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Residential Energy Sustainability in China and Germany: The Impact of National Energy Policy System

Chunhong Sheng [1,*], Yun Cao [2] and Bing Xue [3]

[1] China Center for Special Economic Zone Research, Shenzhen University, Shenzhen 518060, China
[2] School of Governance, Technical University of Munich, 80333 Munich, Germany; yun.c.cao@gmail.com
[3] Institute for Advanced Sustainability Studies e.V. (IASS), 14467 Potsdam, Germany; bing.xue@iass-potsdam.de
* Correspondence: chunhongsheng@szu.edu.cn

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Abstract: The energy consumption and carbon emission of Chinese households is growing rapidly and will continue to do so for the near future. Currently, Chinese energy policies mainly focus on the industrial sector instead of the residential sector. Among industrialized countries, Germany has performed relatively well in the residential sector, which can provide valuable lessons for China. This paper investigates the policy-making, implementation, and resulting patterns of Chinese and German residential energy policies from a multi-level perspective. The policy system study provides a holistic view over the factors influencing residential energy sustainability. The main findings are: (1) the German residential energy policy system follows a hybrid policy model, combining top-down and bottom-up policy designs, with more demand-side or market-oriented policies, and a high level of public participation, resulting in remarkable headway toward sustainability in the residential energy sector; and (2) the Chinese energy policy system is characterized by top-down, supply-side oriented market policies with limited public participation. The policy implication of this study for China is to shift its top-down policy paradigm to a hybrid policy model that facilitates public participation in the residential energy sector.

Keywords: residential energy; energy policy; China; Germany; public participation

1. Introduction

Residential energy sustainability is critical in tackling climate change. The residential sector is one of the main energy consumption sectors, besides transportation, industries, service, and the commercial sector. The sustainability of the residential energy sector is not a primary focus of the Chinese national energy policies. In China, the growth of residential energy consumption is faster than that of the industrial sector since 2011. The data show that, in 2015, the energy consumption of China's industrial sector decreased by 1.15%, while the energy consumption of the residential sector rose by 6.11% [1]. Residential energy consumption made up about 11.7% of the total energy consumption in China in 2015, and it is estimated that residential energy consumption will continue to grow. Chinese residential energy consumption is at a crossroads and national policy design matters for its future development. This paper attempts to find a best case from the international community to shed some light on how to achieve sustainability through national energy policies.

Germany represents a good case study of how to achieve residential energy sustainability through various national policies. From the development of residential energy consumption in major industrialized countries, it is obvious that households with similar living standards or income can have very different energy consumptions and vastly different levels of CO_2 emissions (Table 1).

In 2014, residential electricity consumption in the United States was about 2.8 times that of Germany. From 1990 to 2014, residential energy consumption decreased 8% percent in Germany, while it is increased by 47.6% in Japan. Further, while German households consumed more electricity than French and English households in 1990, by 2014, the situation had reversed. One strong explanatory factor for these huge differences in residential energy consumption across industrialized countries is the diverging national energy policies, how it is implemented and the resulting policy paradigms. This article argues that the pattern of national energy policy systems matters in achieving residential energy sustainability.

Table 1. Average electricity consumption of households per capita of China, Germany, Japan, the United States, France and England in 1990 and 2014 [2].

Average Electricity Consumption of Households per Capita kWh/cap	China	Germany	Japan	The United States	France	England
1990	41.8	1725	1491	3702	1659	1638
2014	524	1586	2200	4393	2197	1687

China and Germany are both strong regulatory states in the energy sectors as well as leaders in energy transition. This article investigates the impact of national energy policy paradigms on residential energy sustainability by comparing China and Germany's policy system in the residential sector. China and Germany adopted different policies tools to increase the share of renewable energy sources in energy consumption and energy conservation in the residential sector. This article compares their policy-making, implementation, and results in the renewable energy and energy saving in the residential sector and then analyzes the differentiated patterns in terms of political, economic, ecological, and social dimensions of sustainability. Finally, this article illustrates the possible implications for China and the potential of bilateral cooperation between the two countries.

2. Literature Review and Analytical Framework

Much of the literature on energy policy focuses on energy reduction policies and efforts in the industrial sector in China, which is to be expected, as China has put significant effort into regulating the industrial sector. However, an increasing number of scholars are focusing on the impacts of national energy policies on residential energy consumption, even though the importance of the research area is underappreciated. Households play an increasingly important role in energy consumption, not only by pro-environmental behaviors (switching off lights or purchasing energy-efficiency electric appliances), but also by acting as an economic and social unit (making energy-efficient housing renovations as homeowners, or building energy-sustainable local communities) [3].

The Chinese government has adopted multiple policies to reduce residential energy consumption. Existing research has analyzed the tiered pricing system of electricity (TPE) and its impacts on household energy conservation [4–6] as well as electric vehicles for private families [7,8], to name a few. The majority of studies focus either on the public acceptance of some specific policies or the effects of the specific policies [9]. There is a lack of holistic studies evaluating the design of the regulatory tools and the general patterns. Therefore, this research aims to find similar patterns among the different policies and the common factors that lead to the policy results, and attempts to advance our understanding of the policy system and its impact on sustainability through a systematic investigation of the policy-making process, the involved stakeholders, and the policy results. A comparative study of policy patterns can help us to find the similarities and differences between various policies [10].

Interactions between public policy systems and their impacts on sustainability in energy sector have been explored by various scholars [11–14]. Sovacool [11] argued that polycentric policy making mechanisms can result in better climate change and energy governance through a comparison of Bangladesh, Brazil, China, and Denmark. He emphasized the involvement of different stakeholders, from global, national, local, to public in the decision-making process, which can achieve "equity, inclusivity, information, accountability, organizational multiplicity, and adaptability." While both

China and Germany have polycentric policy mechanisms, their residential energy policies are not equally effective, which key factors leading to heterogeneous policy results could be identified by examining the broader policy systems in both countries.

