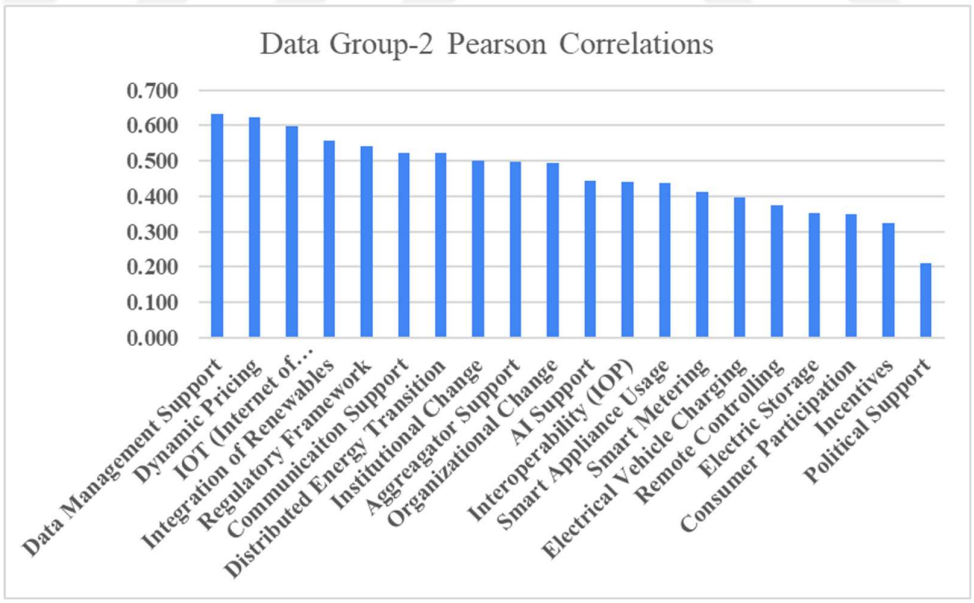


Figure 24: Data Group-2 Pearson Correlations

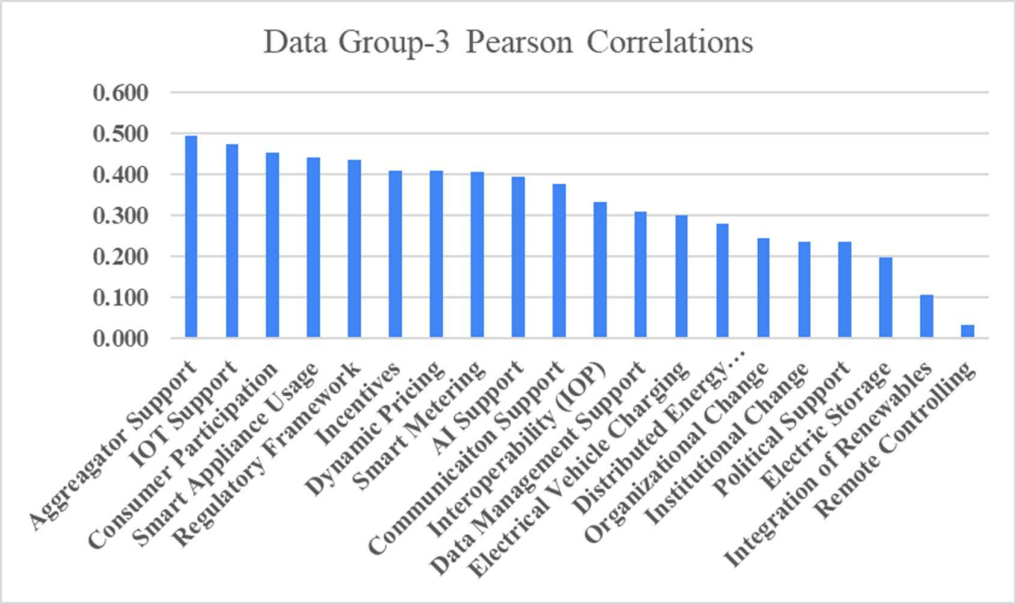


Figure 25: Data Group-3 Pearson Correlations

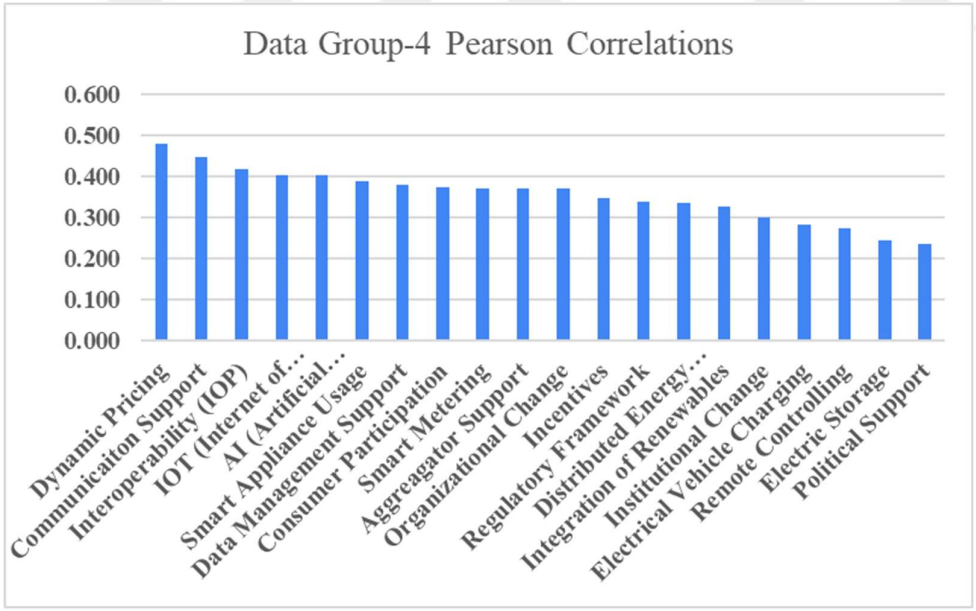


Figure 26: Data Group-4 Pearson Correlations

APPENDIX F: Expert Views

Data Group-1 (Western Provinces of Türkiye) Expert Views:

