Smart Gas Grid Concepts at Greener Energy Era

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Abstract

As the adoption of the Internet of Things increases, cities are becoming smarter. For the past decade, gas distribution companies are also focusing on adopting smart city concepts such as smart metering. In the eve of transforming into a smart gas grid, IGDAS – the gas distribution utility company for a city of 15 million residents (Istanbul), needed a literature review for analyzing the latest smart grid concepts. A systematic review was carried out on leading research databases. After applying the inclusion and exclusion criteria, 21 papers were selected to be included in the systematic review. Out of those 21 papers, it became obvious that the greener energy era has shaped the research profile drastically toward the adoption of novel methods such as hybrid systems. The focus on cloud computing is on the rise as well as the novel AI methods for solving demand forecasting problems.

Keywords
Smart grid, IoT, smart metering, green energy, gas utility.

1. Introduction
Sustainable urbanization and modern city life involve providing critical infrastructure services such as electricity, telecommunication, water, gas, and transportation to support the basic livelihood of the citizens and businesses. Due to the increasing urban population density in the world, sustainable infrastructure services have become indispensable means of effective management of work dissemination in smart cities. As the cities get smarter, the utility companies start to leverage smart meters where remote management of the meters allows companies to reduce the personnel and service vehicles on the field. The more frequent and reliable data collection is achieved using hybrid communication protocols.

A strategic view of a smart city or intelligent urban ecosystem applies a digital approach to foster collaboration and engagement across citizens, industries, and governments. As cities are evolving at a rapid pace, utility companies are trying to get smarter as well. They aim not only for efficiency but also for environmental friendliness.

The remote management of the meters allows companies to not only reduce the personnel and service vehicles on the field (less carbon footprint) but also have real-time readings to propose solutions for load profiling, fraud detection, demand forecasting, and predictive maintenance. In the end, distribution companies are expecting reduced costs, greater awareness of consumption for end-users, and better management of precious resources for everyone.

The current research has two different objectives: (1) Give guidance to the utility companies on the recent trends related to the adoption of smart meters (2) Point out possible research areas that haven't been extensively studied yet in the gas utility domain.

2. Literature Review

The energy utility companies started utilizing automated meter readers (AMR) more than a decade ago. The early meters were communicating the reading values (usage values on the meter) and communicating it to the utility companies. These meters helped in the sense that manual readings were not needed anymore. As a result, more frequent readings could have been carried out (Foudeh and Mokhtar 2016). Less human involvement also meant fewer errors in readings. However, the communication in those meters was one way. The utility companies had no means of closing a membership or activating a new one remotely. Unless the meters could support two-way communication, manual intervention was still required.

Then there came the Automated Metering Infrastructure (AMI) that has meters with two-way communication capability. The utility companies could read the meter values as well as send commands to the meters. Even though AMI had many benefits, the adoption of gas and water meters was much slower (Sun et al. 2016). Because smart meters required a continuous source of energy to operate. The electric utility companies already had that resource, whereas the water and gas utility companies needed a battery-operated smart meter to solve their issues.

IGDAS is a large-scale gas utility company serving millions of customers in Istanbul, Turkey. It will launch a smart meter adoption pilot project which targets thousands of smart meters. Before getting into such a large-scale adoption, they decided to team up with a university and learn the latest trends and technology for smart meter systems by carrying out an extensive systematic mapping study. While working on the mapping study, they discovered new trends which would be useful for other utility companies and researchers as well. The rest of the paper is organized such that section 3 describes the methodology, section 4 lays out significant research related to gas smart metering, section 5 presents the results and discussion, finally we conclude with section 6.

3. Methodology

We started with the aim of a systematic mapping study (Petersen et al. 2018). We focused on IEEE, Springer, ACM, Elsevier, and Web of Science as the search databases for the systematic mapping study. The initial phases also included Google Scholar. However; we have discovered inconsistencies in the results such as filtering the results giving us more results. Thus, it was decided to leave Google Scholar out of search databases.

