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An in-depth analysis of the evolution of the policy mix for the sustainable energy transition in China from 1981 to 2020

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HIGHLIGHTS

- Mapped evolution of China's policy mix for sustainable energy transition 1981–2020.
- Over time China forms complex policy mix by layering and packaging instruments.
- China has increased the diversity and number of policy instruments used.
- Rise in charges on emissions and decrease in subsidies for renewables is observed.
- Policy experimentation dominates policy instruments used to reduce carbon emissions.

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ABSTRACT

Global warming and the acute domestic air pollution in China have necessitated transition to a sustainable energy system away from coal-dominated energy production. Through a systematic review of the national policy documents, this study investigates the policy mix adopted by the Chinese government to facilitate its energy transition and how that policy mix has evolved between 1981 and 2020. The chronological analysis emphasizes two dimensions of temporal changes in the policy mix: (1) changes in the policy intensity and density, and (2) the shift in policy instrument combinations. The policy mix has evolved from a few authority-based instruments to the current response that has a large density of instruments with a good diversity of instrument types. The Chinese government imposes an increasing policy intensity on air pollution abatement and a decreasing policy intensity on renewable energy support, and experiments with innovative policy instruments to reduce carbon dioxide emissions. The evolutionary trajectory features layering new policy instruments, calibrating existing ones and some degree of policy replacement and sequencing. Overall, the study shows that the Chinese government has adopted a complex mix of policy instruments to abate emissions (e.g. carbon dioxide and sulphur dioxide) in the coal-based energy system and to support renewable energy technologies. The study provides an in-depth understanding of Chinese policy design in the environment and energy fields and contributes to the public policy literature by filling a research gap – the comparative lack of empirical analyses on the temporal changes in the policy mixes.

1. Introduction

To date, 184 parties to the United Nations Framework Convention on Climate Change (UNFCCC) have ratified the *Paris Agreement*, aiming to hold the global temperature rise under 2 degrees Celsius (°C) above pre-industrial levels over the course of the 21st century [1]. China is the largest CO_2 emitter, with more than 10 billion tons of emissions in 2014 [2]. Coal consumption is a major source of CO_2 emissions in China, accounting for about 72% of the total CO_2 emissions in 2014 [2,3]. Coal combustion is also largely responsible for China's severe air pollution [4,5], causing high public health risks such as respiratory disease, lung cancer and cardiovascular and cerebrovascular diseases [6–8]. As such,

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Abbreviations: CDM, Clean Development Mechanism; ETS, Emission Trading Scheme; FIT, Feed-In Tariffs; MEE, Ministry of Ecology and Environment; MEP, Ministry of Environmental Protection (dismantled); MRV, Monitoring, Reporting and Verification; MWR, Ministry of Water Resources; NEA, National Energy Administration; NDRC, National Development and Reform Commission; PDF, Pollutant Discharge Fee; SAT, State Administration of Taxation; SEPA, State Environmental Protection Administration (dismantled); TGC, Tradable Green Certificate; TCZ, Two Control Zones

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China's energy transition from the coal-based energy system to a low-carbon energy system with fewer emissions and a greater share of renewable energies is of importance to global climate change mitigation, domestic air pollution abatement and public health improvement.

Public policies play a crucial role in informing, directing and accelerating the energy transition [9,10]. Policy instruments to support renewable energy technologies are critical to the sustainable energy transition, yet the lock-in of the incumbent coal-based energy system creates barriers to the diffusion of alternative energy technologies [11]. Environmental concerns about air quality and climate change issues reflect a set of societal expectations or interests that purposively pursue the sustainable transition from coal-based energy systems [12]. Environmental policy instruments, such as emission trading schemes (ETS), can serve as concrete tools to destabilize the coal-based energy regime [13,14]. All in all, to move the transition to a sustainable energy system forward, a government needs to formulate a policy mix consisting of both policy instruments to support diverse renewable energy technologies and policy instruments to destabilize the lock-in of coal-based energy technologies [15,16].

It should be noted that a dramatic expansion of renewable energy infrastructure incurs unintended consequences. Take hydroelectricity as an example. Hydroelectricity is gaining worldwide interest, with China the leading country in developing small-scale hydropower projects [17]; hydroelectricity accounts for over 16% of the global electricity production [18,19]. Hydroelectricity has the advantages of low emissions per unit electricity generated, low operation and maintenance costs, operation flexibility even in remote rural areas and efficiency and profitability [19]. However, construction of hydroelectricity infrastructure, such as dams and reservoirs, alters hydrologic characteristics and has negative impacts on the downstream river ecosystem [20]. It is essential to ensure adequate environmental flows in the river to sustain aquatic ecosystems [21,22]. Some policy instruments, such as environmental impact assessments (EIA) and watershed-level management plans, have been used by governments to prevent the negative environmental impacts of hydroelectricity projects [17]. Renewable energy development should therefore be pursued in a sustainable way, and policy instruments are needed to mitigate these unintended consequences [19].

This study examines the evolution of the environmental policy mix that has contributed to the transition of the electricity generation industry to a lower level of emissions and a greater share of renewable energy technologies in China between 1981 and 2020. We focus on the policy mix containing three policy strategies: 1) reducing CO_2 emissions from the conventional coal-based energy technologies, 2) promoting renewable energy technologies and 3) controlling air pollution from the conventional coal-based energy technologies. The Chinese experience could shed light on transitions to sustainable energy systems in other country contexts.

The rest of the article is structured as follows. Section 2 provides a brief overview of the policy mix literature. Section 3 details the analytical framework, the data and the methods used. Section 4 traces the evolution of China's environmental policy mixes by five-year increments between 1981 and 2020 and analyzes the changes in the environmental policy mixes in China in-depth. Section 5 discusses the main findings and Section 6 concludes the article.