Expert 1: *"Smart grids play an important role in the energy sector today by increasing energy efficiency and security. In the future, they can improve the quality of life with more renewable energy integration and integration with smart devices."*

Expert 2: *"I think that the progress of smart grid transformation in Türkiye within the foreseeable time depends on a handful of people who do their job with passion and do not give up. I hope their numbers will increase. Smart grid transformation continues as an element that makes human life easier."*

Expert 3: *"The needs and demands of current consumers will change day by day. When examining this, it will not be healthy considering that even the houses are now exceeding the installed power. For this reason, instead of wasting time here, it would be better to allocate the same time to efficiency, especially in the smart grid. For example, ensuring that street lighting turns on after a certain time in the evening with sensors or other stimulating inventories."*

Expert 4: *"I think that regulations should be clear, clear and compelling for the efficient and effective use of smart grids. Otherwise, companies are moving towards establishing systems that will ensure regulation and with the most cost-effective solution, ignoring performance and cyber security. Especially if the penal terms of the regulations and obligations are above the investment to be made, companies will not mind the risk of fines. Apart from all these, training human resources and specializing in this subject is the key to success."*

Expert 5: *"In creating smart grid, it is of great importance to benefit from the knowledge and experience of technical personnel who provide fault analysis and elimination within the existing system. Although I have a 4-year undergraduate education and 3 years of field experience in the distribution sector, we can detect most unpredictable and unexpected faults and shorten the fault detection time, thanks to the perspective of the technical staff who have been serving in the sector for 13 years, to the fault and the network. Some malfunctions are predictable and undetectable. There may be situations where the electricity grid does not act according to the book and is considered impossible. At these points, faults found thanks to the previous experiences of the technical staff can be surprising and beyond the known."*

Expert 6: *"I have been working as an operator in a distribution company for 14 years. It will be beneficial for us, especially as people who operate smart grids, but*

unfortunately, smart grid investments cannot be made while distribution companies cannot make the necessary investments in parallel with the development of the country, especially on the distribution side. I don't think it can be done easily. If call letters are given to 20-30 MVA solar power plants for the sake of financial income in regions where there is no consumption even according to the unlicensed regulation, it seems a bit fanciful that we are talking about smart networks."

Expert 7: *"It is necessary to establish an institution that will coordinate the production, transmission and distribution sectors, as well as communication and public authority. Necessary regulations and communiqués should be created in a comprehensible manner and built on the existing system. It should be explained how the Smart Grid system will change society and how it will contribute to daily life. The short, medium and long-term goals should be explained and these goals should be measured. All stakeholders need to establish a structure that will finance the necessary infrastructure investments and complete the necessary control mechanisms to prevent smart grids from being interrupted. The training of technical and administrative staff who will guide the sector will be important in this regard. It should not be forgotten that local governments will be an important actor in the integration of Smart Grid systems. Establishing a savings-oriented tariff system, considering end-user-based energy usage demands and energy supply security, will increase users' participation in the system."*

Expert 8: *"The first parameter that should be taken into consideration is that there may be a delay in the smart grid transformation processes because there is a higher infrastructure need than our country or our citizens can financially meet and that there may be delays due to financial problems beyond technical problems."*

Expert 9: *"Important factors for the transition to smart grids in Türkiye in the short-medium term:*

- *Renewal and re-establishment of the distribution infrastructure in accordance with smart grids*
- *Establishing regulation*
- *Creation of financial models*
- *Political authority support*

In addition, economic conditions play a very important role in accelerating or slowing down this process. Since distribution companies are advancing their investment processes with the tariff structure and are working on an implementation period basis, 5-year plans can be made and these plans depend on financing; a "smart grid" initiative that does not progress in parallel with the distribution companies will be inefficient."

Data Group-2 (Central Provinces of Türkiye) Expert Views:

Expert 1: *"One of the most important factors that the smart grid should affect is ensuring electricity supply continuity and significantly reducing saidi and saifi values."*

Expert 2: *"It is very important that smart grids can be adapted to the existing distribution system structure and newly established facilities are revised according to this smart grid and their reliability."*

Expert 3: *"Regulations in smart grid should be designed as a system whole, not textual. There are 21 distribution companies. It would be more feasible to spend the workforce on a single system rather than on different systems. All systems, from SCADA to communication, should be local and work with the same algorithm in all regions. In addition, since there will be a planning that needs to prioritize investment, it is important that the areas to be prioritized is clear. In fact, design is the most critical phenomenon by considering production, transmission and distribution without separating them."*

Expert 4: *"In smart grid systems, the ability of the staff responsible for the relevant distribution network to monitor the data instantly and retrospectively from the first breaker to the last consumer meter by connecting to the network via IoT Systems will make a positive contribution to the reliability of the fault times, number of outages and remote monitoring systems. In addition, the SCADA system should be expanded not only in Medium Voltage networks but also in Low Voltage networks and the ability to perform remote control between boxes, especially in city centers, is important in terms of ensuring energy continuity in the network."*

Expert 5: *"Before the smart grid, our existing infrastructure must be completely improved, our measurement circuits must be closed to intervention and in this period when the transition to national meters is being discussed, these meters must be designed fully compatible with the smart grid."*

Data Group-3 (Eastern Provinces of Türkiye) Expert Views:

Expert 1: *"Teaching this subject as an elective in relevant faculties and departments of universities can offer a wider range of solutions in smart grid systems, which are at the idea and design stage and enable them to take shape according to needs."*

Expert 2: *"Manual and various industry 4.0 activities are carried out together in the existing electricity distribution infrastructure. The biggest problem is that digital systems created at different times for different needs cannot be brought together on a common basis. For this reason, to create the principle of smart grids in electricity*

distribution networks full-time and under ideal conditions, existing digital systems that do not speak a common language or cannot be made to speak should be replaced by structures that can be developed and adapted to AI systems. Since some digital systems, which are indispensable today, will be insufficient to meet both needs and new technologies in the very near future, early detection and transformation processes should be started from these points".

