



# Smart Grids and Smart Cities - A Systematic Mapping Study

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## Abstract

Smart grid and smart city concepts are very popular, exciting and interrelated research, development and application areas in the 21<sup>st</sup> century. Hence, these research activities have become important task from the scientific community, practitioners, and policy makers. Smart grid allows using different energy sources more effectively, reliable, and sustainable. Smart city applications makes human life easier and more comfortable, by getting economy, governance, environment, living, healthcare, energy and mobility smarter. This paper presents a systematic analysis of published literature related to smart grid and smart city studies between 2014 and 2017. 6975 papers (4340 conference proceedings, 57 book chapters, 2578 articles) have been considered in total. The papers are classified with according to their focus, research and contribution type. A systematic mapping study is performed according to this classification. Then, recent investments and future trends have discussed.

**Keywords:** Microgrids; power systems; smart cities; smart grids; systematic mapping.

## 1. Introduction

Smart grid can be described as a systematic and efficient usage of novel knowledge on communication, security and information at the fields of smart infrastructure, management and protection systems instead of the conventional energy system, which is inadequate currently. Despite having a relatively new field of study, smart grid subject has been studied and implemented in many areas such as power generation, power transmission, power distribution, data modelling, wireless sensor network, phasor measurement, sensors, smart metering, demand response management, distributed resources, alternative energy resources, electric vehicles, security, reliability, communication, optimization, auction etc. [1]. Principal components of the smart grid are commonly classified under eight headlines including system situation assessment and operations, transmission and distribution automation, distributed generation through renewable sources, electric vehicles, electric storage, smart appliances, demand participation and tariff operations [2].

Also, smart city is interrelated with smart grid and aims to make a city more livable, comfortable, sustainable and able to use its potentials effectively. Nowadays, many cities have adopted this concept into their agendas with the intention of offering a prosperous life to their inhabitants. Currently, some of them have already been implementing their projects including adaptive traffic control, smart parking, smart buildings, smart water

usage, smart public services, smart street lighting, smart waste management and smart meters [3,4].

In this paper, it is aimed to provide statistical information about smart grid and smart city studies by using published papers. Totally 6975 papers are classified into two main sections as smart grid and smart city. The results are presented as a systematic mapping study. The Web of Science, Science Direct, IEEE Xplore data bases are investigated for the literature and repetitive parts are omitted. For search operation on these databases, the papers containing its title “smart grid” and “smart city” words are considered. As a consequence, between 2014 and 2017 years, based on the classification method, from IEEE Xplore, Web of Science - ISI Web of Knowledge, and ScienceDirect databases 4482, 1606 and 887 papers are classified respectively.

This study is organized into three main parts: (i) Introduction, (ii) Material and Methods, and (iii) Conclusion. Description of the research methodology is given in section (ii). Then primary studies, smart grid and smart city approaches for some prominent countries are explained. Systematic mapping results are demonstrated on bubble graph at the bottom of the section.

## 2. Material and Methods

The objective of this study is to identify the relation between academic papers of the countries and investments of the governments by using an overview of existing research papers on smart grid and smart city.



### 2.1. Research Questions

The overall goal is defined in four research questions (RQ):

*RQ1. What are the publication trends for smart grid?*

With this question, it is clarified that which main and sub-topics are studied in the world.

*RQ2. How many studies have been published regarding with smart grid and smart city between 2014 and 2017?*

This question aims to obtain the real publication data which belongs to this period.

*RQ3. What are the possible future trends, needs and investment perspectives of countries?*

Thanks to response of the RQ, it is easy to view the structure of smart grid and smart city investments country by country.

*RQ4. What is the correlation between the total count of academic studies and investment rate of countries?*

At the end of the study, this judgment criteria is handled to perform real map between academic studies and country investments.

### 2.2. Primary Studies

It has been used the classification method in [1] principally for smart grid papers. At first, all smart grid studies have been categorized into three main topics: (i)

Smart management system, (ii) smart infrastructure system, (iii) smart protection system. Then they have been divided into sub-topics as shown in Figure 1.