2. A brief overview of the policy mix literature

2.1. Conceptualization of policy mixes

The term "policy mix" refers to cases where policy-makers use bundles of policy instruments that are expected to attain policy goal(s) more efficiently and effectively than using a single instrument [23,24]. A policy mix contains abstract policy goal(s) and concrete policy instruments [25,26]. It also contains two other elements: the policy strategy and the instrument mix [27,28]. A policy strategy suggests a long-run strategic orientation serving the abstract policy goal(s), consisting of policy objectives and principal plans to achieve the objectives [27]. An instrument mix contains multiple policy instruments to attain the policy objectives of a policy strategy, and each policy instrument contains a specific policy target that contributes to a policy objective[1].

As an illustration, with the abstract goal of transiting to a sustainable energy system, one policy strategy is to support renewable energy technologies. In adopting this policy strategy, one of China's policy objectives is to increase the share of non-fossil fuel consumption to 15% by 2020, while the 13th Five-Year Plan (FYP, 2016–2020) outlines as the principal plan the development paths of various non-fossil fuel resources to achieve the policy objective, which is further concretized in a set of policy targets and instruments [29].

The concept of the "policy mix" is often used interchangeably in the literature with the concept of the "policy package" (see Appendix A1 for further explanation). As defined in [26], a policy package is "a combination of policy measures designed to address one or more policy objectives, created in order to improve the effectiveness of the individual policy measures, and implemented while minimizing possible unintended effects, and/or facilitating interventions' legitimacy and feasibility in order to increase efficiency."

2.2. Policy instruments' typology and interactions

Policy instruments, also known as policy tools or measures, are the building blocks of a policy mix [30]. Hood's "NATO" typology classifies policy instruments into four categories based on the use of governing resources: nodality, authority, treasure and organization [31,32]. According to [31,32], nodality-based policy instruments rely on a government's ability to disseminate or collect information; authority-based policy instruments rely on the legitimate authority a government possesses; treasure-based policy instruments lean on a government's ability to utilize its stock of money or fungible chattels to attain policy goals; and organization-based policy instruments are used when a government organizes its material and personnel resources, for example in the format of state-owned enterprises, to achieve policy goals. There are other typologies of policy instruments, but this study uses the NATO typology to address how a government utilizes its resources to shape society [32].

Policy mix research addresses the interaction between different instruments that affects the extent to which policy goals are realized [33,34]. Taeihagh et al. [30,35] and Taeihagh [36] have extensively explored the relation between policy instruments, policy goals and policy interactions, identifying five types of interactions among policy instruments: precondition, facilitation, synergy, potential contradiction and contradictions[2].

2.3. Temporal changes of a policy mix

From the temporal perspective, different modes of policy change exist that draw from historical institutionalism, emphasizing that transformative institutional changes can happen through endogenous

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[1] In this conceptualization, policy goals are considered at a higher level of abstraction than policy objectives [102]. The term "policy goals and objectives" refers to the direction of an intended action, not the action itself; "policy target" is a more specific, narrow and quantifiable concept [44,103].

[2] Accordingly, 1) *precondition* refers to the case where a policy instrument is strictly required for the successful implementation of another one; 2) *facilitation* refers to the case where the successful implementation of a policy instrument can make another policy instrument work better; 3) *synergy* refers to the case where two policy instruments "facilitate" each other; 4) *potential contradiction* refers to the case where two policy instruments come into conflict in terms of outcomes or incentives given certain contingencies; and 5) *contradiction* refers to the case where two policy instruments generate "strictly" conflicting outcomes or incentives.

and incremental change processes [37,38]. Streeck and Thelen [37] introduced the institutional change mechanisms of replacement, layering, drifting, conversion and exhaustion. 1) *Replacement* refers to the situation when new institutions replace existing ones; 2) *layering* refers to the situation of adding new elements to existing institutions; 3) *drifting* refers to the situation when old institutions remain constant in spite of changes in the institutional environment, causing a gradual erosion of old institutions; 4) *conversion* refers to the situation when existing institutions are re-deployed to serve new purposes; and 5) *exhaustion* refers to institutional erosion gradually over time. These modes of institutional changes are widely applied in public policy studies [25,36], where public policies are considered as institutions [37]. Policy changes through these mechanisms can be intentional or unintentional [39,40]. Policy-makers intentionally activate layering, conversion or drifting processes to patch flaws in an existing policy mix, just as software designers use "patches" to correct flaws in their operating systems and programs [40,41]. Policy layering is common in reality, and what is layered can be a single policy instruments or a policy package [39,42]. Policy replacement in terms of packaging a new policy mix to replace the previous one happens less than policy patching [43].

A policy mix can be formulated through a systematic policy packaging process [35,36,44], and it occurs when a completely new policy area emerges or when the existing policy mix faces total overhaul [36,40]. Most complex policy mixes were in reality built up over time through incremental processes of layering, conversion and drifting; the starting point of this policy development could be one single policy instrument or an initial package of policy instruments [40,42]. Policy mixes formulated in this way are likely to be less well-designed than a policy mix formulated through a systematic policy packaging process [40].

2.4 Research gap

Investigating designs of complex policy mixes is a trending direction in policy design research [45] and is becoming popular in areas of environment policy, energy policy and innovation policy. Empirical studies on the design of policy mixes can be a complex affair [46]. Scholars have tried out a few ways of displaying policy mixes in tables or figures [30,47–49]. These empirical studies of policy mixes are of importance to the further development of the policy mix discussions and provide references for mapping Chinese policy mixes in this study.

Investigating how policy mixes evolve over time is also a promising research direction for contemporary policy design studies [45]. Many studies examine a snapshot of a policy mix addressing pairwise instrument interactions or emphasizing the characteristics of a policy mix at a particular point in time. For instance, Taeihagh et al. [30,35] analyze the policy interactions between transport emission reduction instruments aimed at the promotion of active transportation in UK. Among a few studies that examine the evolution of policy mixes, Scordato et al. [50] analyze the policy mix development for the sustainability transition in Sweden. This study shows that destabilizing policies are significant for the sustainability transition. Scholars have highlighted the necessity of further understanding the temporal factors and how policy mixes evolve in the real world [36,43,51].