Falcone et al. [12] demonstrated that the networking of different actors involved in the decision-making process can result the best outcome in terms of cooperation. While some policy systems allow various actors to participate in the policy making, implementation, and assessment process, others have limited channels to embrace various actors into the system. Many scholars claim that a policy mix with multiple policy goals is necessary to achieve a sustainable energy transition [13,14]. This study argues that both the policy mix and the policy system generating new policies matters. Kivimaa and Kern [14] demonstrated that a policy system including both dimensions of policy mixes by "creating the new" and "destructing the old" can make sustainability transitions more possible. This study shows the virtue of comparing the policy paradigms of different countries in order to identify the important factors that promote a sustainable energy transition.

This study deploys a multi-level analysis approach to study the national, provincial, and local levels of policy actors, thus facilitating the understanding of the roles that macro-level (national government), meso-level (local governments and firms), and micro-level (households and individuals) actors play in the policy system [15–17]. The macro level mainly embodies governmental interference in residential energy sectors through laws and regulations. The meso level includes local governmental bodies and firms, examining the power of market-oriented policies. The micro-level studies the role of households and individuals. The channels of between different levels are stressed; for example, if households and individuals have opportunities to exert their influence at the meso and macro levels in forms of social organizations.

To measure the policy sustainability performance, four key dimensions based on the United Nations Sustainable Development Goals (SDGs) are discussed in this article [18]. The first is the political perspective, which checks how policy affects public participation in residential energy; the second is the economic perspective, which checks the costs and benefits of household energy; the third is the ecological perspective, which checks the environmental impacts of national energy regulation on households; and the fourth is the social perspective, which looks at social fairness, such as energy poverty issues. Sustainability research embodies not just the analysis of the existing human–environmental problems, but also the practical solutions to these problems, which makes it both descriptive-analytical and transformational in nature. Indicators of sustainable development on affordable and clean energy which can be used for comparison between different countries include, for example, the reduction rate of primary energy consumption, the share increase of renewable energies in final energy consumption or electricity consumption and energy consumption and CO_2 emissions from private household consumption [19].

In this article, three independent variables are chosen to explain variance in residential energy sustainability (Figure 1): the first is related to command-and-control regulation: the degree of governmental interference as an indicator to measure the policy's influence on residential sector. The second explanatory factor is based on market-driven residential energy policies: the level of involvement of supply or demand side policies. The third independent variable is the freedom of the public in the voluntary policies to set up organizations regarding residential energy sustainability.

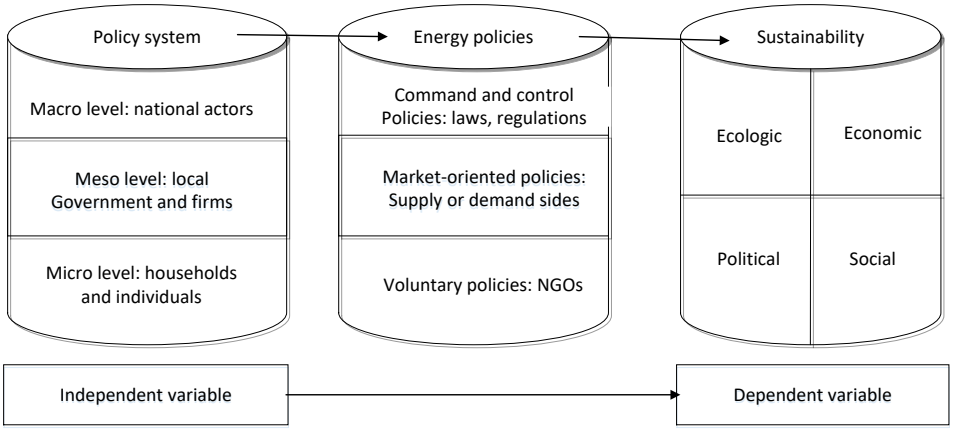

Figure 1. Independent and dependent variables.

3. Data

As introduced above, residential energy policies in China and Germany can be grouped into command and control, market-driven and voluntary energy policies (Table 2). Case studies are used to analyze the impact of national energy policies on the residential energy sector, which is often used in the comparative studies of public policies [20]. Comparative policy analysis helps to improve the understanding of how cultural traditions, political competition, and governmental structures influence public policy characteristics. International case comparisons can help to collect positive and negative experiences, solve global policy issues, and facilitate international cooperation [21].

Table 2. China and Germany's major policies for residential energy management.

	China	Germany
Command-and-control energy regulation	Law of the People's Republic of China on Conserving Energy Renewable energy law Provisions on the Administration of Energy Conservation for Civil Buildings Opinions about Renovation of Materials for Wall and Energy Conservation in Construction Regulation on Energy Conservation in Civil Buildings The 11th, 12th, 13th the Comprehensive Work Plan for Energy Conservation and Emission Reduction Green Building Action Plan Opinions of promoting the clean heating in northern China Interim Management Measurements for distributed solar energy projects	Thermal Insulation Ordinance Renewable energy sources act (FIT in EEG) Energy Performance of Buildings Smart Metering Further development of Energy savings ordinance 2014 Energy Efficiency Strategy for Buildings Heating Installation Ordinance Energy industry act
Market-oriented energy regulation	Residential tiered pricing for electricity (TPE) (Mandatory) Peak and valley pricing for residential electricity (Voluntary) Residential tiered pricing for gas Home Appliances Going to Countryside	On-site energy consultation Market Incentive Program for Renewable Energies in Heat Market KfW Energy-efficient Construction Energy efficiency checks for low-income households Replenishment of the KfW programs for energy-efficient construction and renovation Upgrading the CO_2 Building Renovation Program Quality assurance and the optimization of existing energy consultation
Voluntary energy regulation	Home appliance's energy efficiency labeling Household energy conservation propaganda, including education, public advertising, outdoor slogans Assessment standards for green buildings	Environmental Label "Blue Angel" Energy Consultancy and Energy Checks of the Federation of German Consumer Organizations Energy Labeling of Household Appliances Energy Efficiency Campaign National Top Runner Initiative

Empirically, we conduct a comparative analysis of residential energy sustainability in China and Germany because not only are the two countries global leaders in formulating and implementing national energy policies, but both are actively transitioning toward sustainable energy development. However, the results diverge: energy consumption in the Chinese residential sector keeps on growing, while the German's is falling. Thus, these two countries provide a comparison of two different approaches that can be used to identify those factors contributing to energy sustainability in the residential sector. This article also adopts a systematic analysis for China and Germany's national energy policies regarding the residential sector. The information of this article comes from diverse sources. It includes mainly government documents, academic works, and expert interviews.