Given that the main focus was around smart meter adoption of gas utility companies the search keywords were decided to be as follows: ("natural gas" || "gas utility" || "gas grid") && ("smart meter" || "smart grid" || "Automated metering infrastructure" || "AMI")

The search has returned 800 papers. Out of those papers, we focused on the ones whose research focus on both gas utilities and smart meters. Out of the first 200 papers, only 21 of them satisfied the exclusion and inclusion criteria (note that the systematic mapping study is not completed yet). Those papers give us a good idea of the focus areas for the future of AMI for gas companies.

4. Focus Areas of Recent Smart Gas Grid Publications

4.1. Green Energy

The demand for energy has been on the rise, so are carbon emission. In order to prevent a possible climate crisis, governments are putting regulations to promote green energy. There are many different green energy resources (solar, wind, geothermal, etc.).

Besides solar and wind power usage, biogas production is also gaining interest. The biogas production plants are producing the biogas by composting materials. They can act as a microgrid that feeds the energy to an existing system.

Lemmer and Krümpel (2017) have investigated the option for biogas production to act as a backup energy resource in case the demand is increased. Normally the process of decomposition is an organic process, but there are new chemicals that can speed up the production.

Lemmer and Krümpel (2017) investigate the operation of anaerobic filters for highly flexible biogas production. Due to safety reasons, the storage of biogas is limited to a certain amount by regulatory laws in Europe. That is why the storage up front is not a viable option. Having a network of biogas production plants where they can feed each other on the rising demand for energy (Lemmer and Krümpel 2017).

Due to recent incentives and regulations, the adoption of green energy is higher than before. Nonetheless, the green energy resources are introducing new challenges to solve as well. Such as the volatility of green energy production. Some very common green energy resources (solar, wind, etc.) rely on atmospheric conditions. In order to overcome this challenge automated control scheduling (ACS) for adjusting power production and lack in renewable energy systems is presented (Alarifi et al. 2021). The scheduling control is maintained by deep Q- learning to describe the operation and deficiency status of energy systems.

Based on environmental conditions and the definitive control schedule, the power generation functions of the systems can be modeled. The energy production system examines the environmental situations suitable for gaining maximum profit, and power distribution is also modeled. The performance of the offered system was examined using the following parameters: operational profit, imbalance factor, right prediction of operations, and time delay. The experimental study proves the reliability of the offered method by achieving much operational profit and decreasing imbalance and time delay for the different consumers, energy requirements, and imbalance factors, respectively.

One way to increase green energy usage has been setting up microgrid infrastructures. Such microgrids produce energy depending on the current situational availability of the resources. For example, if it is a windy day, the wind-powered microgrid could be producing energy more than usual. In such cases, the electric microgrid might utilize the excess energy produced by the microgrid. That is why there has been research on operational flexibility assessment for different Multi Energy Microgrid (MEM) options (Holjevac et al. 2017). Mixed Integer Linear Programming (MILP) was used for this review and the Receding Horizon Model Predictive Control (RH-MPC) algorithm was used for short-term analysis. The model studied optimizing various flows to coordinate microgrids, serve end-consumer needs and be active in the energy market. Another innovation is to analyze different MEM configurations with different properties by examining different technologies, MEM configurations, and different modeling concepts. Although the effect on annual operational flexibility seems small in the study, the difference seen in terms of cost is significant. The article presents a comprehensive multi-energy microgrid. Holjevac et al. (2017) plan to further examine and include energy infrastructure to improve modeling.

Even though the usage of green energy has increased over the past decade, they are far from being the sole energy resource for highly populated areas. This meant the adoption of hybrid energy systems. Depending on the load, the production can be increased on a certain energy source. For example, for a cloudy day, the demand for heating would increase. On such a day, solar energy might not be enough to power all the households. The system can fall back to electricity usage.

4.2. Hybrid Smart Energy Grids

Low-carbon emission and efficient operation of energy resources are accepted as the main trends of the intensive research and development in the energy field. The concept of Integrated Energy Systems (IESs) was suggested with connections and interactions among various energy systems at the urban or community level. IESs directly connect to various energy consumers and combine different forms of energy with flexible topological structures. The reliability assessment of IESs can quantitatively analyze the effects of energy conversion on IESs.