3. Methodology

3.1. Analytical framework

Fig. 1 displays three policy strategies that are the focus of this article and exemplar policy instruments. The policy strategy of reducing CO_2 emissions from traditional energy technologies refers to those instruments that directly target CO_2 mitigation, such as CO_2 ETSs. The policy strategy of promoting renewable energy technologies focuses on wind energy, solar photovoltaic (PV) and hydroelectric technologies[3]. The policy strategy of air pollution abatement focuses on emission reductions of sulphur dioxide (SO_2) or nitrogen oxide (NOx). SO_2 is the major cause of acid rain, a precursor to the formation of particulate matters (PM) and a major by-product when high-sulphur coal is consumed in power plants and industrial facilities [52,53]. NOx pollution degrades urban air quality [54], causes acid deposition [55], induces the formation of sulfate and nitrate particles [56] and is also a by-product of coal combustion [57]. In the study, we cover sectoral instruments, such as the emission limits of electricity plants, and economy-wide instruments such as EIAs, which help reduce emissions in all sectors.

Although the three policy strategies are linked, it is necessary to differentiate them from each other. CO_2 emissions and air pollutants both stem to a large extent from fossil fuel combustion [58,59], and CO_2 mitigation policies have "co-benefits" for local air pollution abatement [60,61]. Regulations on the emissions of SO_2 or NOx are found to be beneficial to CO_2 mitigation as well [52]. In addition, the development of renewable energy technologies can benefit air quality and greenhouse gas (GHG) mitigation by substituting renewable energies for fossil fuels and reducing the long-term costs of emission abatement [62–64].

We address the changes in the intensity, the density and the types of policy instruments over time. The measurement of policy intensity and policy density follow [65]. The density measures the number of the policy instruments. In the environmental policy field, an increase in policy intensity refers to a higher cost of polluting behavior or to a greater investment of resources, effort and activity. For a regulatory instrument such as emission level limits, a stricter emission limit value indicates a higher intensity. For a subsidy instrument, the level of the subsidy reflects the intensity. The types of policy instruments also imply the policy intensity. For instance, authority instruments are normally more stringent than nodality instruments.

3.2. Data and method

We traced the development of the environmental policy mixes in the electricity sector between 1981 and 2020 by five-year increments. First, China's FYPs for social and economic development were reviewed to identify the policy objectives and principal plans. Second, we searched for relevant Chinese policy documents to identify the instrument mix serving each policy strategy. The policy documents were taken from the *pkulaw* database (www.pkulaw.cn), which incorporates China's national-level and local-level policy documents[4]. In China, the central government is the main policy-making body in the electricity sector, so we limited the search to national policy documents in this study. In the end, we performed the analysis based on a review of 237 Chinese policy documents. Third, the policy documents were coded manually and an Excel spreadsheet was used to record the information. We have grouped

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[3] Nuclear and biomass energy are not considered in this study because we do not consider nuclear energy to be a renewable energy, following studies such as [101,104], and due to the high political complexity, safety and waste concerns that nuclear energy raises [59,105]. Biomass energy is also not considered in this study as it has a minor share of the electricity sector in China [83,106]. For instance, in 2017, the electricity generated from renewable energies and nuclear energy included about 64.9% of hydroelectricity, 13.5% of nuclear electricity, 16.1% of wind electricity, 5.3% of solar PV electricity and about 0.2% of biomass, geothermal or other sourced electricity. The data can be found at CEIC database, which collects these data from China's National Bureau of Statistics: https://www.ceicdata.com/en.

[4] In this study, the unit of analysis is the issued policy document. Based on the information extracted from the policy documents, we identify the policy instruments used by the Chinese government. The data resolution used in this study is daily, because our dataset of policy instruments contains the date when each policy document was released and the date when each policy document became effective.

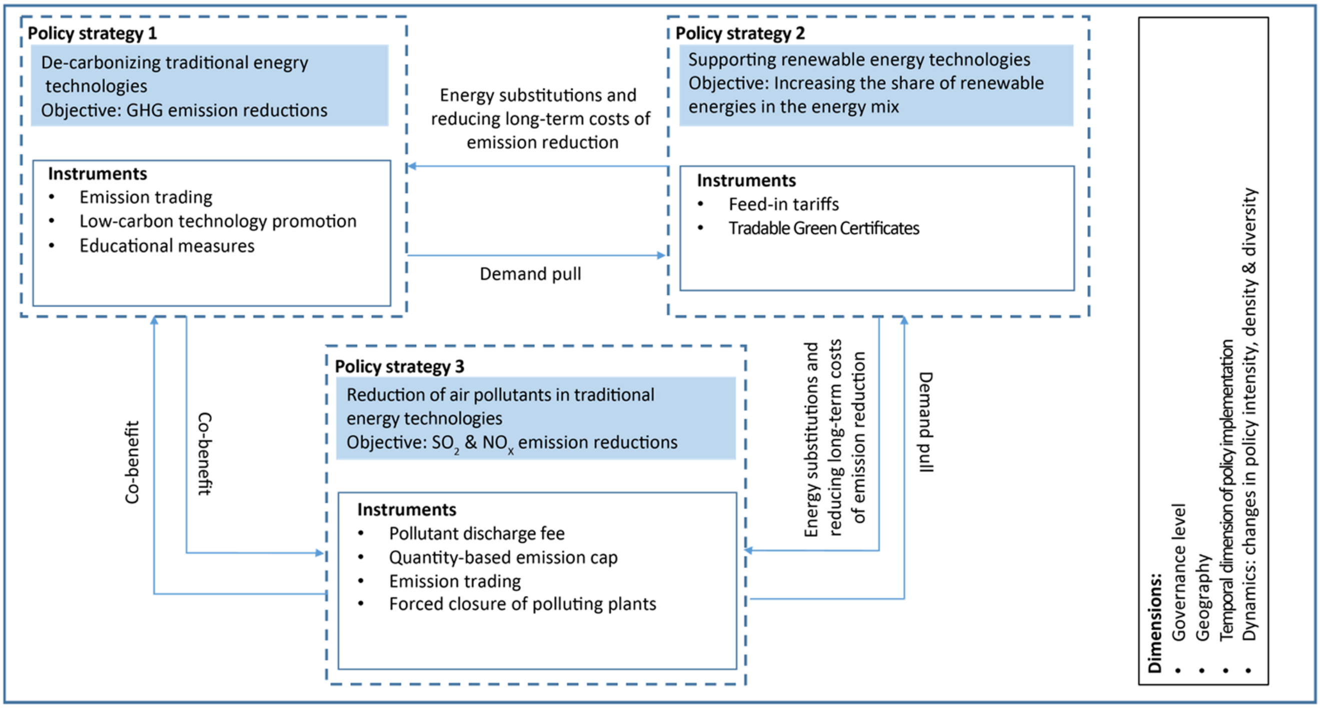

Fig. 1. An exemplar environmental policy mix for the low-carbon energy transition.