3.1. The Chinese Residential Energy Policy Top-Down Policy System

The Chinese power sector has a typical top-down policy making structure, with the central party and government departments at the top national macro level making key decisions (Figure 2). Implementation is the responsibility of the State-owned enterprises (SOEs), provincial and local governmental departments, as well as relevant companies, such as home appliance producers, while households are the policy recipients at the bottom of the system. The Chinese Party Central Committee (CPCC) and the State Council lay out the general principals of the energy policy, while the National Development and Reform Commission (NDRC), particularly the National Energy Administration (NEA) and the Department of Price in NDRC, the Ministry of Ecology and Environment (MEE), the Ministry of Finance (MOF), and the Ministry of Housing and Urban-Rural Development (MHURD), are the specific policies makers.

At the meso level are the various energy policy implementation actors. The first group consists of different energy SOEs, with power generation companies, including the China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, State Power Investment Corporation (the big five), and other small power companies. There are also the power grid companies, including the State Grid and China Southern Grid, Inner Mongolia Power, and other local grid companies. In 2015, the CPCC and the State Council published a policy on Further Deepening the Reform of the Electric Power System; subsequently, many new power broker companies have been established [22]. The second group of residential energy policy implementation actors consists of different levels of local governments, including the provincial governments, local bureaus of price, local bureaus of environmental protection, etc. These local government departments usually make specific implementation action plans according to the local conditions. The third group of policy implementation actors consists of the producers related to residential energy sectors, such as home appliance producers, building developers, and other energy products producers.

At the bottom micro level are the households. They are the policy targets, in this top-down system. It is difficult for the households to participate in the macro national policy-making process and the meso level of policy implementation process. The different policies targeting the residential energy sector are limited in the ability to realize policy aims, energy savings, energy efficiency, and renewable energy in the residential sector. Tiered pricing for electricity only targets the top 20% of households, while over 60% of China's population lives in urban areas. Furthermore, the electricity price of the top 20% of households is still relatively low [23]. Coal and gas in northern China is confronted with serious problems due to one cut policy without consideration of the market factors [24]. The home appliances going rural policy raised the share of home appliances greatly in rural areas in general. The share of energy efficient buildings and distributed renewable energy generation is still very small in the household sector [25,26].

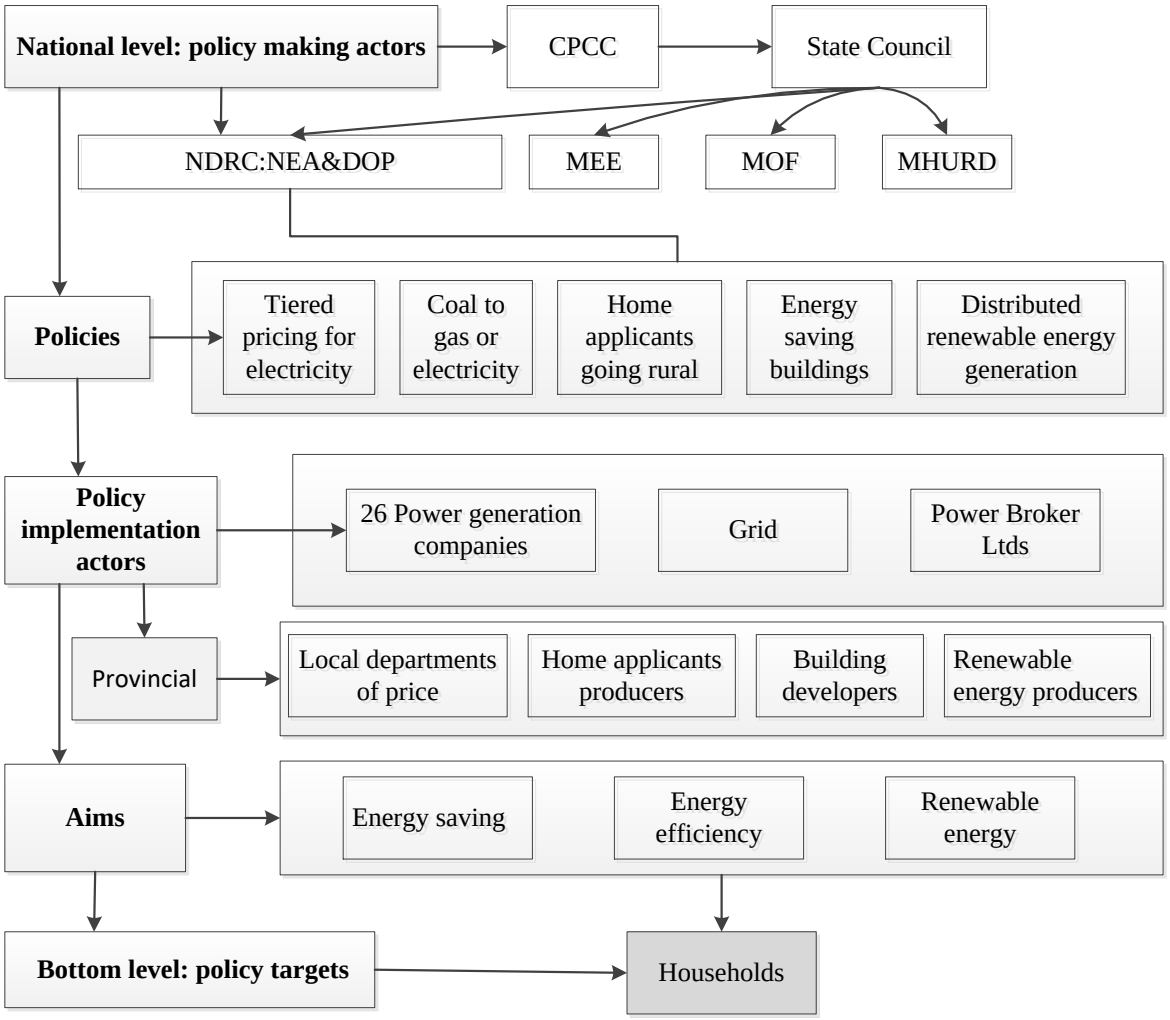

Figure 2. Chinese residential energy policy makers, policies, and implementation actors (authors generated from different sources, including governmental documents, laws, and regulations).