A new reliability assessment approach to Integrated Energy Systems (IESs) is introduced in (Lei et al. 2018). The optimal load curtailment (OLC) algorithm and reliability assessment algorithm are both improved in the suggested approach. For the OLC problem, Lei et al. (2018) develop a hierarchical decomposition optimization framework for both the energy hub optimal shipment and the optimal power flow problems. Case studies are made on an IESs test case that combined the IEEE-33 bus system with a 14-node gas system and a practical case combined the IEEE 118-bus power system with Belgian natural gas network Numerical results show the efficient and robust performance of the proposed approach. Also, the impacts of the energy conversion process and energy hubs on IESs reliability are analyzed in detail.

Another tale on a hybrid model was a multi-agent approach (Klaimi and Vinyals 2018). The intermittent and non-predictable nature of renewable energy sources results in slower adoption, especially for busy district areas. Klaimi and Vinyals (2018) propose a method to convert the energy between different energy networks (gas and electricity for the time being).

Their focus is on optimizing energy usage at the district level. The optimization problem is modeled using different agents. They incorporated the Alternating Direction Method of Multipliers (ADMM) algorithm. Unfortunately, they have tested the proposed solution only in a simulation environment.

There have been several use cases around mixing electricity and gas grids with the aim to increase energy efficiency and reduce costs. One such study was carried out by (Sardou et al. 2018). Electricity networks attract the most attention in smart grids, but their dependence on natural gas networks cannot be denied. Sardou et al. (2018) propose a framework where they work together. The electricity networks in the article are natural gas-fueled and consist of microgrid aggregators (MGA). The ε-constraint method was used and evaluations were made considering the critical clearing time (CCT).

Sardou et al. (2018) also cover a case study on this concept. Based on the Belgian gas network IEEE 24-bus test system, the coordinated operation of the electricity and gas networks has been examined. The proposed coordinated work includes natural gas network costs. The work was carried out properly. It has been taken into account in unexpected situations during the operation of electricity and gas networks. As a result, it was concluded that the two networks working together are more efficient. Thanks to this study, the benefit of coordinated work in terms of cost and safety has been demonstrated.

The increasing energy demand has necessitated an improvement in routing the energy. For this reason, Li et al. (2020) propose an integrated energy system method based on Lyapunov optimization. The article focuses on structuring and analysis. Energy balance equations, energy storage, flexible loads, and other operating constraints are mentioned. Interactions between energies including electricity, natural gas, hydrogen, heating, and cooling are being studied extensively.

Hybrid energy centers act as an interface between energy producers and consumers. Traditional energy centers cannot meet the needs of the market. The energy router concept was originally presented based on the smart distribution network and microgrid. In a smart grid, the energy system coordinates multiple energy sources and improves energy. Therefore, a new home energy management framework is proposed by analyzing the power flow problem of energy centers (Li et al. 2020). A probabilistic optimization approach has been made in a renewable energy-based house. The propulsion strategy for combined cooling, heating, and integrated energy systems is power and wind energy. And the model is transformed into a mixed-integer linear programming formulation. A study was conducted for energy centers with conversion, storage, and demand-side management. It has been tested using real data from the literature review, demonstrating that the proposed strategy can be programmed. Li et al. (2020) aim to develop an intelligent algorithm in multiple time scales, taking into account the time feature.

After the introduction of green energy resources and hybrid grids, the optimization of which resource to use arouse. While the optimization of energy demand and production has been a challenge over the past decades, with the introduction of hybrid energy resources the problem became even harder. Wirtz et al. (2020) propose a linear programming method for efficient heating and cooling using a bi-directional low-temperature network (BLTN). They compare the results against previously installed individual HVAC systems for each building. The BLTN leverages the low-grade waste heat.

They applied the prosed algorithm on a research campus in Germany. The proposed method reduced the cost by 42%. The reduction of CO2 emission reached 56%. Even though the proposed method shows that BLTN usage is much more effective when compared to individual HVAC usage, it has certain shortcomings, such as the need to know the price and temperature upfront.

Demand forecasting and management is still a key challenge not only for regular utility grids but also hybrid grids. There has been several significant papers on this topic.