the policy documents into five-year batches to examine the policy mix serving each FYP. Fourth, after collecting and coding the relevant policy documents, we have presented the policy mix evolution in narratives in Section 4; this is followed by an in-depth discussion in Section 5. The Appendix A2 and A3 and the Supplementary Tables display the detailed search method, the coding framework and the tables summarizing the policy documents we reviewed.

4. Evolution and analysis of the environmental policy mix

Fig. 2 displays the timeline of the main policy change events between 1981 and 2020 and the policy objectives of the FYPs relating to the low-carbon transition of the energy system (for a more comprehensive description of the evolution of the environmental policy mix in China between 1981 and 2020, see Appendix A4). Since the early 1980 s, the Chinese government has been spending resources for reducing air pollutants and supporting hydroelectricity development, whereas the policy instruments to reduce CO_2 emissions and to support wind or solar PV technologies have mostly been implemented since the 10th FYP period (2001–2005).

4.1. General changes in the density, diversity and intensity of policy instruments

Fig. 3 summarizes the environmental policy mix between 1981 and 1990, and Fig. 4 summarizes the policy mix between 2016 and 2020. Comparing Figs. 3 and 4, it is evident that the density and diversity of the policy instruments has dramatically increased over the years.

Between 1981 and 1990 (6th and 7th FYPs), a total of five policy instruments have been identified. The government utilized its authority, organization and treasure resources to abate air pollutants and to build up the hydroelectricity infrastructure, but nodality-based instruments remained to be utilized more widely. Two out of the three instruments to reduce air pollutants were authority-based instruments. Mitigating GHG emissions had not been targeted by the social and economic development plans. In the 1980 s, electricity supply was far lower than electricity demand in China. In this period, the government had an absolute monopoly over the electricity industry and determined the price and the amount of electricity produced. Hydroelectricity was the only renewable energy source for electricity generation that caught the attention of policy-makers. The government prioritized the construction of large and medium hydropower projects, and also launched a program in 1983 to encourage small hydropower projects to increase access to electricity in remote rural areas.

By the 13th FYP period (2016–2020), the number of policy instruments had increased from five to 44 instruments. The 13th FYP had more specific and quantifiable policy objectives regarding CO_2 mitigation, the share of non-fossil fuels and SO_2 and NOx emission reduction. The Chinese government utilized nodality, authority, treasure and organization-based instruments in combination, with seven instruments to mitigate CO_2 emissions in coal-based energy technologies, 22 instruments to encourage renewable energy technologies and 15 instruments to reduce air pollutants in coal-based energy technologies.

The seven policy instruments directly targeting CO_2 emission reductions include developing clean development mechanism (CDM) projects, establishing the CDM Fund, developing “low-carbon” cities or provinces, piloting CO_2 ETS, setting CO_2 emission reduction targets for local governments, promoting low-carbon technologies and organizing public information campaigns. The majority of the policy instruments rely on government treasury resources, and nodality instruments are well used. Nonetheless, fewer instruments rely on governmental authority or organizational resources. In terms of policy intensity, the government has imposed a smaller policy intensity on CO_2 mitigation compared with the policy intensity of reducing air pollutants such as SO_2.

By the 13th FYP period, an instrument mix was implemented to support a comprehensive coverage of diverse renewable energy technologies. The majority instruments of the instrument mix use treasure resources at the government’s disposal to address the positive externality of renewable energy deployment, and the economic development in China over the years has built a treasure foundation for the implementation of these instruments. Many other policy instruments are organization-based and play a critical role in guiding the electricity market, planning provincial quotas for renewable energy and making quotas for each renewable energy resource. State-owned enterprises also dominate the Chinese electricity sector [66,67]. In contrast to the

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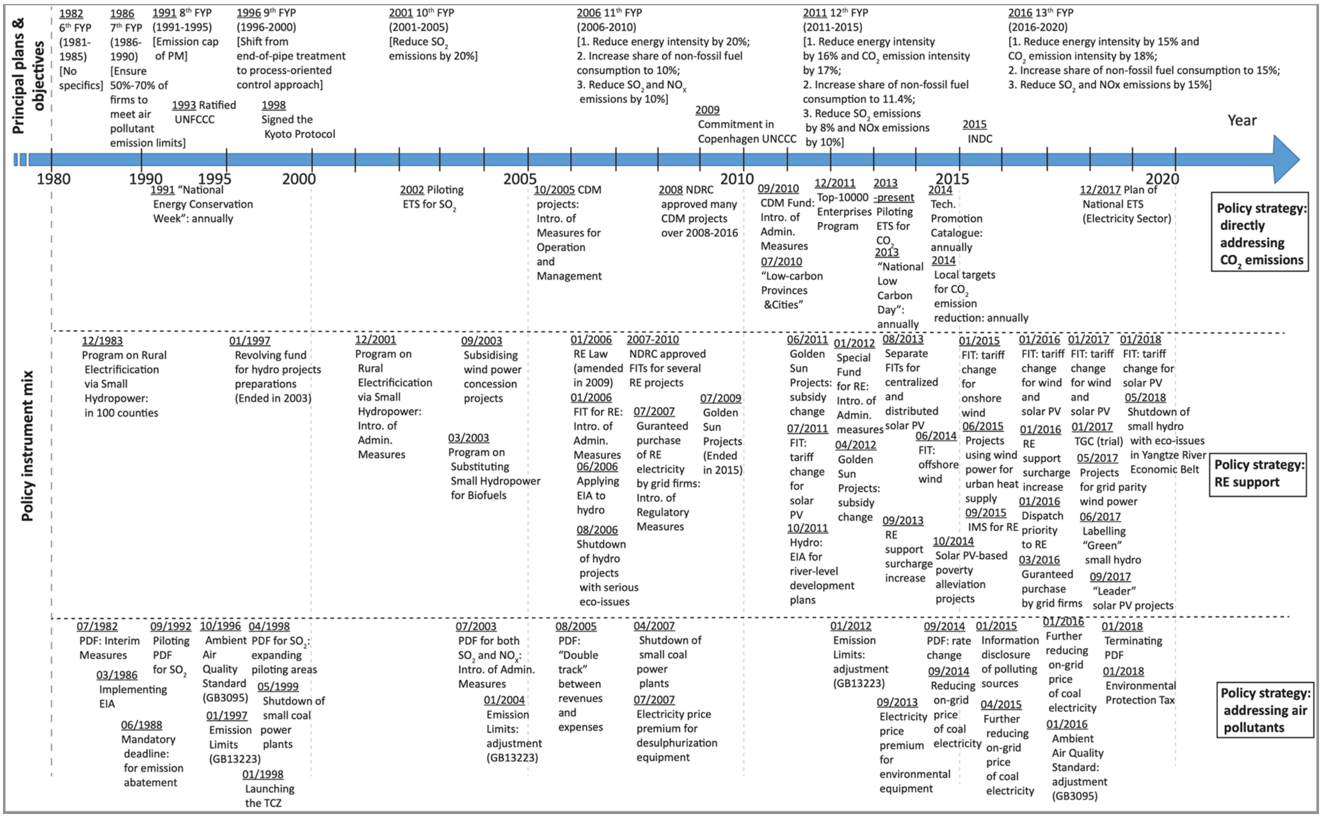