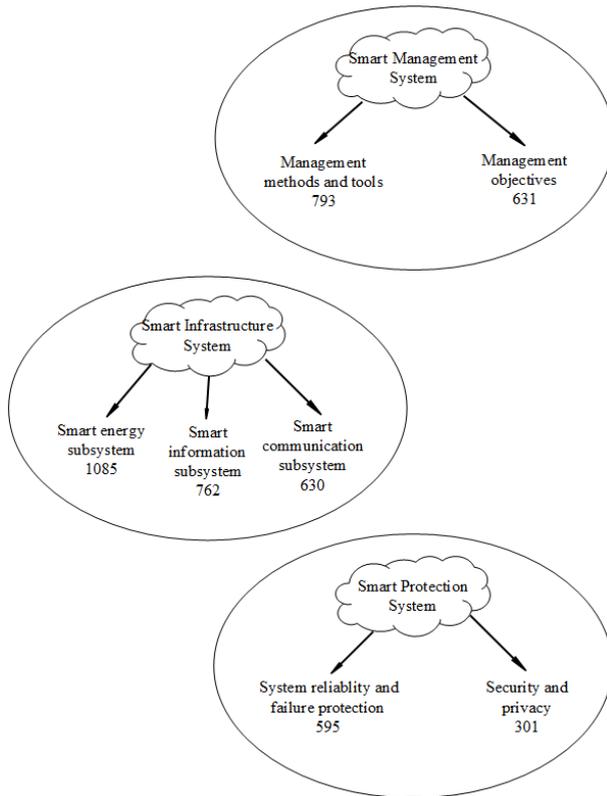
By analyzing the publication numbers on smart grid and smart city subjects, between 2014 and 2017 years, 6975 published papers are investigated: 4918 of them, 70.51% of total, is related to smart grid; 2092 of them, 29.99% of total, is related to smart city; 35 of them, 0.50% of total, is in common.

According to Table 1, most research has realized in the field of smart infrastructure system with 2477 papers that are 50.37% of all smart grid studies and 35.51% of all studies. It is obviously seen in Table 1 that publication numbers are increased regularly.

The most research on smart infrastructure system has been performed on smart energy subsystem with 1085 papers that are 43.80% of all smart infrastructure system and 22.06% of total papers related to smart grid according to Figure 1. Management methods and tools topic is second in publication number ranking with 793 papers that is 55.69% of smart management systems and 16.12% of all smart grid research studies. Least studied topic is security and privacy with 301 papers that is 33.59% of smart protection system and 6.12% of all smart grid papers.

**Table 1.** Distribution of publication years over primary research focuses.

Research Focuses	2014	2015	2016	2017	Total	Paper Publishing Rate
Smart Infrastructure System	628	648	630	571	2477	35,51%
Smart Management System	356	359	421	288	1424	20,42%
Smart Protection System	191	254	254	197	896	12,85%
Smart City	263	425	620	749	2057	29,49%
Other	36	40	23	22	121	1,73%
Total Work	1474	1726	1948	1827	6975	100,00%

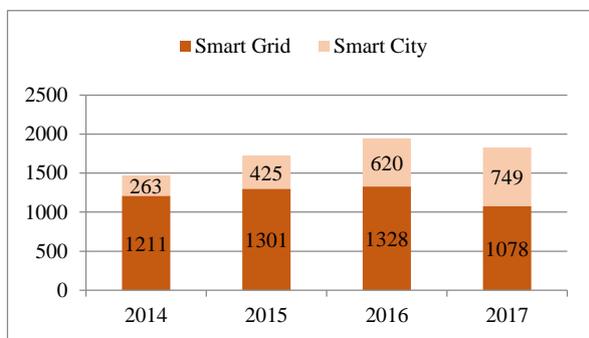


**Figure 1.** Number of published papers on smart grid subsystems.

**Table 2.** Distribution of publication years over publication types.

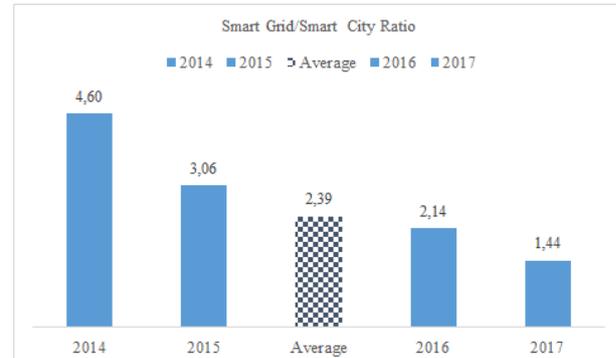
Publication Types	2014	2015	2016	2017	Total
Book Chapter	8	15	13	21	57
Conference	1046	1166	1188	940	4340
Journal & Magazine	420	545	747	866	2578

According to Table 2, the most of the researches are conference papers with the number of 4340 that are 62.22% of all studies.



