Research and analysis of energy internet from the perspective of NSFC

Congchuan Hu¹, Yongzhen Wang², Yuxuan Liu¹, Jing Zhang¹ and Yongtian Li³

¹ Luneng Group CO., LTD, Chaoyang District, Beijing, 100020, China;
² Energy Internet Research Institute, Department of Electrical Engineering, Tsinghua University, Beijing, 100084, China;
³ School of Environmental Science and Engineering, Tianjin University, Tianjin 300350, China

Email: wyz80hou@tju.edu.cn

Abstract. Energy Internet (EI) is an emerging discipline that integrates cooling, heating, power and gas in physical, information and value flows, so it has a very distinctive interdisciplinary feature. The current situation of EI needs to be sorted out and summarized in time, so as to provide a reference for its future development. To some extent, the National Natural Science Foundation of China (NSFC) reflects the research focus and trend of EI in China. Therefore, this paper tries to analyse the programs of EI from the perspective of NSFC, the results revealed that 1) EI becomes a research hot point of combined cooling, heating and power instead of electricity only after micro grid and smart grid; also, this is one of the reasons that researches on EI mostly focus on the electrical science and engineering currently; 2) One of the purposes for EI is to solve the problem of abandoning wind and light energy;3) The number of NSFC supporting programs involving the topics of EI, multi-energy complementarity and integrated energy system accounts for 43% of 124 EI-related funds totally; 4) The distribution of the NSFC supporting programs about EI reveals the crossing and integration of multiple disciplines, such as electronics and information systems, computer science, automation, management science and engineering, mathematics.

1. Introduction

Energy Internet (EI), as a new development form of energy system, has a deep integration between energy generation, transmission, storage, consumption and energy market and Internet, so as to achieve the multi-objective optimization of energy systems. Therefore, the EI and its concept have gained great attention in discussion of energy conservation, emission reduction and energy structure adjustment in China[1].

In fact, EI is closely related to multi-energy complementarity, comprehensive energy, smart energy, etc. [2, 3, 4]. It is necessary to expound the relationship of above concepts and their research history at different levels and dimensions, to obtain a clearer understanding about EI. To some extent, the National Natural Science Foundation of China (NSFC) reflects the research focuses, development history and progress trend of China's frontier science and technology. For example, Du Jun et al. [5] searched funds information about oncology in the NSFC Science Information System, including its date of application, funding category, application code, supporting unit, approved amount and other information. Chu Hanting et al. [6] analyzed the distribution of NSFC supporting institutions and the research characteristics of funding programs in the field of NSFC recommendation system, through
the statistics of nearly five year funds in general programs and the programs for young investigators. Therefore, this paper, from the perspective of NSFC, sorts out and analyzes the development history and status quo of EI in China, so as to provide references to the development and research of Chinese EI.

2. Research objects setting and its searching method

Based on the key words about EI issued on the NSFC in 2019, and some key references on EI are also considered in this paper [7-9], the following keywords are selected as objects of EI in this paper: heating and cooling, virtual power plant, micro energy network, energy complementarity, comprehensive energy, energy router, EI, block chain + energy, big data + energy, energy + business, consumption, the source-network, smart grid, micro-power grid. These keywords can be searched according to the method of keywords included in the title, without considering the keywords contained in the body of the funds. At last, several results are revealed as the following:

3. Results and discussion

3.1. Total EI-related NSFC supporting programs and its annual distribution

Firstly, there are a total of 124 EI programs supported by NSFC from 1997 to 2018, as shown in Figure 1. Simultaneously, the supporting programs related to EI are increasing year by year. For example, since 2012 (exclusive of 2018), the number of NSFC supporting programs related to EI has reached 4 (2012), 5 (2013), 9 (2014), 13 (2015), 24 (2016) and 35 (2017), respectively. Two reasons are conclude as follows:

On the one hand, it can be seen that since Energy Internet became the hot topic in Third Industrial Revolution at 2011, EI has been regarded as one of the core keywords in the energy system of NSFC. At the same time, during this period, the Energy Internet Research Institute of Tsinghua University was established in April 2015. In October of the same year, the Energy Internet Research Center of North China Electric Power University was built up. Also, in 2016, the Smart Grid Research Institute of State Grid was changed into the Global Energy Internet Research Institute. From September to November 2018, China Energy Research Association, IEEE PES and China Electrical Engineering Society respectively set up their Energy Internet professional committee. The establishment of the above research institutions accelerated academic researches on key technologies of EI and promoted the funding programs related to EI.

![Figure 1](image.png)

Figure 1. Total distribution of NSFC supporting programs related to EI.
On the other hand, it can be seen that Energy Internet is not a new concept. It is established on the basis of the evolution of energy system under the development of social economy and technology. Accordingly, the supporting program of NSFC of EI reflects the trend of keywords selection and expansion. In detail, programs related to the broad concept of Energy Internet have been supported in the early stage by NSFC. For example, in 2010, Shanghai Jiao Tong university was approved as the fund project of "research on the dynamic characteristics of combined cooling, heating and power supply building energy system based on dynamic load prediction", which explored the design and control methods of energy system matching building load characteristics. In 2013, Tianjin university was supported the fund project named "general modeling, simulation and theoretical research on security analysis of integrated energy system based on extended Energy Hub", and put forward a variety of general models of integrated energy system [10-12].