Fig. 2. Timeline of China's environmental policy mix evolution, 1980–2020. Note: PDF – Pollutant Discharge Fee; RE – Renewable Energy; IMS – Information Management System; Admin – Administrative; Intro – Introduction.

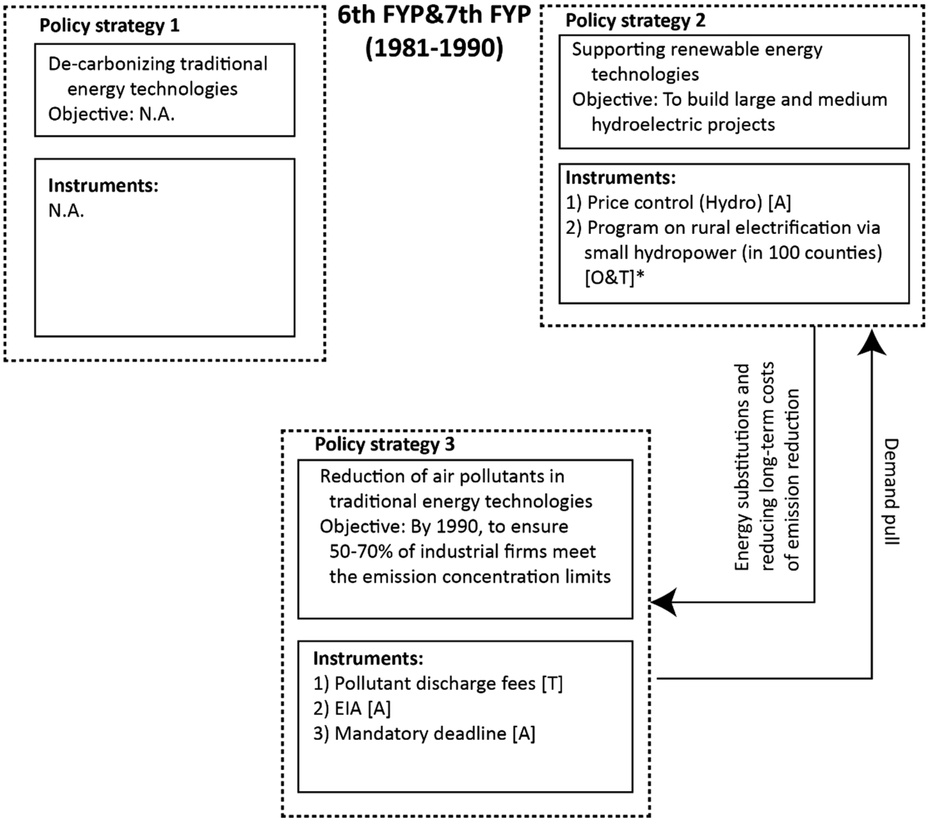

Fig. 3. Policy mix during 1981–1990. Note: The letters in square brackets show the policy instrument types according to the NATO model. "N" – nodality; "A" – authority; "T" – treasure; "O" – organization. * denotes that the program involves multiple types of policy instruments.