3.2. The German Residential Energy Policy System

The German power sector has a hybrid policymaking structure, including the different levels of governments, representatives of industrial actors and local communities (Figure 3). On the national level, the federal government needs to find a consensus between the national policy targets and the local interests, and then designs policies accordingly. The major implementation actors are companies in the energy sector, the federal states and local governments, financial institutions and intermediaries, as well as relevant companies, such as energy consultancy firms. Households are not only policy recipients on the bottom, but also play the roles as renewable producers, investors of energy-efficient renovations, and owners of larger installations in local communities. The federal legislative (Bundestag and Bundesrat) lay out the legislative basis for energy policies, while the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUB), and the Federal Ministry of Finance (BMF) are the most involved policymakers.

At the meso level are the various energy policy implementation actors. The first group consists of different power energy companies, including RWE, E.On, EnBW, Vattenfall Germany, their spin-offs such as innogy and Uniper, and other small power companies or municipal utilities (Stadtwerke). The largest four transmission grid operators are 50 Hertz, Amprion, TenneT, and TransnetBW. The renewable industry is highly heterogeneously constructed, ranging from big players such as

Siemens, Enercon, and SMA, to small firms and Stadtwerke and beyond to individual homeowners, and is represented by organizations such as the Renewable Energies Agency (AEE) [27]. The second group of the residential energy policy implementation actors consists of different levels of governments, federal agencies, and government advisory bodies such as the Federal Environmental Agency (UBA), the Federal Motor Transport Authority (KBA), and the Federal Network Agency (BNetzA), among others [27]. Local governments usually make specific implementation plans according to local conditions. The third group of policy implementation actors consists of the different producers related to residential energy sectors, such as home appliances' producers, building developers, and other energy products producers.

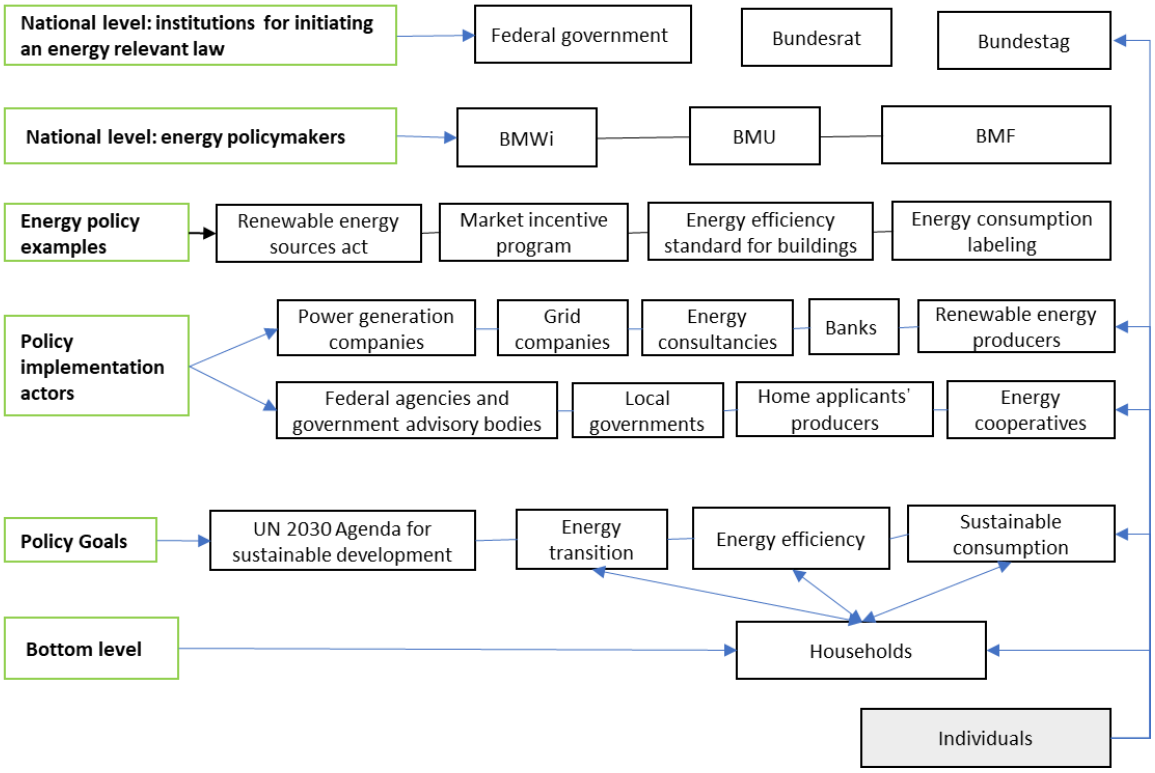

Figure 3. German residential energy policy makers, policies, and implementation actors (authors generated from various sources, including governmental documents, as well as laws and regulations).

At the bottom micro level are the households. They have developed support for phasing-out of nuclear power in the agenda and actively implemented energy transition policies, with efforts ranging from home rooftop photovoltaic arrays to investing in local citizen energy cooperatives. The German energy policy system is a hybrid approach, with both top-down and bottom-up policies. Households on the micro level have the right to organize social organizations in the form of non-governmental organizations or energy communes, which then participate in meso-level policy implementation. They can also influence the national energy policymaking through their votes. As Chinese households are limited in setting up social organizations and limited in investing in energy system, they have limited influence on the meso and national energy policies.