Expert 3: *"Dynamic pricing as a demand response program in smart grid systems does not currently seem possible in accordance with our country's legislation. However, if dynamic pricing policies with this and similar structures can be proven to be a more efficient option in energy supply compared to the forced load shedding option, I believe that pilot applications can be started as an alternative in the coming periods."*

Expert 4: *"We will need a lot of time for the smart grid system to be established. Because the inventories used in these systems must be robust and usable. In general, since the economic cost of newly built systems is high, there is a tendency to use cheap materials. This reduces the efficiency of the new system and we create a system that is worse than the old system."*

Expert 5: *"When Smart Grid is mentioned in Türkiye, only smart meters come to mind. This is not an accurate definition in terms of grid operation. As it is known, energy reaches the consumption point after the production, transmission and distribution stages. First of all, while it is necessary to focus on making the production, transmission and distribution networks smart, traceable, controllable and controllable, smart networks workshops held under the leadership of meter companies highlight the perception that only consumption points (Meters) should be smart in Türkiye."*

Expert 6: *"In the distribution sector, almost every distribution company has made significant progress in transforming its network into a smart one, but unfortunately, regulation cannot keep up with the R&D in distribution companies. However, there are almost no competent and qualified personnel in the public institutions we are associated with. This is why I give pessimistic answers to some questions, so to speak. We frequently use artificial intelligence-supported systems and analyses in our current processes and produce projects and I believe that in the near future, many manual processes will be transferred to artificial intelligence and will make us progress very quickly."*

Expert 7: *"The necessary information and its importance must be explained to the relevant control and management centers for the smart grid."*

Expert 8: *"Although we have taken serious steps in the creation of smart grids, we have not completed the process yet. It seems that this process (smart grids) will create*

phases within itself. With the digitalization of energy (which is not yet completed), smart grids will have a huge place in the distribution sector."

Expert 9: *"The best way to quickly see all the problems that may arise regarding the applicability of the smart grid system is to try to implement it in provinces such as Hakkari."*

Data Group-4 (Institutions of Türkiye) Expert Views:

Expert 1: *"I think it can be more efficient and faster to design smart grids starting from users to producers. First, we can start with the electrical appliances we use at home such as refrigerators, dishwashers, air conditioning systems and electric vehicle chargers etc."*

Expert 2: *"I think that infrastructure improvements are very important to allocate more capacity in substations to increase renewable energy production. Modernization of infrastructure, transformers, transmission lines and distribution lines, considering renewable energy production, will enable smart grids to become widespread more quickly."*

Expert 3: *"A transformation that requires an end-to-end perspective, starting from making receiving loads efficient and smart, powered by renewable energy and storage systems and where demand management is carried out with accurate measurement and smart algorithms. Like every transformation, there are obstacles to this. Each stakeholder's expectations and the benefits they see for themselves are different. The benefit expectations of the user, distributor and manufacturer are different. It is very difficult to combine all these expectations in a way that satisfies everyone. In fact, it is almost impossible. I see reducing demand and power to the optimum level and preventing losses as the most important issue. Highlighting renewable energy sources is another important element."*

Expert 4: *"Smart grids have their own trust issues. If complete cyber security cannot be ensured, in case of an operational error or external intervention, if there is no backup manual system, we will be completely blind, deaf and dumb in the electrical sense. As a matter of fact, it happened in the past and continues to happen on a local basis.*

Instead of full transformation of the network, keeping the old one as a backup system is safe, since they are managed with manual or electromechanical control systems, the part affected by cyber-attack or any electromagnetic shock wave is minimal.

Electricity can become as smart as the end consumer wishes. But it gets smarter in the production and transmission phase, that is, the control leaves the automation systems

and passes into the hands of artificial intelligence, which makes me uneasy as someone on the production side. (Like sitting in the back of a motorcycle driven by someone else).”

Expert 4: *“The grid related software programs, applications and systems throughout the country should be the same in all distribution companies and that they are even installed by the Electricity Institutions (TEDAŞ, TEİAŞ, EÜAŞ..) and provided to the distribution companies. This makes smart grid more reliable and systematic.”*

Expert 5: “*The concept of Smart Grid is a very broad concept. Small-scale IOT-supported projects are being tried in the public sector, but those working in the transmission and distribution department need to be more specifically informed about this issue. Cyber security systems began to be partially used in download centers. However, cyber security in energy covers a wide range of areas, from mobile network lines to the security of datacenters where data is stored. On the distribution side, smart meter specifications have been prepared and are planned to be implemented within 2 years.*

Currently, lighting subscribers come to the data center with the infrastructure established with the remote reading system (OSOS) and a headend software is displayed. Data of lighting subscribers (approximately 260 thousand meters) located throughout Türkiye can be monitored live every half hour. It took approximately 6 years to install the required topology and software. We estimate that it will take approximately 10 years to implement the national smart meter installation for all customers. I estimate that efforts to make sense of the data collected in this context with artificial intelligence and reporting software will take approximately 10 years. The main thing here is to make the collected data meaningful and use it as good output.”