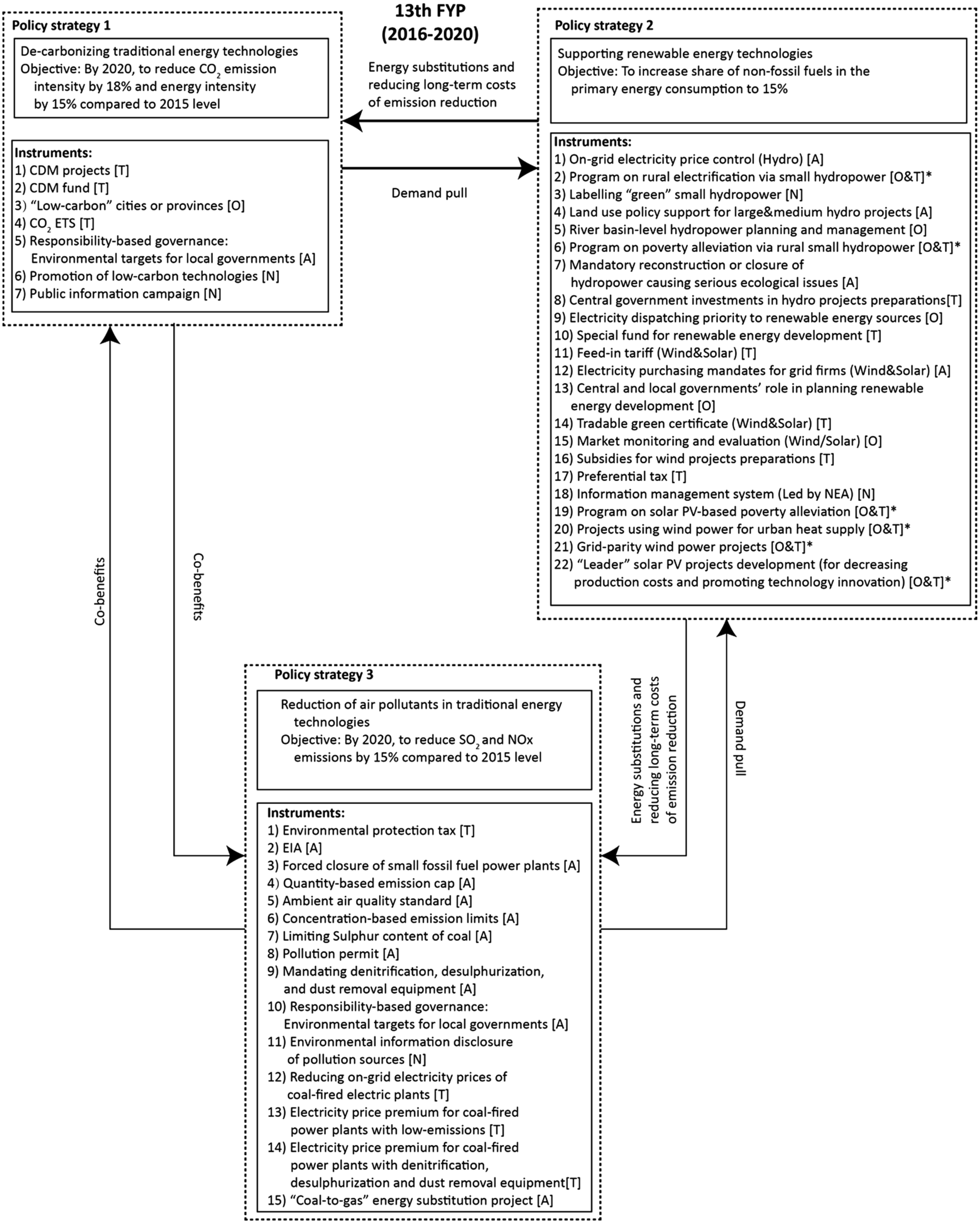

Fig. 4. Policy mix during 2016–2020. Note: The letters in square brackets show the policy instrument types according to the NATO model. "N" – nodality; "A" – authority; "T" – treasure; "O" – organization. * denotes that the program involves multiple types of policy instruments. Fig. 4 does not include policy instruments implemented after 1981 but terminated before 2016.

absolute monopoly that existed previously, the 2003 and the 2015 electricity reforms in China have led to an increase in market competition, making space for renewable energy project developments. In addition, the Chinese government has established six programs using both the organizational and the treasury resources of the government to promote hydropower, solar PV and wind power projects. In terms of policy intensity, in the 10th FYP period (2001–2005) and the 11th FYP period (2006–2010), the government imposed a high policy intensity on renewable energy development by providing generous subsidies or high rates of feed-in tariffs (FITs), especially for wind or solar PV electricity generators. In China, the FIT instrument was not applied to hydroelectricity in consideration of its low-level production cost; in fact, the on-grid hydroelectricity tariff is even lower than the on-grid thermal tariff on average [68]. In the 13th FYP period, the government has reduced the policy intensity of supporting renewable energy technologies by reducing the tariff rates of the FIT, encouraging projects to achieve the grid-parity pricing of renewable electricity and experimenting with the policy instrument of tradable green certificate (TGC) to reduce the government's financial burden and respond to technology maturation and production cost decrease.

The instrument mix to promote renewable energy technologies also contains some instruments to address the unintended curtailment issues and ecological issues incurred by the rapid expansion of renewable electric installations. For instance, the government mandates that grid firms should purchase electricity generated from renewable energy resources. To encourage a sustainable development of hydroelectricity, the EIA instrument has been applied to both hydroelectric projects and to river-level hydroelectricity development plans since 2011. In June 2017, the Ministry of Water Resources (MWR) launched the program "Green" Small Hydropower Stations, which would label some small hydropower stations as "green" provided they met certain environmental criteria. In May 2018, to address the ecological issues incurred by the rapid expansion of small hydropower in the Yangtze River Economic Belt, the MWR, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) together decided to conduct a thorough investigation into small hydropower projects in the region, retrofitting or shutting down those causing serious ecological problems[5].

The 13th FYP aims to reduce SO_2 and NOx emissions by 15% compared to 2015 levels. To achieve the objective, 15 policy instruments have been implemented, including 10 authority-based instruments, four treasure-based instruments and one nodality-based instrument. The Chinese government tends to use authority-based policy instruments to reduce air pollutants coercively, such as setting concentration-based emission limits, imposing quantity-based emission caps (*zong liang kong zhi*), setting air quality standards and limiting the sulphur content of coal. Regarding treasure-based policy instruments, the environmental protection tax has been implemented since 2018 to increase the costs of coal-based energy technologies; an electricity price premium (*huan bao dian jia*) has been implemented since 2013 to reward coal-fired power plants with denitrification, desulphurization and dust removal equipment; and the on-grid electricity prices of coal-fired plants have been reduced to enhance the salience of the electricity price premium. Nodality instruments are still not widely used. The amended Environmental Protection Law in 2015 emphasized the use of nodality instruments for environmental purposes, such as enforcing the instrument of environmental information disclosure. In terms of policy intensity, an increasing policy intensity can be observed based on information such as the increasing charges on emissions and tighter emission limits and air quality standards. Between 1981 and 2020, there has also been a change in policy focus from end-of-pipe emission treatment to a more holistic and process-oriented control approach.