4. Chinese Energy Regulations in the Residential Sector

The Chinese energy system has a long history of subsidizing residential electricity consumption with industrial and commercial prices, with residential electricity pricing being much lower than other sections [6]. Low residential electricity prices have failed to provide incentives for energy-saving in households. To change the low price for residential electricity, the NDRC promulgated the TPE in the residential sector in 2010, which became effective nationally in 2012. The TPE ensures that the

majority of residential consumers did not experience a rise in electricity prices, while only the 20% of the families in the third tier (the electricity price raises about 0.3 CNY per kWh) is impacted. Even among the 20% of the highest tier, a majority of these families which have a higher income are not motivated to save energy because they care more about the quality of life; therefore, the influence of the TPE is moderate in the energy efficiency field [23,24]. Furthermore, the top-down character of market-oriented policies suffers from the complexities of regional differences, and one size does not fit all; the three sizes of TPE do not fit all as well. The tension of TPE lies in the government dominated policy-making while the public lack information about TPE [28].

Most Chinese energy regulations is command and control rather than market-driven and voluntary regulations. The power system reform from 2002, separating power generation and power grids, does not touch the residential sector, since households are still not free to choose suppliers yet [29]. Currently, much of the Chinese command-and-control energy policies in the residential sector are in the form of the governmental regulations rather than laws. Its implementation largely relies on different levels of government bodies instead of the participation of the households. For example, the energy conservation for civic buildings targets public services related buildings, such as governmental buildings, schools, and hospitals, while it is not well implemented in the private residential buildings [30]. The governmental energy regulatory goals are often not backed up by concrete and detailed implementation actions. There are no specific standards for energy efficiency in residential buildings yet, for example. Even through China is a strong state country, compared with its large population in the form of households, its capacity to utilize administrative regulations for residential energy is limited. The Chinese government lacks the information, finance, and knowledge to implement its policies effectively.

In the market-driven energy regulation in the residential sector, the majority of policies target at suppliers to achieve its aims. Take the Home Appliances Going Rural in 2008 as an example, the key stakeholders are home appliance producers and provincial governments, as they are the ones applying for the funds and gaining the benefits, while the households are passively involved during the process. The consumers have limited power to supervise the actions of the producers and local governments, which resulted in corruption that twisted the policy purposes [31–33]. Some producers use second-hand or bad quality appliances to apply for the subsidy, thus subverting the aim of energy efficiency or savings. Typically, Chinese market-driven energy policy subsidizes the producers, thus influencing the residential sector indirectly. These fiscal policies tend to stimulate the economic development rather than improve the energy efficiency. The number of homes appliances in rural areas rose greatly after these policies, which resulted in the energy consumption of rural households soaring. In Figure 3, it is obvious that, after the Home Appliances Going Rural policy, rural ownership of the home appliances increased significantly (Figures 4 and 5), thus implying the growth of rural residential energy consumption as well. By the way, the "hood" in Figure 5 is the general group including exhaust hood, extractor hood, or range hood.

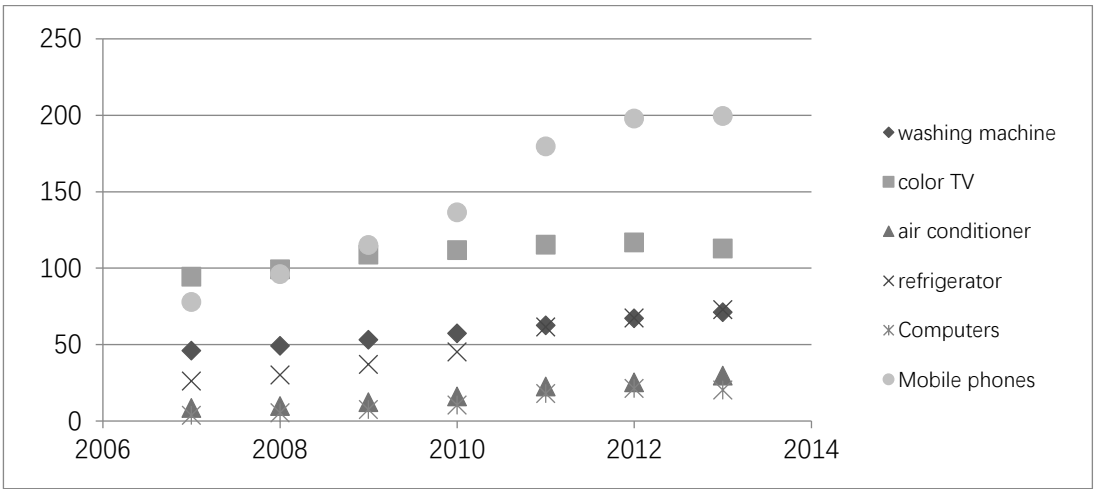

Figure 4. Home appliances ownership in 100 rural households after the Home Appliances Going Rural since 2008 [34].

The gap between urban and rural households is narrowed by the policy. This implies that the energy consumption of the rural household will gradually reach the level of the urban households.

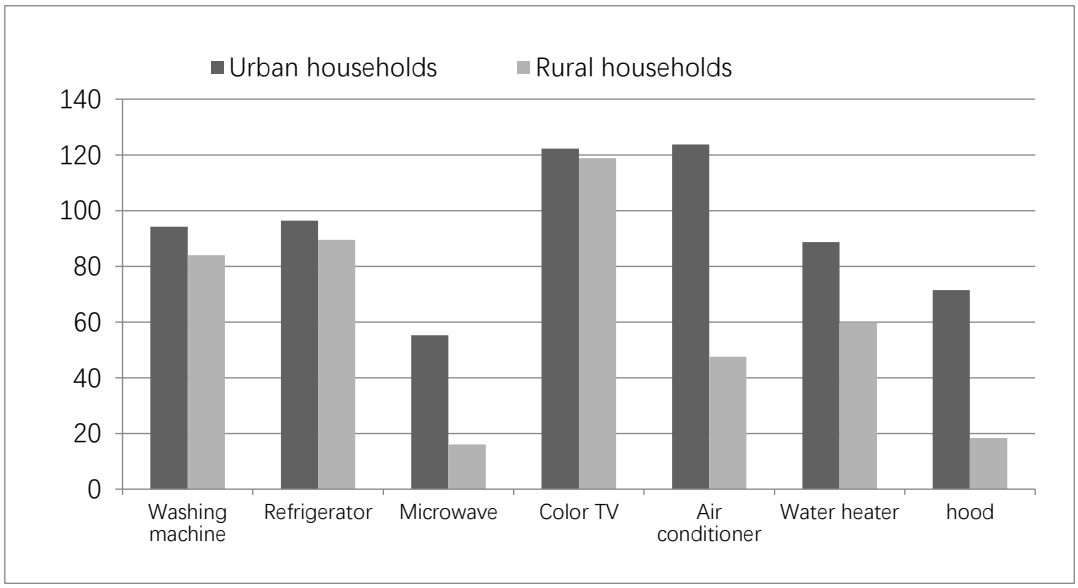

Figure 5. Household home appliances' ownership, percent of 100 households in 2016 [30].