**Figure 2.** Number of published papers on smart grid and smart city.

As seen in Figure 2, the total academic studies that belong to smart grid are nearly at the same range between 2014 and 2017. On the other hand, the total count of smart city studies is increasing year by year. While the total published paper numbers are increasing between 2014 and 2016, they are decreased in 2017 because of the smart grid paper counts. According to Figure 3, the ratio between smart grid and smart city is getting lower from 2014 to 2017.



**Figure 3.** Smart grid to smart city ratio over years between 2014 and 2017.

As shown in Table 3, China is the first country with 792 papers that are 16.10% of all studies.

**Table 3.** Academic study counts of top 10 countries on smart grid.

Rank	Country	Pcs	Percentage
1	China	792	16.10%
2	USA	772	15.70%
3	India	376	7.65%
4	Italy	247	5.02%
5	Canada	216	4.39%
6	Germany	214	4.35%
7	UK	163	3.31%
8	Australia	140	2.85%
9	Iran	131	2.66%
10	Korea	115	2.34%

**Table 4.** Academic study counts of top 10 countries on smart city.

Rank	Country	Pcs	Percentage
1	Italy	251	12.20%
2	China	219	10.65%
3	USA	145	7.05%
4	Spain	144	7.00%
5	India	129	6.27%
6	UK	96	4.67%



7	Germany	59	2.87%	BE	128	62	190
8	Greece	52	2.53%	SE	102	69	171
9	Brazil	47	2.28%	Avg	107,94	52,19	160,13
10	Portugal	45	2.19%	AT	84	68	152

As seen in Table 4, Italy has the highest number of papers in smart city, but it is forth in smart grid. While Spain does not take place in top 10 countries regarding smart grid, in smart city publications it is forth country. Obviously, European countries are seen to be more interested in smart city studies.

**Table 5.** Published academic study counts of top 10 countries on smart grid and smart city subjects together.

Rank	Country	Pcs	Percentage
1	China	1011	14.49%
2	USA	917	13.15%
3	India	505	7.24%
4	Italy	498	7.14%
5	Germany	273	3.91%
6	Spain	259	3.71%
7	UK	259	3.71%
8	Canada	258	3.70%
9	Australia	175	2.51%
10	Brazil	153	2.19%

In Table 5, it is shown overall study counts of both smart grid and smart city topics. Considering the top 10 countries, 35.19% of academic studies have been published in Asia, 29.92% in Europe and 27.27% in North America, respectively.

### 2.3. Smart Grid Approaches of Some Countries

In this section, we investigate the interest of countries and regions on smart grid subject. First, we consider emerging developments in Europe. In 2007, the European Union made a decision to reach goals which are 20% reduction in greenhouse gas emissions (GHG), 20% increase in energy efficiency, and 20% of EU's energy consumption from renewable energy by 2020 [5].

**Table 6.** Amount of investments (million EUR) in EU countries on smart grid R&D and demonstration projects [6].

Countries	Demonstration	R&D	Total
DE	520	289	809
UK	628	146	774
FR	550	130	680
ES	344	177	521
DK	117	161	278
IT	172	67	239
NL	166	43	209

CH	47	76	123
NO	41	71	112
FI	29	77	106
PT	62	27	89
EL	53	25	78
PL	32	36	68
LU	61	0	61
Non-EU	30	28	58
RO	49	9,1	58,1
CZ	36	7,1	43,1
SI	28	13	41
IE	25	8,8	33,8
HU	14	1,8	15,8
SK	3,7	8,2	11,9
LT	8,9	1,2	10,1
BG	5,1	2,9	8
LV	3,5	4,2	7,7
HR	2,4	3,8	6,2
CY	1	3,7	4,7
EE	2,3	1	3,3
MT	1,2	1	2,2

**Table 7.** Number of smart grid R&D and demonstration projects in EU [6].

Country	Demonstration	R&D	Total
DE	152	178	330
UK	101	96	197
DK	50	131	181
ES	79	99	178
FR	91	68	159
IT	77	71	148
AT	46	82	128
NL	58	66	124
BE	44	65	109
CH	21	70	91
SE	37	53	90
NO	22	64	86
Avg	32	43	75
PT	26	42	68
EL	29	33	62
Non-EU	18	39	57
FI	24	31	55



PL	16	34	50
SI	22	21	43
IE	14	20	34
RO	14	16	30
CZ	9	13	22
HU	10	7	17
BG	7	10	17
HR	5	9	14
SK	4	8	12
LV	3	6	9
CY	3	6	9
EE	3	3	6
LT	3	2	5
MT	2	3	5
LU	2	0	2

The distribution of investment amounts and project numbers by countries in Europe are shown in Table 6 and Table 7, respectively. The number of demonstration projects is 992, and R&D projects are 1346. The amount of smart grid investments in EU countries is €3.346 billion for demonstration, €1.618 billion for R&D and totally €4.964 billion investments have been carried out according to [6]. As given in Table 7, Germany (DE) has the maximum project count and Luxemburg (LU) has the minimum one. The average demonstration number is 32 and R&D is 43. The average ratio of demonstration project counts is 42.43%. So, it represents R&D project counts are much more than demonstration projects.