With all these policy efforts over the years, China has made significant strides toward a sustainable energy system. Wind electricity production increased from 2.89 billion kWh in 2006 to 295 billion kWh in 2017, while the solar PV electricity production increased from 8.37 billion kWh in 2013 to 96.7 billion kWh in 2017 [69,70]. Chinese wind electricity installed capacity has ranked first in the world since 2010, followed by the US, Germany and India [71]. China has also built up the largest combination of solar PV installations and developed the largest manufacturing industry for solar PV cells and modules [72]. The CO_2 emission intensity (kg per 2011 PPP$ of gross domestic product – GDP) has gone down from 1.41 in 1990 to 0.59 in 2014, a decrease of 58% [73], even though the total CO_2 emissions have been increasing over the time. The SO_2 emission intensity (g per 2011 PPP$ of GDP) has decreased from 0.005 in 1998 to 0.001 in 2016; total SO_2 emissions peaked at 25.89 million tons in 2006 and decreased to 11.03 million tons in 2016 [74,75].

4.2. *In-depth analysis of policy change processes*

This section contains an in-depth discussion about the policy change processes of critical policy instruments to reduce air pollutants, support renewable energy technologies and reduce CO_2 emissions.

4.2.1. *Replacement of the pollutant discharge fee (PDF) by an environmental protection tax*

The PDF served for Chinese air pollution abatement from 1982 to 2017. It was recalibrated many times with the aim of improving the implementation effectiveness of the policy instrument, including by expanding its geographical scope, increasing its intensity, adding more target pollutants and changing the administration of the revenues.

The instrument was first applied to PM emissions in 1980 s, then extended to SO_2 in 1992 and applied to NOx in 2003. The charging rate on SO_2 emission increased from 0.2 yuan/kg to 0.6 yuan/pollutant equivalent (PE, with 1 PE = 0.95 kg SO_2) in 2004 and to 1.2 yuan/PE in 2014. The policy instrument was first implemented in some pilot schemes, and then expanded in 1998 to the acid rain control zone and the SO_2 control zone (referred to as "two control zones", TCZ) - geographically delimited areas that received policy priority for controlling both SO_2 emission and acid precipitation; it was applied nationally after 2003. This policy intensity increase can be partially attributable to the growing authority of the environmental protection department. The State Environmental Protection Administration (SEPA) was established in 1988 as a vice-ministerial level department; it was upgraded to the ministerial level SEPA in 1998, then to the cabinet-level Ministry of Environmental Protection (MEP) in 2008 and was reorganized as the current the Ministry of Ecology and Environment (MEE) in 2018.

In January 2018, the PDF was terminated, while the environmental protection tax was layered onto the policy mix. The PDF and the environmental protection tax both follow the principle of "the polluters pay", but there are some differences in the administrative measures. First, the MEP collected the PDF, but the State Administration of Taxation (SAT) will collect the tax [76]. The MEP had accumulated the monitoring and enforcement resources during the long-term implementation of the PDF [77]; therefore, the implementation of the environmental protection tax will be dominated by SAT with the facilitation of the current MEE. Second, while the revenues from the PDF were shared between the central government and the local governments, the environmental protection tax will mainly contribute to the revenues of local governments. The requirement is that the local governments will take the major responsibility for implementing environmental policies. Third, the environmental protection tax is supported by the Environmental Protection Tax Law (2018) and violators will be held liable under the terms of this law. The pollution discharge fee was supported by an administrative regulation, Regulation on the

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[5] The NDRC has broad administrative and planning control over the economy of China, including the role of promoting sustainable development strategy and coordinating energy development. The NEA was established in 2008 and works under the NDRC to address energy-related affairs.

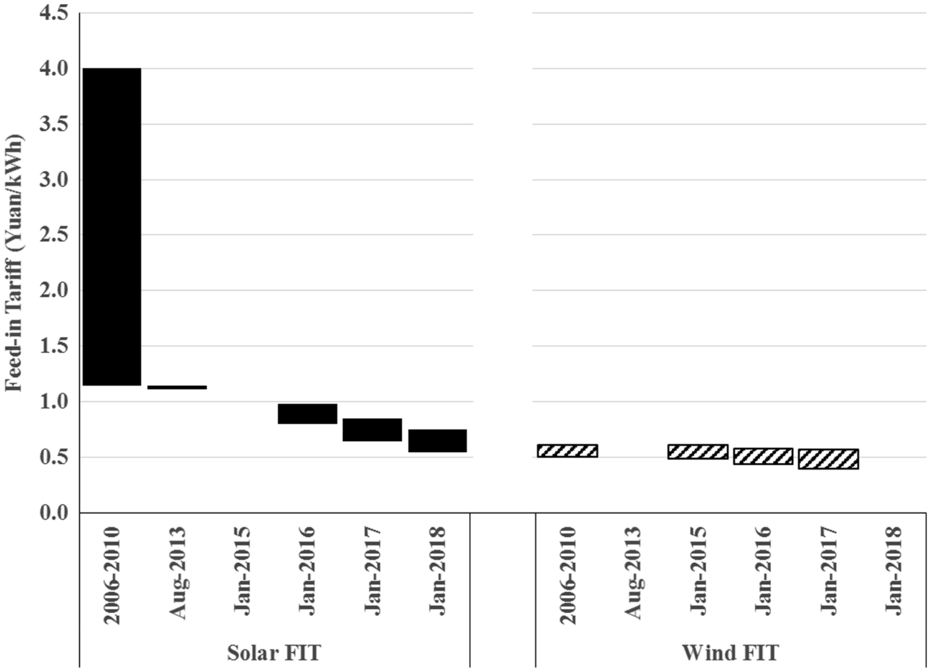

Fig. 5. FITs of solar PV and on-shore wind electricity in China.

Collection, Use and Management of Pollutant Discharge Fees, issued by the State Council in 2003 and had less legal authority than the law, so the change from the PDF to the environmental protection tax also indicates an increase in policy intensity.

4.2.2. Layering TGC onto FIT

Renewable energy technologies emerge in market niches which need support from the government, but with technology maturation and production cost decrease over time they can start to compete with the dominant regime [78]. In China, the gradual calibrations of the FIT policy instrument and the introduction of the TGC policy instrument reflect a decrease in the policy intensity imposed on renewable energy technologies.