3.2. The most related keywords with Energy Internet in NSFC
In last two decades, it is necessary to accelerate the development of clean energy in order to reduce carbon emission and fulfill the commitment of coping with climate change. In fact, China is rich in clean energy resources, such as hydropower, wind power and light energy, which exceed 660 million, 3.5 billion and 5.5 billion kilo watts respectively [13]. However, these clean energy resources are in an unbalanced distribution nationwide. Both wind power and light energy are operated at random. Therefore, China was facing the severe problem of abandoning wind-water-light power with its interregional grid construction lagging, serious power barriers between provinces, and imperfect market mechanism in power operation during the 11th Five-Year Plan [14].

Figure 2. Distribution of EI-related NSFC supporting programs by category.

Therefore, on the one hand, the scientific researches on renewable energy consumption have become an urgent need. It can be seen from Figure 2, 30 approved funding programs are involved in energy consumption, which is the most among the NSFC supporting programs related to EI. The problem of abandoning wind-water-light power has been relieved to some extent through the keen attention to the renewable energy consumption during the 12th and 13th Five-Year Plans. For example, the ratio of wind curtailment dropped by 5 percentage points during the 13th Five-Year Plan. The light electricity curtailment decreased by 1.8 billion kWh. Therefore, the construction of EI to realize cross-
regional, trans-continental and even global optimal allocation of clean energy will become a hot issue in the future.

On the other hand, there are as many as 49 NSFC supporting programs involving the topics of energy Internet, integrated energy system and multi-energy complementarity, most of which are also concentrated in electrical science and engineering disciplines. This is closely related to the reason that the researches on electricity have been shifted to the ones on the combined cooling, heating and power in EI after micro-grid and smart grid. Among them, the number of approved funding programs including EI in title is 9 (2014), 3 (2015), 6 (2016) and 7 (2017), respectively.

3.3. Distribution of EI-related NSFC supporting programs by disciplines

According to the distribution of approved funding programs involving EI in the disciplinary category (as shown in Figure 3), electrical science and engineering ranks the first with 57 programs. Engineering thermophysics and energy utilization comes the second with 20 programs. The automation and other first-level disciplines funded by NSFC include electronics and information systems, management science and engineering, macro-management and policy, mechanical engineering, computer science, water science and marine engineering, building environment and structure engineering, chemical engineering and industrial chemistry, etc. It can be seen that the EI involves three levels, such as physics, information and value levels, and four links, such as source, network, load and storage, indicating the flourishing inter-disciplines are integrated. Therefore, to build a global EI and promote the transformation of green and low-carbon energy is an objective of human beings.

![Figure 3. Distribution of EI-related NSFC supporting programs by discipline.](image)

3.4. Funding category of EI related NSFC supporting programs

The integration of EI is an important trend in its development process. On the one hand, the electrical power-related technologies such as efficient and clean power generation, advanced power transmission and transformation, operation control of large power grid, and energy storage, all are constantly making innovations and breakthroughs. On the other hand, energy and electrical power will be deeply integrated with modern information and communication technologies, such as artificial intelligence, big data, Internet of things and 5G [15].
In fact, the above unit technologies have difficulty and technical characteristics at different development stages. Therefore, different funding categories should be set up and complemented each other to form the current natural science funding system. As shown in Figure 4, EI-related NSFC supporting programs has cover the general funding project, the youth fund program, the key fund program, the joint fund program, the project of international (regional) cooperation and exchanges NSFC, the national outstanding youth science fund program, the local science fund program, the science fund project/emergency management program for directors of NSFC department of management sciences, and the joint research fund program for overseas Chinese, Hong Kong and Macao young scholars, covering nearly all NSFC categories. Among them, as many as 55 general funding programs for EI were approved, followed by 41 youth science funding programs and 8 local science fund programs.

![Figure 4. Percentage of NSFC supporting programs related to EI.](image)

3.5. Energy Internet, smart grid and micro grid in the view of NSFC

Figure 5 shows the number of NSFC funding programs related to EI and the funding programs related to smart grid and micro grid. Comparing with 124 EI-related funding programs, 139 funding programs related to smart grid were approved, while a total of 109 micro-grid project were funded by the end of 2018. The basic and applied technology research on the scientific issues related to EI was supported by the NSFC, and it has become one of the key directions.