Expert 6: *“While transforming to smart grid, it is necessary to avoid unnecessary investments that are not financially feasible. When designing smart grids, it would be appropriate to focus primarily on the needs of users with high by classifying them according to the energy levels of users connected to the distribution system. Any changes to the entire system will prevent the correct use of resources, increase energy costs and create an overdesigned system. The biggest obstacle in the system integration of renewable energy is that the distribution and transmission system is designed for worst-case scenarios. With the introduction of smart grids, more renewable energy integration into the system can be achieved by dynamically monitoring the load demand balance and transmission distribution system carrying capacities. I believe that one of the most important benefits will be this feature. In a world where the number of electric vehicles is rapidly increasing, the most critical issue is that electric vehicles contribution to smart grids”.*

Expert 7: *"Smart grid infrastructure investments, as in other areas, are directly related to the country's economic indicators. Smart grid transformation costs will be the most decisive point. In addition, the high cost of devices compatible with smart grids will cause usage and migration scenarios to be followed manually. I believe that possible cyber security risks, in addition to the cost disadvantage, will be an important barrier for end users in transitioning to smart grid."*

Expert 8: "*For smart grid in Türkiye, only smart meters and technological developments at the point of consumption are mentioned. Unless transmission and distribution systems that cannot be operated properly, having a smart meter at the point of consumption will not be of much benefit in an environment where energy continuity cannot be provided to the consumer.*

To reduce the malfunctions occurring in the production, transmission and distribution network, the technologies in the Ring Main Unit systems and the systems that detect the malfunctions should be developed. Most importantly, for energy continuity, the establishment of closed ring systems especially in city networks should be given priority.

In a world where there is no energy that can be transported safely to the point of consumption, it is not right to talk about a smart electricity grid just because the meter is smart."

Expert 9: "*In order to prepare the infrastructure for smart grid transformation, authorities must prepare the legislation and ensure that all services of the companies in charge are provided online. It is necessary to integrate small solar power plants under 50 kW, wind generation and in-home vehicle charging station data into smart systems and simplify their installation."*

Expert 10: "*Before integrating renewable energy sources with vehicle charging stations, there should be restrictions on the sale of electric vehicles."*

Expert 11: "*Correct process management, correct legal regulations, carrying out projects considering long-term solution options and providing strong support from the management can enable smart grids to be implemented faster."*

Expert 12: "*In parallel with the increase in renewable energy and energy storage systems, it is important to quickly implement smart grid studies together with legislative regulations in order to operate the grid in a more sustainable and reliable manner with all its dynamics."*

APPENDIX G: ANOVA Analysis Results

RQ-2) Is there a statistically significant difference between the effects of independent variables of smart grid transformation success?

One-way ANOVA: **All Independent Variables**

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	$\alpha = 0.05$

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	19	430.5	2.6570	**35.23**	**0.000**
Error	9460	6083.8	0.6431		
Total	9479	6514.3			

Means

Factor	N	Mean	StDev	95% CI
Remote Controlling	474	4.5190	0.6377	(4.4468; 4.5912)
Smart Metering	474	4.5169	0.7039	(4.4447; 4.5891)
Consumer Participation	474	3.9346	0.8186	(3.8624; 4.0068)
Integration of Renewables	474	4.4325	0.7862	(4.3603; 4.5047)
Data Management Support	474	4.4072	0.7477	(4.3350; 4.4794)
Distributed Energy Transition	474	4.3713	0.7508	(4.2991; 4.4435)
Electric Vehicle Charging	474	4.2595	0.8290	(4.1873; 4.3317)
Smart Appliance Usage	474	3.8629	1.0011	(3.7907; 3.9351)
Aggreagator Support	474	3.7004	0.9349	(3.6282; 3.7726)
Regulatory Framework	474	4.4409	0.7076	(4.3687; 4.5131)
Incentives	474	4.2426	0.8290	(4.1704; 4.3148)
Interoperability (IOP)	474	4.4198	0.7025	(4.3476; 4.4920)
Institutional Change	474	4.1814	0.8153	(4.1092; 4.2536)
Organizational Change	474	4.1814	0.7561	(4.1092; 4.2536)
Dynamic Pricing	474	4.0633	0.8379	(3.9911; 4.1355)

Communicaiton Support	474	4.3460	0.7545	(4.2738; 4.4182)
AI Support	474	4.1730	0.8171	(4.1008; 4.2452)
IoT Support	474	4.3523	0.7669	(4.2801; 4.4245)
Political Support	474	4.2004	0.9423	(4.1282; 4.2726)
Electric Storage	474	4.3059	0.8078	(4.2337; 4.3781)

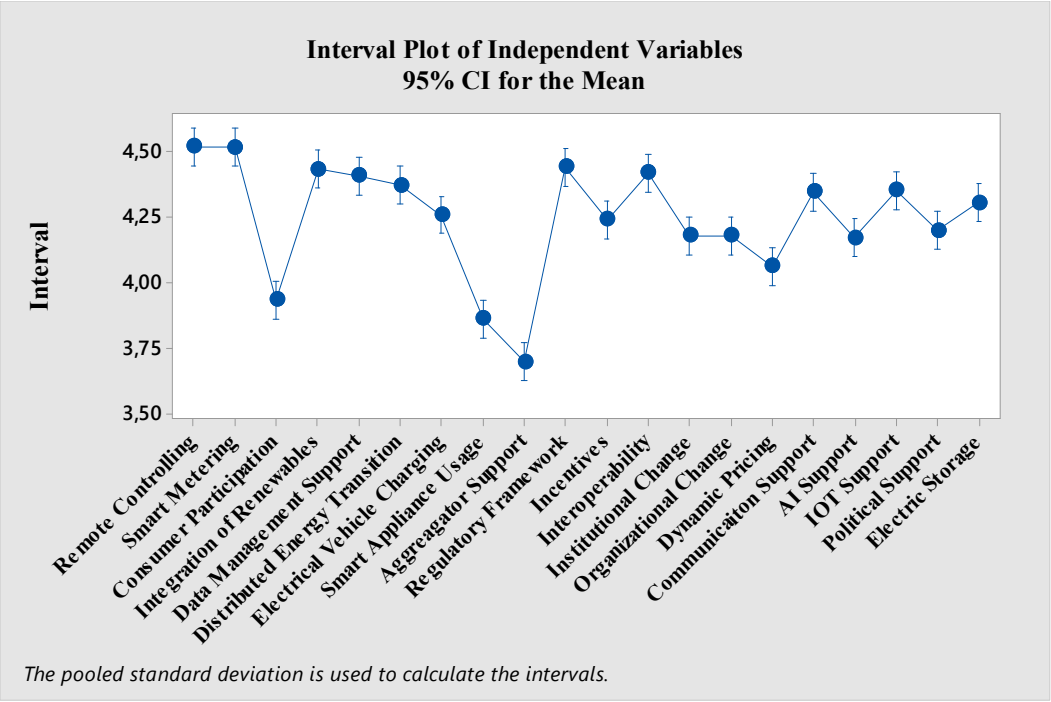


Figure 27: Interval Plot of Independent Variables

RQ-3) Is there a statistically significant difference between the effects of independent variables of smart grid transformation success with respect to regions of Türkiye?