4.3. Energy Demand Forecasting and Demand Management

In order to achieve the decarbonization goals, it is important to accurately forecast the demand. Most of the gas usage is for space heating(Watson et al. 2018). In order to move from natural gas to electricity, it is important to know the peak demand. Preventing outages can be assured by having enough storage capacity enough for peak demand time frames.

Watson et al. (2018) use half-hourly dataset from 2009 and 2010 to estimate the peak demand. They first sanitized the data to ensure high-quality results. In the end, they estimated the peak demand to be much less when compared to previous research which estimated the peak demand based on different data sets. Even though the other data sets do have daily data unlike the current paper which has half-hourly data, the other data sets are newer compared to this one.

Given how difficult it is to predict the demand, many researchers tried out artificial intelligence algorithms such as neural networks or genetic algorithms. One novel research on that topic is carried out by (Sharma et al. 2021).They applied several machine learning algorithms on a 2018 dataset (6-hour intervals of gas consumption data). They investigated the weekday vs weekend effect, as well as holiday effect. They took the seasonal effects, temperature, and wind chill index into account.

Given that the data is collected every 6 hours, the researchers decided to separate the day into 4 different blocks. They tested 4 different machine learning algorithms for each block. Different blocks had different algorithms as winners. There wasn't just one algorithm with the best result. However, for the overall performance the model, which combines both the principal component analysis and conjugate gradient algorithm for optimization of deep learning artificial neural networks, performed the best.

Another study focused on the deep recurrent neural network model. Su et al. (2019) try forecasting the natural gas demand based on customer behavior and government regulations. For the prediction, they used the Deep Recurrent Neural Network model. They also predict the state of the gas pipeline through a deep learning algorithm. The results are used for predicting the price of gas using a genetic algorithm.

One large-scale adoption of such a method was carried out in Italy. The study wasn't only focusing on forecasting but also managing the demand. Montuori and Alcázar-Ortega (2021) explain a real-life case where a gas utility company applied an approach where the end-user can take direction on when to increase their usage or not. The town is located in the North of Italy where about 16000 people live. The customers were selected based on their willingness to adjust their usage (flexible consumers). Based on the overall gas consumption, some of the flexible customers were asked to reduce their consumption and delay certain gas usage heavy operations a few days.

The results show that the flexible customers gained 15% to 20% reduction in their gas bills, whereas the gain raise up to 50% for the utility company. Even though the current real-life adoption proved to be a great success, it has certain limitations such as a customer signing up for flexible usage not following the orders coming from the utility company. Due to demand forecasting and management being such a complex problem, there has been several different research on adoption of game theory to manage the demand. One such research was shared by (Aras Sheikhi et al. 2015).

4.4. Cloud Computing

Aras Sheikhi et al. (2015) define a smart energy hub as a system that is connected to an electric and gas grid. The customer who owns the smart energy hub can select which energy input to use for generating power and heating. The paper creates a simulation environment where the data is stored in the cloud and users can participate in a game where they can choose the energy source depending on the game incentives.

The results of the simulation showed that the total cost for the end-user has decreased and the peak to average ratio of the electricity demand also decreased. This shows that demand management is possible by using game theory. However, the results are not tested in a real-life environment. The user engagement might not be as high compared to a simulation environment.

Another novel research where a cloud computing system was adopted was carried out by (A. Sheikhi et al. 2015). The research paper defines a smart energy hub as a combination of multiple smart grid nodes. In that hub, electricity and gas are used for generating heat and electricity for the customers. The paper stores all the data coming from the smart meters in the cloud, where they claim that data processing and management are much easier.

In the current research, they propose the usage of game theory for managing the demand for energy. Each smart energy hub is assumed to know the current price for gas and electricity, depending on the pricing, the customers are allowed to choose the resource of the energy based on the price. They have carried out a simulation of the proposed game theory, the simulation results show that the demand can be managed. As a result, energy efficiency and price reduction can be achieved.

The adoption of cloud systems can also be observed in the security of the smart gas grid. The integration of the Cyber-Physical Energy System contributes to the development of smart grids thanks to real-time calculation and precise control. It is aimed to integrate the smart grid with natural gas, heat, and other energy systems.