The lack of demand side policy is a challenge for designing national energy policies in China, which is related to the third category of national energy policies that stimulate voluntary actions for sustainable residential energy management. The long history of the strong role of state in the power sector has simultaneously weakened social power. The Chinese government mobilized propaganda institutions to raise the public awareness in energy saving, such as public advertising, education, and slogans. However, the power of social organizations is constrained and limited in China [35], adversely impacting voluntary residential energy conservation. Taking urban community governance as an example, many property management teams in urban residential communities are not selected by residents in the community, which limits their participation in public affairs [36]. In the energy sector, for community energy saving, collective actions and self-governance for voluntary energy actions are needed, but these same collective actions are discouraged by the government, which also weakened social power in voluntary energy saving.

In rural areas, villagers' participation in renewable energy generation is still rare in China. There is a lack of policies that protect the interests of farmers as smaller investors in the renewable energy projects. Not sufficient compensations are provided to farmers who give up land for distributed wind energy development in China. While there are subsidies, distributed solar energy is not profitable for residents who install it on their roofs; thus, most family solar panels are installed by people who are professionals in the solar energy sector [37]. The limitation of social organization has prevented voluntary action that lead to residential energy savings and renewable energy generation [38].

5. German Energy Regulations in the Residential Sector

As the frontrunner of energy transition, Germany has rapidly increased its renewable energy share from around 6% in 2000 to 36% in 2017, and aims to reach 40%–45% in 2025, as set out by the Renewable Energy Sources Act [39]. Numerous studies show that the success of Germany can be traced back to well-designed energy regulations, combining the strengths of a comprehensive legal framework and initiatives from locally rooted actors. Public participants from the residential sector are active actors in the design of energy policies instead of passive recipients [40]. Since current household energy consumption in Germany accounts for 26% of the total national energy consumption [41], many regulations directly target private households.

To develop the renewable energy and to ensure the participation of final consumers on the power market, Germany has applied and reformed the feed-in tariff under the framework of the Electricity Supply Law and Renewable Energy Law many times to provide the most effective financial incentive for renewable energy producers and private household power generators. As regulated by these laws, not only must local grids buy and integrate the generated renewable power into its network, but the national cost settlement system was also redesigned to balance out regional disparities [42]. Through a series of legislations, financial subsidy programs, and improved energy consultancy services, the rights and possibilities for final consumers in the electricity markets are greatly strengthened. Currently, electricity prices in Germany are not decided by the government, but by the market competition principle. It is made up by the following elements (Table 3): 21% acquisition/sales, 25% grid maintenance fee, 23% renewable surcharge, and 16% value-added tax [43]. Household consumers can easily check and compare the electricity prices of different power providers and switch their electricity provider without undergoing a complicated process.

Table 3. Composition of power price for German households using 3500 kWh in 2018 [43].

Composition	Acquisition/Sales	Grid Fee	Value-Added Tax	Concession Fee	Renewable Surcharge	Electricity Tax	Other Surcharges
price (ct/kWh)	6.18	7.27	4.70	1.66	6.79	2.05	0.55
percentage	21%	25%	16%	6%	23%	7%	2%

Due to the major environmental impacts in the manufacture and consumption of energy-intensive home appliance products, market-based policies in Germany not only focus on the manufacturing processes or product attributes but also on consumer behaviors. Thus, the key stakeholders are not just the manufacturers of home appliances and governmental agencies, but also consumers and homeowners. To increase the sustainability of household energy consumption, public participation was further strengthened, not only by increasing the proportion of the renewable energy in the power mix, but also by guiding household energy consumption behavioral changes. A few studies analyze the private-household customers' preferences for renewable electricity products in Germany and the impact of energy policies on the residential energy consumption models [44,45]. The values perceived by electricity saving behaviors are not only caused by pure economic calculations, such as money-saving incentives, but also related to the customers' well-being [46].

In the housing sector, the well-designed legal framework has provided a high degree of policy stability. Compared to extensive governmental intervention in China, Germany has published many climate and energy-related policies in the form of law in the last decades [47]. This has helped

to protect investor incentives against uncertainties in the overall economic development. Many market-based and voluntary policies target directly end-users, for example the financial subsidies and energy-saving consultancy services are provided to the house owners to support energy-efficient renovations. Additionally, the Market Incentive Program (MAP) implemented by BMWi provides extra funding for small-sized renewable-powered installations as heating and cooling sources at home parallel to the large installations' subsidy program organized by the German Bank for Reconstruction (KfW). In 2015, the BMU initiated a new "Hauswende" policy, designed to facilitate energy conservation in renovation projects, while the NAPE introduced a new labeling system for existing heating systems as well as a "heat check" program to promote heating modernization.

6. Analysis

This article argues that the design of the energy regulation in the residential sector has strong impacts on its sustainability. Sustainability or sustainable development is a rich and evolving concept discussed and assessed in academia and in practice for many years. As defined by frameworks developed by different institutions and scholars, sustainability can be evaluated in the following four dimensions: political, economic, ecological, and social [48,49]. In this section, we discuss how the design of energy policies in both countries influences energy sustainability in the residential sector, focusing on the aforementioned dimensions.