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	$\alpha = 0.05$

One-way ANOVA: **Remote Controlling versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.2998	0.1499	**0.41**	**0.662**
Error	230	83.5800	0.3634		
Total	232	83.8798			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.6316	0.6023	(4.5097; 4.7534)
DG-2	72	4.6111	0.6179	(4.4711; 4.7511)
DG-3	66	4.5455	0.5866	(4.3993; 4.6917)

One-way ANOVA: **Smart Metering versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.185	0.09245	**0.17**	**0.845**
Error	230	126.055	0.54807		
Total	232	126.240			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.5053	0.7127	(4.3556; 4.6549)
DG-2	72	4.4722	0.7115	(4.3003; 4.6441)
DG-3	66	4.5455	0.8073	(4.3659; 4.7250)

One-way ANOVA: **Consumer Participation versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	4.665	2.3323	**3.46**	**0.033**
Error	230	154.863	0.6733		
Total	232	159.528			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	3.8211	0.7987	(3.6552; 3.9869)
DG-2	72	3.792	0.871	(3.601; 3.982)
DG-3	66	4.1212	0.7945	(3.9222; 4.3202)

One-way ANOVA: **Integration of Renewables versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.882	0.4411	**0.64**	**0.527**
Error	230	158.122	0.6875		
Total	232	159.004			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.4105	0.7786	(4.2429; 4.5781)
DG-2	72	4.2917	0.8465	(4.0991; 4.4842)
DG-3	66	4.439	0.879	(4.238; 4.640)

One-way ANOVA: **Data Management Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	1.037	0.5184	**1.01**	**0.366**
Error	230	118.045	0.5132		
Total	232	119.082			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.3684	0.7445	(4.2236; 4.5132)
DG-2	72	4.4167	0.7071	(4.2503; 4.5830)
DG-3	66	4.5303	0.6843	(4.3566; 4.7041)

One-way ANOVA: **Distributed Energy Transition versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.128	0.06379	**0.11**	**0.899**
Error	230	137.589	0.59821		
Total	232	137.717			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.3579	0.8110	(4.2015; 4.5142)
DG-2	72	4.3333	0.7316	(4.1537; 4.5129)
DG-3	66	4.3939	0.7622	(4.2064; 4.5815)

One-way ANOVA: **Electric Vehicle Charging versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.374	0.1870	**0.26**	**0.768**
Error	230	162.484	0.7065		
Total	232	162.858			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.3579	0.8241	(4.1880; 4.5278)
DG-2	72	4.264	0.872	(4.069; 4.459)
DG-3	66	4.333	0.829	(4.129; 4.537)

One-way ANOVA: **Smart Appliance Usage versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	4.514	2.257	**1.99**	**0.139**
Error	230	260.362	1.132		
Total	232	264.876			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	3.737	1.122	(3.522; 3.952)
DG-2	72	3.847	1.057	(3.600; 4.094)
DG-3	66	4.076	0.982	(3.818; 4.334)

One-way ANOVA: **Aggregator Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	4.629	2.315	**2.26**	**0.106**
Error	230	235.087	1.022		
Total	232	239.717			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	3.547	0.976	(3.343; 3.752)
DG-2	72	3.556	1.047	(3.321; 3.790)
DG-3	66	3.864	1.021	(3.618; 4.109)

One-way ANOVA: **Regulatory Framework versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.667	0.3333	**0.60**	**0.548**
Error	230	127.213	0.5531		
Total	232	127.880			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.4632	0.6967	(4.3128; 4.6135)
DG-2	72	4.3472	0.7720	(4.1745; 4.5199)
DG-3	66	4.3636	0.7773	(4.1833; 4.5440)

One-way ANOVA: **Incentives versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.241	0.1203	**0.16**	**0.854**
Error	230	174.790	0.7600		
Total	232	175.030			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.2737	0.7915	(4.0975; 4.4499)
DG-2	72	4.2917	0.8465	(4.0892; 4.4941)
DG-3	66	4.2120	1.0000	(4.001; 4.424)

One-way ANOVA: **Interoperability versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.967	0.4836	**0.87**	**0.421**
Error	230	128.114	0.5570		
Total	232	129.082			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.4000	0.7351	(4.2491; 4.5509)
DG-2	72	4.3750	0.8297	(4.2017; 4.5483)
DG-3	66	4.5303	0.6615	(4.3493; 4.7113)

One-way ANOVA: **Institutional Change versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.236	0.1179	**0.15**	**0.862**
Error	230	182.090	0.7917		
Total	232	182.326			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.1789	0.7852	(3.9991; 4.3588)
DG-2	72	4.125	0.918	(3.918; 4.332)
DG-3	66	4.106	0.994	(3.890; 4.322)

One-way ANOVA: **Organizational Change versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	2.763	1.3817	**2.31**	**0.102**
Error	230	137.631	0.5984		
Total	232	140.395			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.1368	0.8070	(3.9805; 4.2932)
DG-2	72	4.1806	0.7930	(4.0009; 4.3602)
DG-3	66	4.3939	0.6990	(4.2063; 4.5816)

One-way ANOVA: **Dynamic Pricing versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.465	0.2327	**0.31**	**0.736**
Error	230	174.496	0.7587		
Total	232	174.961			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	3.9368	0.8355	(3.7608; 4.1129)
DG-2	72	4.0417	08297	(3.8394; 4.2439)
DG-3	66	4.000	0.9610	(3.789; 4.211)