Yang et al. (2018) carried out research on a multi-layer distributed cloud network (MDC). They architected the cloud architecture with a 5G-based hierarchy. In addition, they offer an allocation model with two levels. They say they can be overcome with the cloud system in microgrids and MDC to overcome the challenges in Cyber-Physical Energy Systems in complex and busy situations. In addition, they also offered a single-level model with scalarization. The system cost has been optimized. While computation in NS requires a lot of effort, the method has been developed with the cloud system designed thanks to microgrids. This system provides a great deal of efficiency. The article proves that the performance of the proposed system is good.

4.5. Reliability of the Smart Grid

Large-scale adoption of gas-fired power plants (GPPs) significantly speeds up the integration of power systems and natural gas systems (NGSs). Because the operation of NGS has a significant effect on the reliability of the power systems, it is important to simultaneously evaluate the reliability of power systems and NGS. Furthermore, due to the stochastic failures and various operating characteristics of components, the integrated gas and power systems (IGPS) considering multiple states can be viewed as a multi-state system. For this reason, a multi-state model is proposed for reliability evaluation of IGPS based on universal generating function (UGF) techniques (Bao et al. 2019).

The effects of NGS could be included into the reliability evaluation of power system. Moreover, nodal reliability indices for both the NGS and the power system are suggested to evaluate the reliability performances of IGPS. The suggested methods are validated using the integrated gas and power test system.

There have been architectural suggestions with the hope to increase reliability as well (Panayiotou et al. 2021), that have discussed applying industry 4.0 in a smart gas grid by presenting a use case for the Greek gas distribution network. This article aims to design and implement a series of actions regarding more efficient operations and business processes for gas distribution networks belonging to DEDA SA by using pipeline automation, innovative technologies, and information systems.

The study has exhibited the architecture of implementation with seven layers. These are representing, physical equipment on level 0, Sensors smart meters on level 1, SCADA on level 2, Equipment Monitoring System, Maintenance Management on level 3, products lifecycle management on level 4, ERP and customer relationship management level 5, business process management on level 6, respectively. The study has stated the importance of using business process modeling in correspondence with automation equipment thereby Industry 4.0 methodologies became especially apparent. another critical purpose for DEDA is the decrease of grid maintenance costs by observing the network in real-time, while facilities management could occur in more efficient utilization of the company’s resources.

4.6. General Considerations

There are many different energy sources such as the widely adopted ones such as electric and gas as well as the ones which have large-scale adoption such as electrolytic hydrogen. When there are many options to choose from including the hybrid approaches, mathematical models come into play.

Due to the unpredictable nature of renewable energy sources, there may be times when there is a surplus of energy. Sometimes the surplus energy might be sold for even negative prices just to balance the system. That is why effective energy storage is more important than before. The excess amount of energy produced by the renewable energy sources might be used for the generation of hydrogen through the electrolysis of water. Walker et al. (2016) call this processing power to gas utilization.

Walker et al. (2016) compare different energy storage mechanisms and try to select the best one using the analytical hierarchy process. They concluded that power to gas outperforms the other storage options in bulk energy storage, utility transmission, and commercial energy storage. However, for residential storage, batteries are still the best option. For any AHP run, the weights of the criteria make a big difference in the results. The weights selected for the current research might be different based on different evaluation criteria.

Stoyanova and Monti (2019) also tried to address the optimization study. However, their goal was a very hard one to achieve that target finding an optimization algorithm for multi-purpose domains. A study was made for multi-purpose domains. Optimization studies are carried out for non-energy areas in Smart Cities that integrate heterogeneous energy. A comprehensive optimization study is being carried out for urban areas. Optimization work applied by considering multiple domains (regional and social) provides an optimal holistic solution. The key advantage of the system is the exploitation of cross-domains. In this way, the overall performance of the system increases with interactions. It requires level modeling to deal with compatibility issues between domains, so optimization is proven right by domain-specific simulation. Multi-objective Pareto optimization is presented in detail in Smart Cities. Various optimization formulas were applied to the test scenario. Since it is more sensitive for heterogeneous fields, the ε-constraint method was deemed appropriate. NS calculation performance, which is advantageous in terms of time, has been applied as the calculation method. Estimates were made for 1300 units out of 500 buildings.