With the large-scale grid-connection of new energy and the continuous improvement in energy saving and consumption reduction, the development of power grid requires the overall planning and coordination in centralized and distributed power generation, and power demand side management and diversified power consumption services. Furthermore, the flexible adaptability and interactivity of power grid need to be improved. In the future, with the growth of China's power demand and energy transformation, the existing power grid will be restricted by the grid structure, short circuit current, and regulatory capacity, so that they cannot meet the needs of large-scale access, large-scale configuration and flexible regulation of clean energy[16-20]. So we have to plan for long-term development and accelerate to build an intelligent and efficient EI.
4. Conclusions
Statistics, classification and analysis have been done on various NSFC funds related to EI in this paper. From the perspective of NSFC, some results revealed or proved as following:

![Graph showing number of NSFC supporting programs related to EI, smart grid and micro grid.]

**Figure 5.** Number of NSFC supporting programs related to EI, smart grid and micro grid.

1) Solving the problem of abandoning wind/light power is one of the external drives of EI research.
2) Following smart grid and micro grid, the EI becomes a new hot point in the parallel and integrated research of combined cooling, heating and power.
3) The programs related to EI, multi-energy complementarity and comprehensive energy system account for about one third in the total of NSFC funding programs.
4) The discipline involving EI is developing more diversely, such as electrical engineering, computer science and engineering, engineering thermal physics and energy utilization, electronics and information system, automation, management science and engineering, mathematics, building environment and structure, macro management and policy, and energy management.

It is worth noting that the results of this paper from the perspective of NSFC are helpful to the scientific exploration of EI, but there are also some limitations and inadequacies in this paper, and the definite conclusions will be drawn to the future EI, such as the funding programs by foreign government was not included, the keywords of the funding program are not the maximal, some demonstration projects of EI are not considered.

Acknowledgement
This paper is supported by the program of Active design and typical case study of building energy system driven by geothermal energy, which funded by Luneng Group CO., LTD.

References
[1] Wang Y, Zhang N, Kang C Q 2015 Review and prospect of optimal planning and operation of energy hub in Energy Internet *Proceedings of the CSEE* **35**(22) 5669-5681
[2] Zhao J, Wang Y, Wang D, et al. 2018 Recent advance on Energy Internet: definition, indicators and research method *Proceedings of the CSU-EPSA* **10** 1-12.
[3] Ai Q, Hao R 2018 Key technologies and challenges for multi-energy complementarity and optimization of integrated energy system *Automation of Electric Power Systems* **42**(4) 2-10,
[4] Dong Z Y, Zhao, J H, Wen F S, et al. 2014 From smart grid to Energy Internet: basic concept and research framework Automation of Electric Power Systems 38(15) 1-11
[5] Du J, Gao W H, Liu Z 2019 Analysis of Programs in Oncology Funded by Department of Health Sciences National Natural Sciences Foundation of China from 2010-2018 China Cancer 5 1-6
[6] Chu H, Xing X, Meng Z, et al. 2019 Analysis for National Natural Science Foundation of China Funded Programs on Recommender System Rese Computer Engineering and Applications 55(9) 259-263
[7] https://isisn.nsfc.gov.cn/egrantweb/.
[8] Guan Y G, Luo A 2019 Research direction and keyword revision of electrical science and engineering discipline of National Natural Science Foundation of China Proceedings of the CSEE 39(01) 126-129
[9] Chen R 2018 Key areas and key technologies of global Energy Internet power technology innovation Telecom Power Technology 35(11) 265-266
[10] Wang W L, Wang D, Jia H J, et al. 2016 Review of steady-state analysis of typical regional integrated energy system under the background of Energy Internet Proceedings of the CSEE 36(12) 3292-3306
[11] Sun Q Y, Hu S W, Zhang H G 2018 Modeling and application of We-energy in Energy Internet Sci Sin Inform 48 1409-1429
[12] Tu F L, Wu J Y. 2012 Using ANFIS to building load joased on the number of customers Journal of Civil, Architectural & Environmental Engineering (S2) 99-102
[13] Lu Y L, Han M X, Ren H B. et al. 2018 Progress on the design optimization of hybrid distributed energy systems Journal of Shanghai University of Electric Power 34(03) 229-235
[14] Pan E S, Li H, Xiao J Y, et al. 2018 Research on the development and transmission of clean energy in western China considering wide range coordination of multi-energy Electric Power 51(09) 158-164
[15] Chen R 2018 Key areas and key technologies of global energy internet power technology innovation Telecom Power Technology 35(11) 265-266
[16] Zhang Y 2018 Economic mechanism, efficiency evaluation and path selection of China’s Characteristics green development in new era Northwest University
[17] Zhang S N, Yang F, Lu Y H, et al. 2018 Research on global energy interconnection development index Journal of Global Energy Interconnection 1(05) 537-548
[18] Hou J, Wang C, Liu P 2018 How to improve the competiveness of natural gas in China with Energy Internet and “The Belt and Road Initiative” International Journal of Energy Research 42(15) 4562-4583
[19] Hong B, Zhang, W Zhou, Y et al. 2018 Energy-Internet-oriented micro grid energy management system architecture and its application in China Applied Energy 228 2153-2164
[20] Yin C, Yang D, Geng G 2015 Summary of energy internet programs in Germany and its enlightenment to China Dianwang Jishu 39 3040-3049