One-way ANOVA: **Communication Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	3.160	1.5798	**2.64**	**0.074**
Error	230	137.682	0.5986		
Total	232	140.841			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.3895	0.7480	(4.2331; 4.5459)
DG-2	72	4.1806	0.8278	(4.0009; 4.3602)
DG-3	66	4.4697	0.7487	(4.2821; 4.6573)

One-way ANOVA: **AI Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	2.366	1.1832	**1.80**	**0.168**
Error	230	151.196	0.6574		
Total	232	153.562			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.1368	0.8330	(3.9729; 4.3007)
DG-2	72	4.2778	0.7732	(4.0895; 4.4660)
DG-3	66	4.3790	0.8180	(4.182; 4.5750)

One-way ANOVA: **IoT Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.040	0.02001	**0.04**	**0.962**
Error	230	117.428	0.51056		

Total	232	117.468		

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.4421	0.6952	(4.2977; 4.5865)
DG-2	72	4.4583	0.6700	(4.2924; 4.6243)
DG-3	66	4.4242	0.7857	(4.2509; 4.5975)

One-way ANOVA: **Political Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	1.212	0.6058	**0.55**	**0.577**
Error	230	252.711	1.0987		
Total	232	253.923			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.116	1.030	(3.904; 4.328)
DG-2	72	4.167	0.949	(3.923; 4.410)
DG-3	66	3.985	1.170	(3.731; 4.239)

One-way ANOVA: **Electric Storage versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	0.031	0.01552	**0.02**	**0.979**
Error	230	166.467	0.72377		
Total	232	166.498			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	4.3053	0.7865	(4.1333; 4.4772)
DG-2	72	4.319	0.853	(4.122; 4.517)
DG-3	66	4.333	0.934	(4.127; 4.540)

RQ-4) Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation or not?

One-way ANOVA: **All Independent Variables**

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	$\alpha = 0.05$

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	19	8378	440.97	**25.85**	**0.000**
Error	9460	161360	17.06		
Total	9479	169738			

Means

Factor	N	Mean	StDev	95% CI
Remote Controlling	474	6.388	4.174	(6.016; 6.760)
Smart Metering	474	5.999	3.569	(5.627; 6.371)
Consumer Participation	474	7.925	4.198	(7.553; 8.297)
Integration of Renewables	474	5.820	3.827	(5.448; 6.191)
Data Management Support	474	5.892	3.745	(5.521; 6.264)
Distributed Energy Transition	474	8.157	4.392	(7.785; 8.529)
Electrical Vehicle Charging	474	6.807	3.969	(6.435; 7.179)
Smart Appliance Usage	474	8.896	4.659	(8.524; 9.267)
Aggregator Support	474	7.489	4.335	(7.118; 7.861)
Regulatory Framework	474	5.763	3.860	(5.391; 6.135)
Incentives	474	6.118	3.837	(5.746; 6.490)
Interoperability	474	7.826	4.292	(7.454; 8.198)
Institutional Change	474	6.322	4.034	(5.950; 6.694)
Organizational Change	474	6.155	3.920	(5.783; 6.527)

Dynamic Pricing	474	6.835	4.106	(6.464; 7.207)
Communication Support	474	7.120	4.137	(6.748; 7.492)
AI Support	474	7.928	4.363	(7.556; 8.300)
IoT Support	474	6.752	4.200	(6.380; 7.124)
Political Support	474	5.591	4.052	(5.219; 5.963)
Electric Storage	474	7.879	4.731	(7.507; 8.251)

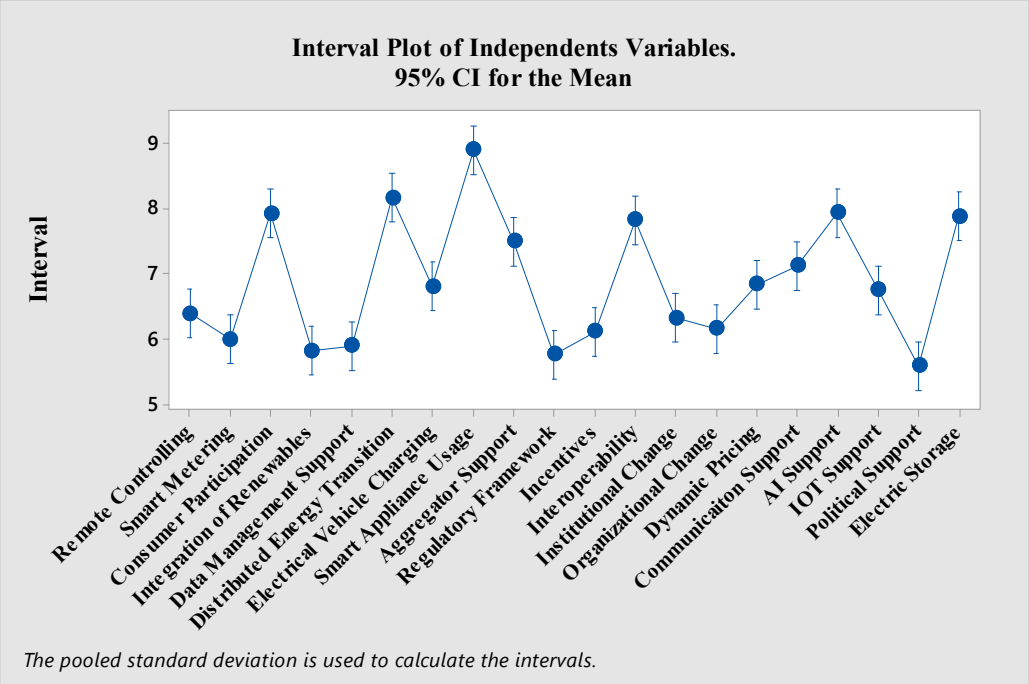


Figure 28: Interval Plot of Independent Variables for Required Time Period

RQ-5) Is there a statistically significant difference between the time periods required to complete the independent variables of the smart grid transformation with respect to regions of Türkiye?