As a result of the study, the importance of integration for heterogeneous areas emerged. However, no method can combine energies. Non-energy areas and synergies were utilized. The applied multi-objective optimization was calculated with Pareto and ε-constraints. This calculation method was found to be suitable for heterogeneous areas. While it can be calculated for 500 buildings, accurate results could not be obtained for 1300 buildings. For this reason, it was seen that a new optimization should be made for different cities. For this reason, it was decided to develop the model for non-energy areas (transportation, logistics, etc.).

One other area which attracted research focus was the connectivity of the smart meters (Mihajlovic et al. 2017). The existing smart meters for gas measurements are updated to become communication data concentrators. The gas smart meters that they used were already compliant with the SPDC standard. They have carried out 2 phase testing. The first test site had no obstacles and the range was 250 meters. The second test site was a rural area with actual smart meters. In the second real-life situation testing, the range dropped to 100 meters. There was only one case where they failed to communicate, where the meter was installed on a metal lamp post. This research shows that some of the smart meters can be updated to act as a concentrator or a gateway for communication. However, the research fails to specify how many meters were used for their rural area testing.

It is great to see that there were many case studies presented in the smart gas grid domain. One such contribution came from (Iyengar et al. 2016). They carried out an analysis based on smart metering data set for a city. Data set has been gathered from approximately 15000 smart meters. This study focuses on the interrelation between energy usage and building size and age, weather, and renewable penetration. Also, the study mentioned high and low weather temperatures affect energy usage %36 and %11.5 respectively. Additionally, the study tries to validate a hypothesis for customer segmentation with the smart meter data. Another output of the study is the energy efficiency analysis of individual homes. Moreover, the study discusses grid stability related to loading modeling, load profiling, and grid integration case for increased solar penetration.

5. Results and Discussion

5.1 Results

Out of all 21 research papers that are included in the current systematic review, 13 of those papers were focusing on the hybrid smart grid where electric and gas utilities are being used together. Based on the energy resource, we laid down the number of citations received in Table 1.

Table 1 – Number of research papers and the received citations based on the energy type.

Energy Resource	Count of Papers	Total Number of Citations Received	Average Number of Citations Received
Gas	5	63	12.6
Hybrid (Electric, Gas)	13	447	34.4
Hybrid (Electric, Green Energy)	1	2	2.0
Hybrid (Electric, Hydrogen, Gas)	1	148	148.0
Hybrid d(Gas, Green Energy)	1	29	29.0
Grand Total	**21**	**689**	**32.8**

As seen in Figure 1, most of the research carried out on gas smart grid is articles published in journals rather than proceedings papers published in conferences or symposiums. This might imply that the research carried out on smart gas grid concepts is detailed and also high in quality. Given that the gas utility companies are backing the research along with pilot applications, most of the research is empirical with solid results. The goals were mainly moving to greener energy, reducing carbon emission as well as better demand forecasting, and reducing cost.