It is obvious that China is one of the leading countries on smart grid. According to [7], China is the largest market in the world for power transmission and distribution. Smart grid, firstly introduced in 2006 in China and it was planned in three stages which are: (i) planning pilot stage between 2009 and 2010, (ii) construction stage from 2011 to 2015, and (iii) leading and promotion stage between 2016 and 2020 [8]. The Chinese government has been planning to invest \$91.6 billion between 2011 and 2020 for smart grid system. Hence, it is also foreseen to save 220 million tons of standard coal consumption [9].

In India, as of March 2017, installed power capacity is 326.832 GW [10]. However, transmission and distribution (T&D) losses are very challenging issue in India, nearly 22.77% in 2014. Distribution utilities are planning to reduce distribution losses under 12% by 2022, and under 10% by 2027, and also smart grid infrastructure investment will be \$44.9 billion between 2017 and 2027 in India [11].

According to Northeast Group, in South America, smart grid infrastructure investments including advanced metering, distribution automation, wide area measurement, home energy management, information

technology and battery storage will reach up to \$20.1 billion from 2018 to 2027. Brazil is the regional leader in this continent with regard to smart grid investment. In the other South American countries, eight of ten have developed important smart grid pilot projects. However, T&D losses are still at high rate with 15% in South America [12].

#### 2.4. Smart City Approaches of Some Countries

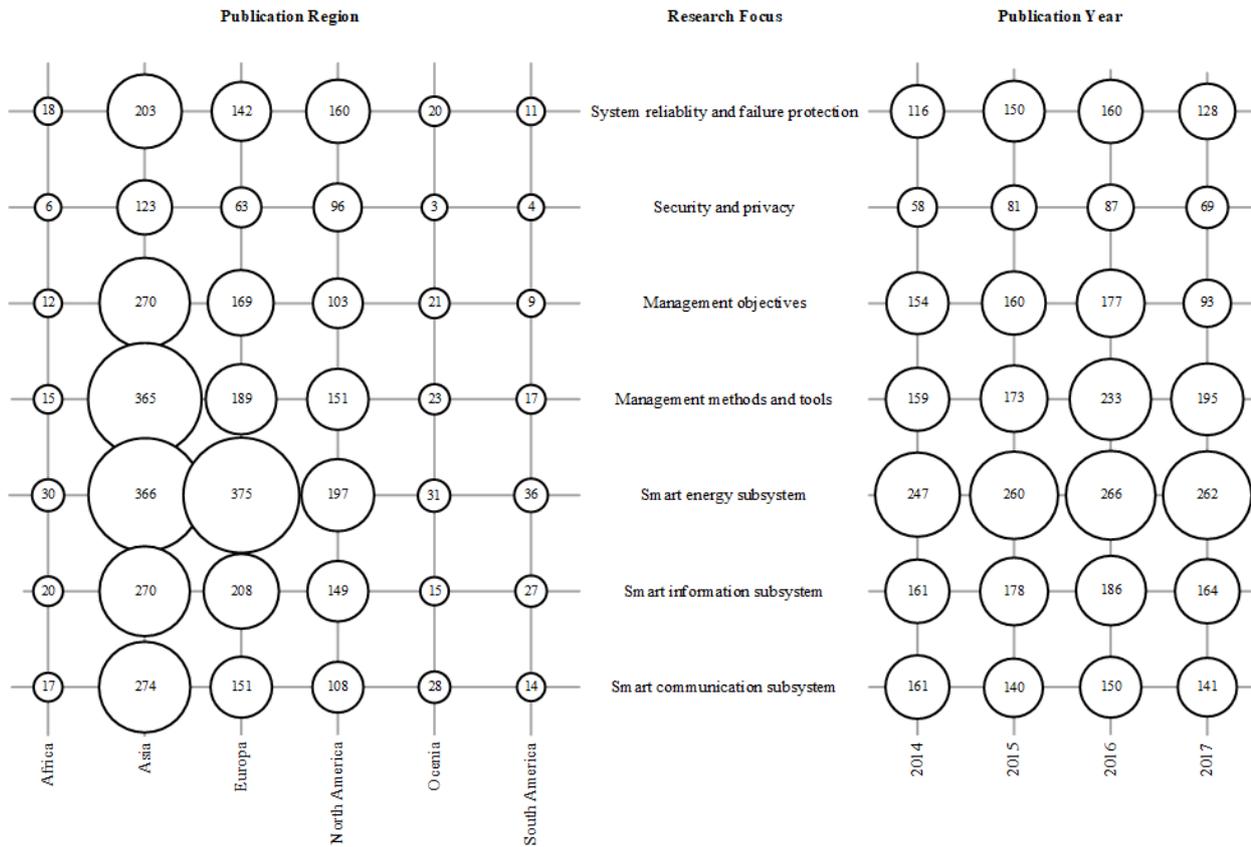
Smart city market in the world is growing regularly. As it was annually \$8.8 billion in 2014, by 2023 it is foreseen as \$27.5 billion. Total smart city investment in the world is expected \$174.4 billion with annually average 13.5% growth rate between 2014 and 2023 [13].