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	$\alpha = 0.05$

One-way ANOVA: **Remote Controlling versus Regions**
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	39.24	19.62	**1.14**	**0.322**
Error	230	3960.15	17.22		
Total	232	3999.39			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	5.974	3.734	(5.135; 6.813)
DG-2	72	6.563	4.800	(5.599; 7.526)
DG-3	66	5.500	3.949	(4.494; 6.506)

One-way ANOVA: **Smart Metering versus Regions**
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	104.9	52.43	**4.17**	**0.017**
Error	230	2889.4	12.56		
Total	232	2994.3			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.895	3.696	(6.178; 7.611)
DG-2	72	6.125	3.565	(5.302; 6.948)
DG-3	66	5.258	3.289	(4.398; 6.117)

One-way ANOVA: **Consumer Participation versus Regions**
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	62.61	31.31	**1.69**	**0.187**
Error	230	4256.99	18.51		
Total	232	4319.61			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	8.363	4.272	(7.493; 9.233)
DG-2	72	8.042	4.109	(7.043; 9.041)
DG-3	66	7.114	4.545	(6.070; 8.157)

One-way ANOVA: **Integration of Renewables versus Regions**
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	34.89	17.44	**1.14**	**0.321**
Error	230	3517.06	15.29		
Total	232	3551.94			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	5.342	3.268	(4.552; 6.133)
DG-2	72	6.264	4.028	(5.356; 7.172)
DG-3	66	5.697	4.577	(4.749; 6.645)

One-way ANOVA: **Data Management Support versus Regions**
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	63.24	31.62	**2.37**	**0.095**
Error	230	3064.06	13.32		
Total	232	3127.30			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	5.100	3.200	(4.362; 5.838)
DG-2	72	5.764	3.933	(4.916; 6.611)
DG-3	66	6.364	3.929	(5.478; 7.249)

One-way ANOVA: **Distributed Energy Transition versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	39.81	19.91	**1.04**	**0.356**
Error	230	4416.66	19.20		
Total	232	4456.47			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.384	4.047	(6.498; 8.270)
DG-2	72	8.361	4.494	(7.344; 9.379)
DG-3	66	7.682	4.713	(6.619; 8.745)

One-way ANOVA: **Electrical Vehicle Charging versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	4.81	2.406	**0.17**	**0.847**
Error	230	3327.62	14.468		
Total	232	3332.43			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.347	3.374	(5.578; 7.116)
DG-2	72	6.688	3.978	(5.804; 7.571)
DG-3	66	6.455	4.177	(5.532; 7.377)

One-way ANOVA: **Smart Appliance Usage versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	8.32	4.160	**0.20**	**0.822**
Error	230	4873.29	21.188		

Total	232	4881.61		

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	9.000	4.416	(8.069; 9.931)
DG-2	72	9.368	4.930	(8.299; 10.437)
DG-3	66	8.917	4.496	(7.800; 10.033)

One-way ANOVA: **Aggregator Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	9.62	4.811	**0.26**	**0.774**
Error	230	4313.83	18.756		
Total	232	4323.45			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.742	3.869	(6.867; 8.618)
DG-2	72	8.215	4.544	(7.210; 9.221)
DG-3	66	7.848	4.708	(6.798; 8.899)

One-way ANOVA: **Regulatory Framework versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	24.81	12.41	**0.74**	**0477**
Error	230	3846.07	16.72		
Total	232	3870.88			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	5.511	3.399	(4.684; 6.337)
DG-2	72	6.229	4.808	(5.280; 7.179)
DG-3	66	6.098	4.148	(5.107; 7.090)

One-way ANOVA: **Incentives versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	27.26	13.63	0.84	**0.432**
Error	230	3719.31	16.17		
Total	232	3746.58			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.074	3.652	(5.261; 6.887)
DG-2	72	6.375	4.264	(5.441; 7.309)
DG-3	66	6.909	4.252	(5.934; 7.884)

One-way ANOVA: **Interoperability versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	2.80	1.401	**0.08**	**0.926**
Error	230	4189.91	18.217		
Total	232	4192.71			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.779	4.327	(6.916; 8.642)
DG-2	72	7.986	3.809	(6.995; 8.977)
DG-3	66	7.720	4.641	(6.685; 8.755)

One-way ANOVA: **Institutional Change versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	51.24	25.62	**1.48**	**0.229**
Error	230	3970.71	17.26		

Total	232	4021.95

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.026	4.039	(5.186; 6.866)
DG-2	72	6.910	4.320	(5.945; 7.875)
DG-3	66	7.045	4.137	(6.038; 8.053)

One-way ANOVA: **Organizational Change versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	33.04	16.52	**0.96**	**0.383**
Error	230	3946.40	17.16		
Total	232	3979.44			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.042	3.670	(5.205; 6.879)
DG-2	72	6.903	4.548	(5.941; 7.865)
DG-3	66	6.174	4.319	(5.170; 7.179)

One-way ANOVA: **Dynamic Pricing versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	10.36	5.182	**0.29**	**0.750**
Error	230	4146.26	18.027		
Total	232	4156.62			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.042	4.247	(6.184; 7.900)
DG-2	72	7.472	4.265	(6.486; 8.458)
DG-3	66	6.985	4.223	(5.955; 8.015)

One-way ANOVA: **Communication Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	20.23	10.11	**0.58**	**0.562**
Error	230	4021.79	17.49		
Total	232	4042.02			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.153	3.987	(6.307; 7.998)
DG-2	72	7.813	4.241	(6.842; 8.783)
DG-3	66	7.212	4.387	(6.198; 8.226)

One-way ANOVA: **AI Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	18.57	9.287	**0.46**	**0.629**
Error	230	4595.69	19.981		
Total	232	4614.26			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.321	3.712	(6.417; 8.225)
DG-2	72	7.993	4.937	(6.955; 9.031)
DG-3	66	7.652	4.915	(6.567; 8.736)