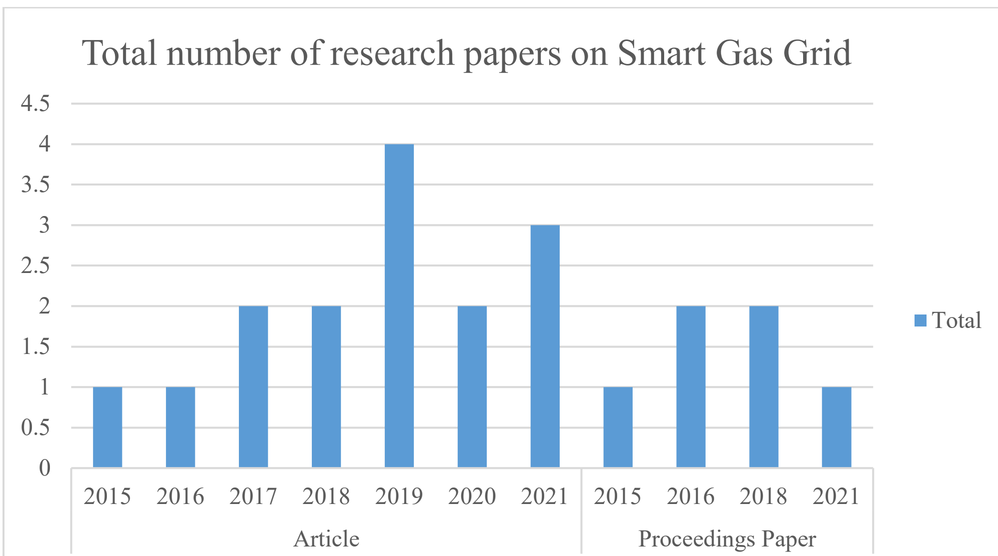

Figure 1 – Number of articles vs. proceedings papers based on years.

The research papers for the smart meter technology of gas utility companies have been published in the following venues (Table 2).

Table 2 – Number of papers published in each venue.

Publication Venues	Count of Papers
2015 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)	1
2016 24th Telecommunications Forum (TELFOR)	1
ACM International Conference on Systems for Energy-Efficient Built Environments	1
APPLIED ENERGY	5
Elsevier - Sustainable Energy Technologies and Assessments 45 (2021) 101036	1
Energy	1
Energy Conversion and Management	1

ENERGY POLICY	1
IEEE International Conference on Automation Science and Engineering (CASE)	1
IEEE Transactions on Smart Grid	3
INTERNATIONAL JOURNAL OF ELECTRICAL POWER & ENERGY SYSTEMS	1
International Journal of Hydrogen Energy	1
ISEEIE: International Symposium on Electrical, Electronics and Information Engineering	1
JOURNAL OF PETROLEUM SCIENCE AND ENGINEERING	1
Working Conference on Virtual Enterprises	1
Grand Total	**21**

5.2 Discussion

The greener energy move resulted in an increase on the adoption of green energy. Unfortunately, we are not yet close to having green energy as our sole energy resource. Hence, many different hybrid energy alternatives are being investigated until we get there. Plain gas research is not that interesting. It accounts for only 24% of the total research. Hybrid systems are gaining interest due to the volatility of green energy resources.

We have known that Hydrogen usage as an energy source is on the rise. The paper that gets the most site is in that category. On the other hand, we can't generalize this finding as the current systematic literature review had only one matching research paper in that category. However, we can confidently state that the hybrid energy model of combining gas and electricity is picking quite a bit of interest (34 citations on average), closely followed by another hybrid energy that combines gas and green energy.

Another interesting finding based on the number of articles vs. conference papers on smart gas metering research is that the number of articles is higher compared to conference proceedings. This might be due to the complexity of the problem domain and the industry and research organization partnership. Nearly all the systematic review papers had empirical data.

Transactions on Smart Grid and Applied Energy are the most relevant journals for smart gas grid research. Both venues focus on combining the researcher and industry. As a result, most papers were either case studies or evaluation research papers with significant contributions.

6. Conclusion and Future Work

The starting point of the current research has been getting the latest state-of-the-art research on smart metering technology for gas utility companies. A systematic review approach was followed to find the related papers. Even though quite a high number of research articles found out that hybrid energy grids are the way to go, the industry has refrained from adopting hybrid energy models (e.g., gas and electric grid). One of the blockers of that adoption is different utility companies managing different resources. The business goals might be conflicting with the greener energy goals.

Demand forecasting and management are still complex problem areas where different AI algorithms are applied. Some of the methods involved the application of game theory but none of the game theory solutions went live with real customers. As a result of this literature review, IGDAS has decided to apply IoT along with novel AI methods for demand forecasting and customer segmentation. The pilot project will also include the water utility company of Istanbul as well. In the future, the electric utility might also be incorporated into this hybrid system.

As future work, we are planning to carry out a systematic mapping including all the papers from the original research (around 800 papers), where the results will be not only focusing on the most cited ones but include all the papers related to smart gas grids. Such a detailed article will reveal the research areas which have not been thoroughly investigated yet.

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