6.1. The Role of State and Public in Residential Energy Political Sustainability

From the political perspective, sustainable residential energy policies should embrace a high level of public participation to ensure the success. Both countries have strong governmental regulation, yet with different styles. Currently, the Chinese energy policy mix is dominated by top-down policies, while Germany has a combination of top-down and bottom-up policies. An energy policy system with better performance needs both strong government regulation and broad public participation from the bottom [50]. Concerning the disruptive nature of renewable energy, it conflicts with traditional energy sources and energy systems, thus emphasizing the need for strong political willingness to push for transformation. Regarding the flexibility of renewable energy sources, particularly distributed renewable energy, active public participation is needed to fill the information gap facing governmental departments.

The different types of state dominance in energy governance matter as well in the residential energy sustainability. The Chinese government adopts administrative regulations, while the German government relies more on laws to promote residential energy saving and renewable energy development. German residential renewable energy developed much faster than Chinese residential renewable energy because Germany incorporated feed-in-tariffs directly into its renewable energy laws while China still lacks a concrete legal framework for distributed renewable energy development.

The level of state control and the autonomy of social organizations also have strong influence on residential energy sustainability. In China, the extensive state intervention has diminished the willingness of the public to participate in energy saving and renewable energy projects. Scholars argue that the Chinese public has a low awareness of energy saving issues, and one possible reason is that they are not given enough autonomy for energy governance issues, even in local communities of house owners. For energy saving measures, collective actions are needed, but it is strictly controlled in China. In Germany, the high autonomy degree enjoyed by social organizations has facilitated the public's active participation in energy cooperatives. For example, farmers can participate in energy cooperatives that generate renewable energy and they work together to save energy through collective measures.

6.2. The Economic Dimension

From the economic perspective, residential energy sustainability implies a sufficient energy supply for sustainable economic development and consumption modes. It is not only firm legitimacy

and long-term competitiveness that facilitates their sustainability efforts, but also consumer behavior that favors sustainable consumption [51]. To achieve energy efficiency goals, the government should encourage consumers to modify their consumption behaviors by providing the right financial and psychological incentives. Excessive governmental intervention in market-based policies can undermine the policy efficiency. Instead, the proper use of market-based policies, such as the expansion of the electricity market in Germany, has helped to redefine the role of the private households as consumers of renewably generated energy, as conscious electricity users, and as investors in energy-efficiency renovations, thus harnessing the huge potential of the public to accelerate the energy transition and sustainable energy consumption.

After reforming the electricity market and allowing the market to set electricity prices, residential consumption in Germany has maintained its proportion in the overall power consumption at a stabilized 26% between 1990 and 2016 [52], despite a more than doubling of GDP growth per capita over the same time period [53]. Some key statistics regarding electricity consumption in Germany between 1990 and 2014 are presented in Table 4, showing that energy consumption in households has been successfully decoupled from economic development.

Table 4. The development of household electricity consumption 1990–2014 in Germany [2].

	Unit	1990	2000	2006	2010	2014
Average electricity consumption of households per capita	kWh/cap	1725	1587	1713	1733	1586
Average electricity consumption of electrified households	kWh/hh	3943	3425	2605	3515	3079
Electricity consumption for electrical appliances and lighting	kWh/hh	1642	1926	1983	2200	2161
Electricity consumption for thermal uses	kWh/hh	2301	1499	1622	1315	918

Along with their rapid development in GDP growth, urban cities in China have seen a substantial rise in electricity consumption (Table 5). In 2016 and 2017, electricity consumption per capita in Beijing and Shenzhen was almost comparable with German averages. However, when comparing the long-term development trend of electricity consumption in both countries, German households have stabilized, if not gradually reduced, their electricity demand, while Beijing and Shenzhen households have increased per capita electricity demand by about 40% between 2010 and 2017, with an annual growth rate of 5%. If energy policies in China fail to stop, or slow, the fast-growing demand for electricity in the residential sector, per capita electricity demand will exceed that of Germany. There are huge potential energy saving and energy efficiency gains existing in the residential sector of Chinese urban areas. Furthermore, the link between economic development and electricity consumption must be broken by developing more renewable energy, by mobilizing residential energy savings, and by harnessing innovations in electricity generation and consumption models.

Table 5. Household electricity consumption in Shenzhen and Beijing 2010–2017 (kWh/per capita).

	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	729	727	791	750	793	808	900	1004
Shenzhen	814	858	993	982	1124	1127	1154	N/A

Source: The statistical yearbook of Beijing and the statistical yearbook of Shenzhen (2017).

6.3. The Ecological Dimension

From the ecological perspective, household energy sustainability should be assessed based upon its impact on the environment, with indicators such as GHG emissions, air pollution levels, and an energy consumption level that fulfills a sustainable living standard. The combination of environmental, energy, and climate policies in Germany in the last years have had substantial ecological benefits. The energy-related greenhouse gases emissions have dropped steadily since 1990, with a strong decline in the residential sector. The energy sector is key to reducing GHG emissions. In Germany, it currently accounts for more than 80% of the emissions [54].

In China, household CO_2 emissions have been increasing, despite the increasing share of renewable in the power mix (Table 6) [55]. CO_2 concentrations vary unevenly across regions. Since coal remains the primary resource used for power generation, GHG emissions are most severe in the north and northwest provinces, where fossil-fueled power plants are used [56]. CO_2 emissions are also remarkably different in urban and rural areas in China [57].

Table 6. CO_2 emissions of residential sector per household 2000-2014 in China (tCO_2/dw).

2000	2005	2010	2014
0.604	0.675	0.682	0.722

Sources: https://www.enerdata.net/.

Severe air pollution problems, especially in big cities in China, have raised public concerns and extensive policy reactions. Command-and-control measures for pollution control, such as shutting down fossil-fueled power plants or heavy polluted industries, are strictly implemented in mega-cities like Beijing, focusing on the supply side of power instead of the demand side. In the coal-to-gas project implemented in north China in 2017, many households experienced gas shortages and expensive power prices due to the limited gas supply capacity [58]. The level of state control over coal for heating is so high that it leaves little space for local adjustments. The implementation of coal bans in the winter of 2017 was backed up by fines and other forms of punishments, which gave households little flexibility to make their own heating decisions.