One-way ANOVA: **IoT Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	38.18	19.09	**1.08**	**0.340**
Error	230	4054.46	17.63		

Total	232	4092.63

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	6.200	3.789	(5.351; 7.049)
DG-2	72	7.125	4.392	(6.150; 8.100)
DG-3	66	6.856	4.533	(5.838; 7.874)

One-way ANOVA: **Political Support versus Regions**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	11.83	5.917	**0.32**	**0.727**
Error	230	4269.64	18.564		
Total	232	4281.47			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	5.589	3.749	(4.718; 6.460)
DG-2	72	5.875	4.605	(4.875; 6.875)
DG-3	66	6.136	4.711	(5.091; 7.181)

One-way ANOVA: **Electric Storage versus Regions**

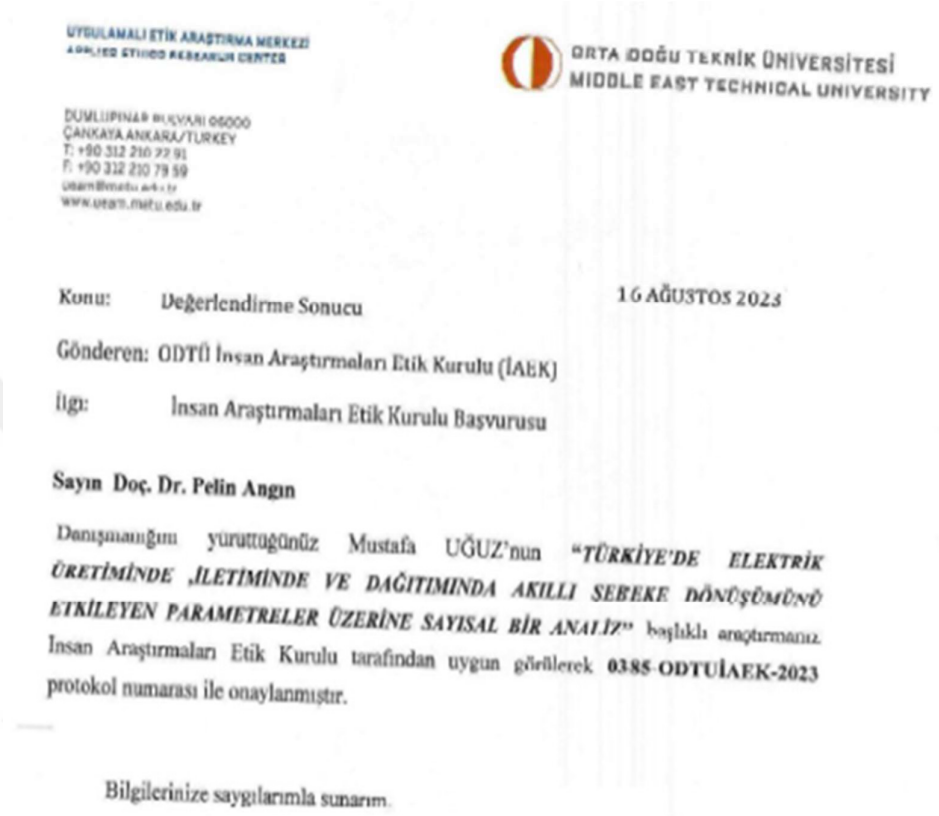
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regions	2	78.32	39.16	**1.65**	**0.195**
Error	230	5464.17	23.76		
Total	232	5542.49			

Means

Regions	N	Mean	StDev	95% CI
DG-1	95	7.263	4.617	(6.278; 8.248)
DG-2	72	8.646	4.934	(7.514; 9.778)
DG-3	66	7.879	5.162	(6.697; 9.061)

APPENDIX H: Ethics Approval of The Survey



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16 AĞUSTOS 2023

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Doç. Dr. Pelin Angın

Danışmanlığını yürüttüğünüz Mustafa UĞUZ'nun ***"TÜRKİYE'DE ELEKTRİK ÜRETİMİNDE ,İLETİMİNDE VE DAĞITIMINDA AKILLI SEBEKE DÖNÜŞÜMÜNÜ ETKİLEYEN PARAMETRELER ÜZERİNE SAYISAL BİR ANALİZ"*** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek **0385-ODTÜİAEK-2023** protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

Figure 29: Middle East Technical University Ethics Council Approval

CURRICULUM VITAE

Mustafa Uğuz graduated from Izmir Science High School. He received the B.S. degree in 2003 and M.Sc. degree in 2006 from Middle East Technical University, Electrical and Electronics Engineering Department, Ankara, Türkiye. In his M.S thesis he has studied power grids, their metering, pricing, and performance-based ratemaking.

Since 2003 he has been working for Arçelik as a Senior Technical Leader. Mustafa Uğuz administered and managed several research programs and product development projects in academia and the private sector, funded by the Turkish State Agencies, TUBITAK, EU H2020 and Industry. He was assigned by TUBİTAK as a member of TUBİTAK Display Technologies Focus Expert Group. For the time being, he is the chairman of TOBB Digital Transformation Task Force. He is the chairman of TOBB R&D Centers and University-Industry Collaboration Commission. He is the Executive Board Member of ECİD (Turkish Electronic Devices Manufacturers Association). He is a High Advisory Council Member of TESİD (Turkish Electronics Industrialists Association). He is the Arçelik representative in DIGITALEUROPE in Brussels. He is the chairman of SRI (Smart Readiness Indicator) Task Force in the EU Commission in Brussels.

EDUCATION

Degree	**Institution**	**Year of Graduation**
MS	Electrical & Electronics Engineering, METU	2006
BS	Electrical & Electronics Engineering, METU	2003
High School	İzmir Science High School	1998

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2003- Present	Arçelik	Sr. Technical Leader

FOREIGN LANGUAGES

Native Turkish, Advanced English, Intermediate German, Intermediate Russian