According to [14], in the EU, the highest number of projects regarding smart city belongs to UK, Spain and Italy. Besides, Italy, Austria, Denmark, Norway, Estonia and Slovenia have high number of projects in EU. In 2011, 240 of 468 European cities were carrying at least one of the smart city characteristics. Initiatives related to smart governance generally concentrate on Northern European countries including France, Spain, Germany, Sweden and UK and also Italy in Southern Europa. On smart mobility initiatives, Spain, Hungary, Romania and Italy have been well concentrated.

In August 2013, the Ministry of Housing and Urban-Rural Development of China declared 193 pilot smart city projects [15]. The Indian government announced to perform 100 cities as a smart city in two decades [16]. In order to the execution of 100 smart cities, it is approved nearly \$15.6 billion [17].

#### 2.5. Mapping

Figure 4 shows the mapping study results as a bubble graph. In this figure, research focuses regarding with smart grid are given with respect to publication region and publication year of 4918 papers. Hence, in the figure Y-axis shows the research focuses, publication region on the left side of the X-axis, and the publication year on the right side of the X-axis. Therefore, it presents a comprehensive point of view regarding smart grid studies between 2014 and 2017. Remarkably, smart energy subsystem is the most published topic in every continent and year. However, the least published topic is security and privacy of smart grids. It is seen that publication numbers of all topics are increased except smart communication subsystem between 2014 and 2016. While Asia, Europe and North America are the most paper published continents, Africa, Oceania and South America are the least published continents on smart grid. The most published paper is in Asia in the world which corresponds to %39.21 of whole world's papers on the subject. The following continents are Europe and North America, respectively.



**Figure 4.** Mapping of research focus on continent and publication year of academic researches regarding smart grid.

### 3. Conclusion

The papers from India are mostly within the subjects of smart infrastructure system, 52.66% of all 376 studies. Smart grid infrastructure investment is projected to total \$44.9 billion over the period of 2017-2027 in India. So, it can be inferred that the most published paper topic and government policy are overlapping. India is the third most papers published country in the world with 7.11% of all studies in smart grid and smart city.

According to smart grid projects outlook 2017, there are totally 950 projects regarding smart grid R&D and demonstration projects with nearly €5 billion, 642 of them that €2.82 billion have been completed and 308 of them that €2,15 billion are ongoing in Europe. Totally 1130 paper related to smart grid is published in Europe. According to Table 8, the most investment is performed by Germany, 15.40% of Europe. United Kingdom, France, Spain, Denmark and Italy are other countries that follows Germany, respectively.

**Table 8.** Top countries in EU in terms of SG # of published papers.

Top Countries in EU in terms of SG	Number of Published Papers	Published Paper Rate	Investment	Investment Rate
DE	214	19%	809	16%
UK	163	14%	774	16%
FR	76	7%	680	14%
ES	115	10%	521	10%
DK	61	5%	278	6%
IT	247	22%	239	5%

The remarkable point in Table 8 is that while Italy ranks sixth at smart grid investment, it is first in published paper number. Furthermore, the relation between the investment rate and published paper are nearly proportional in other European countries.



## Author's Contributions

**Macit Tozak:** Drafted and wrote the manuscript.

**Sezai Taskin:** Supervised the writing progress, provided technical support and helped in arrangement of manuscript.

**Ilker Yildirim:** Provided technical support and helped in manuscript preparation.

## Ethics

There are no ethical issues after the publication of this manuscript.

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