As representative social units, sustainable behavioral changes of households, neighborhoods, and local communities can have large impacts on their environment. Households are defined as more than a physical co-living arrangement, but also as people with heterogeneous needs sharing living spaces, making consumption decisions together, and interacting with the environment as a social unit [3]. Thus, household energy consumption behaviors can neither be simply viewed as a "mass" nor as a linear aggregation of the individuals. National policies need to delegate more policy-making authority to local communities, allowing them more freedom to implement policies tailored to local needs.

How China and Germany responded to air pollution caused by the burning of organic materials is instructive. Seasonal straw burning in rural China triggered extensive administrative supervision and punishments [59]. In Germany, the focus is on educating the public about the benefits of biomass and promoting biofuel installation upgrading through the Market Incentive Program [60]. Biomass is an attractive clean energy resource that is well developed and extensively used for heating and power generation in Germany. In its infancy, biomass is facing political, economic and technical challenges in China [61].

6.4. Energy Justice in China and Germany National Energy in Residency Sector

Energy justice in the residential energy sector is a critical in achieving sustainability. Energy justice can be observed in the decision-making process, the distribution of benefits and costs, as well as the concerns of the weak and poor in the energy systems [62].

In decision-making process justice, Chinese residential energy policy hardly involves the public. The lack of procedure justice has resulted in policy failure. In 2017, the Chinese governments in the north mobilized huge amounts of administrative resources to implement coal-to-gas and coal-to-electricity polices in heating of residential buildings. This administrative policy with strong environmental concerns failed in part due to issues of social fairness. It is reported that many residents suffered from serious cold weather because of the high price of gas and electricity after adapting the coal-to-gas or coal-to-electricity policy [24]. In contrast, the German energy policy making process actively engages the public: when big utilities companies sought to reduce the tariff for renewable sources, their efforts failed due to strong public opposition [63].

Regarding the costs and benefits of residential energy policies, the supply dominated energy polices in the Chinese residential energy sector is also an energy justice issue: the majority of the

benefits are enjoyed by producers, SOEs, and local governments, while the costs are borne by the public. Since most energy companies are SOEs, they have gained unproportioned benefits through the policies. For example, the benefits of renewable energy generation are reaped by the companies, but the renewable energy tariff is paid by citizens. In contrast, the German public was actively encouraged to participate in renewable generation through the FIT, thus enjoying the benefits of the renewable energy, which further results in increased public support for renewable [64]. In China, the potential high cost of residential energy policies is a barrier for more ambitious energy policies in the residential sectors. As the residential sectors have enjoyed a longstanding low tariff for electricity, it is hard for the government to raise electricity prices without giving the public a chance to benefit from the energy policies. To reduce the energy poverty issue caused by energy policies, the Chinese government decided to send renewable energy into the poor rural households. In the TPE system, poor families can enjoy some amounts of electricity for free. In Germany, the energy poverty concern has attracted the attention of the German government, and various financial and fiscal policies have been introduced to reduce the potential negative impacts of ambitious energy policies on low-income families.

7. Conclusions and Implications

This paper argues that, to achieve sustainable transition, it is important to establish a policy system that includes all relevant stakeholders, thus reflecting their interests as well their innovations. To have more successful public policies in residential energy sector, China can learn from the German hybrid policy system, which embraces various actors from different levels, and particularly, allows actors, such as the private and households, at the bottom or micro level to exert their influence on the meso and macro levels.

Although the state plays a dominant role in making energy policies in both China and Germany, the governance approaches are different, While in Germany, state intervention on energy transition is realized by enabling a strong legal framework that facilitates the broad participation of the public and improves information provision for sustainable consumption behaviors, state intervention in China is realized through an extensive bureaucratic system with administrative capacity focused on implementing centrally designed policies aimed at industrial sectors. For the German case, studies focus on the importance of bottom-up initiatives for effective energy policy-making [65,66]. This study argues it is also important to establish a policy system which enables more public participation as well as innovations to play an increasingly important role in sustainability transition. This article argues that the robust civic engagement in the German energy transition is largely due to the policy design of the government, particularly through the feed-in tariff in the Renewable Energy Law [12,45].

A well-designed energy policy system can achieve residential energy sustainability. Furthermore, with strong public participation, national policies can achieve better results. China not only needs to develop local knowledge, but also needs the international expertise if it is to achieve long-term sustainability [67]. One take away for China from the German case is the importance of engaging the public, through public participation in the process of policymaking and implementation as well as by providing incentives for bottom-up action. The Germany energy system shows that the public in the residential energy sector plays many roles: they are consumers, producers, political citizens, and investors. Individuals organize themselves into social units, such as households, local communities, energy cooperatives, NGOs, and so on, all contributing to energy sustainability. The implication is for China to have more demand-side policies that provide incentives for the public to participate in residential energy sustainability, acting as consumers, investors, and producers. Narrow public participation in the political dimension is not enough to explain the success or failure of public policies, including energy policies.

Another important implication for China is it should empower the public to establish social organizations that work toward reducing residential energy consumption and toward a more sustainable energy system. There should be more demand side policies that reduce the barriers for the public to enter into the energy market and that empower the public to enjoy the benefits of the

energy transition, thus encouraging them to help bear the costs of the energy transition. Concerning the limitation of this research, this article can only compare the general policies in the residential energy sector in Germany and China.

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Acronyms

TPE	Tiered Pricing for Electricity
SOEs	State-owned enterprises
CPCC	Chinese Party Central Committee
NDRC	National Development and Reform Commission
NEA	National Energy Administration
DOP	Department of Price
MEE	Ministry of Ecology and Environment of China
MOF	Ministry of Finance of China
MHURD	Ministry of Housing and Urban-Rural Development of China
BMWi	German Federal Ministry for Economic Affairs and Energy
BMUB	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMF	German Federal Ministry of Finance
UBA	German Federal Environmental Agency
KBA	German Federal Motor Transport Authority
BNetzA	German Federal Network Agency
CNY	China Yuan
kWh	Kilowatt Hour
GHG	Greenhouse Gases
NGOs	Non-governmental Organizations
MAP	Market Incentive Program
SDGs	Sustainable Development Goals
NAPE	German National Action Plan for Energy Efficiency
KfW	German Bank for Reconstruction

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