A cornerstone of China's renewable energy development is the Renewable Energy Law, which became effective in 2006. It put in place a package of policy instruments, including FIT. The policy design of a FIT normally includes initial tariff values, the digression mechanism and the contract duration. The tariff digression process of FITs in China is represented in Fig. 5. The market competition of upstream manufacturers and the technology progress led to a smaller gap in the production costs between renewable electricity and coal electricity. The tariff digression mechanism reduces the tariff rates gradually in response to production cost decreases and technological development [79]. The tariff digression mechanism also helps reduce the implementation costs of FIT. The FIT and other subsidy instruments that support renewable energy technologies generated a substantial burden for the public finances in China, leading to the questioning of the sustainability of the treasure-based approach toward renewable energy promotion [80–82]. Under the FIT instrument, the on-grid price gap between the renewable electricity and the coal electricity was subsidized by the Special Fund for Renewable Energy Development, the money for which comes from government expenditure and surcharges on consumer electricity bills[6]. As such, the renewable energy projects were mostly approved by local governments, but the subsidy costs were shared by the nationwide electricity consumers and taxpayers in China [83]. To meet the subsidy demand of FIT, the NDRC had to increase the surcharge rate from 0.008 to 0.015 yuan/kWh in September 2013 and again to 0.019 yuan/kWh in January 2016. The fiscal burden of FIT also became an issue in some other countries [84], and the reliance on high-level FIT might cause unintended curtailment issues [85]. Therefore, the countries (such as Spain, Germany and Denmark) that implemented FIT all reduced tariff rates in the long run [79,81].

In January 2017, to explore a low-cost approach to encouraging renewable energy technologies, the NDRC, the NEA and the Ministry of Finance decided to conduct a trial implementation of TGC for solar PV and wind electricity. The solar PV and wind electricity generators would be given TGCs every month; one TGC represents 1 MWh on-grid electricity from renewable energy sources. At the trial implementation stage, electricity consumers would be able to buy TGCs from electricity generators voluntarily and prices could be negotiated between the buyer and the seller. By selling the TGCs, the renewable electricity generators could earn money in addition to the revenues from sales of electricity fed into the grid. Under the TGC instrument, the government did not need to subsidize the electricity represented by the TGCs. Experience of the TGC instrument in other countries can be categorized into two types: voluntary TGC trading versus compliance TGC trading [86]. The Chinese policy document on the trial implementation of TGC suggested that the renewable portfolio standard (RPS) should be introduced in the near future and that the TGC would then be used to comply with the RPS, implying a transfer from voluntary TGC trading to compliance TGC trading.

4.2.3. Policy conversion from an SO_2 ETS to a CO_2 ETS

A policy conversion can be observed from an SO_2 ETS to a CO_2 ETS, in other words re-deploying existing institutions to serve new purposes.

China piloted an SO_2 ETS in the early 2000 s, accumulating some experience in the implementation of a CO_2 ETS in the 2010 s. The SO_2 emission cap imposed on the Two Control Zones (TCZ) from 1998 was the precondition for the adoption of the SO_2 ETS [87]. The local governments capped within the TCZ were willing to try out the SO_2 ETS as a low-cost approach [88,89]. In 2002, Taiyuan established the first SO_2 ETS pilot, followed by eight other cities and four provinces [90]. However, the SO_2 ETS in China remained primarily conceptual, and only a few transactions happened [91].

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[6] The retail electricity price = the on-grid electricity price + transmission price + renewable energy surcharge & government funds + taxes.

China was comparatively undeveloped at that time and the regulated firms were not rich enough to adopt advanced emission reduction technologies. The electricity sector was the major contributor to SO_2 emissions but had only one corporation, the State Power Corporation, before 2002; this was dismantled into multiple enterprises between 2002 and 2003. Against this background, the market was not free enough to motivate active firm-to-firm trading activities. Government interventions were prevalent and often excessive for SO_2 ETS, causing market congestion. For instance, the SO_2 ETS in Taiyuan did not allow firm–firm trading and the local government had to be either a seller or a buyer in all transactions. The ETS is known as a low-cost policy instrument and, to achieve the cost savings, the ETS market should enable firms with sufficient liquidity to make transactions with one another and encourage competition between mitigation measures. The excessive government interventions would increase the overall compliance cost under the SO_2 emission cap.

Policy learning can be observed from the SO_2 ETS to the CO_2 ETS. The first CO_2 ETS pilots was established in Shenzhen in 2013, and six other CO_2 ETS pilots had been established by 2014. The economic growth over the years in China had provided the economic foundation for adopting state-of-the-art emissions abatement technologies, and an evolving market economy provided better market conditions. Compared with the local experiments of SO_2 ETS, the design and implementation of the CO_2 ETS had some improvements. First, the piloting of the CO_2 ETSs received better legal support. The local Development and Reform Commissions (DRCs) all issued local administrative rules for CO_2 ETSs, and the national-level Interim Administrative Measures for the CO_2 ETS came into effect in January 2015. Second, the piloting of CO_2 ETSs saw fewer government interventions. The firm–firm trading mode was used in all pilots and each pilot established an Emission Exchange as a platform for the transactions. The Emission Exchanges took care of the registrations and trading rules and organized training. Local DRCs provided market oversight. Third, the piloting CO_2 ETSs had more comprehensive monitoring, reporting and verification (MRV) rules. The NDRC also issued the detailed MRV methods and guidance for GHG emissions in various industrial sectors. As a result, the CO_2 ETS pilots have been operating since 2013 and have achieved good compliance rates [92].

Despite these improvements, the CO_2 ETS pilots have also experienced many problems. For instance, there is no legislative law supporting ETS, no derivative products of emission allowances and CO_2 prices are highly volatile [93]. Nevertheless, the case implies that the policy design and implementation can be improved through policy learning over time. The government of China is upgrading the local experiments to a national scheme, which can be considered as an increase in the policy intensity by adding an extra cost to nationwide polluters.

5. Discussion

The transition toward sustainable energy systems is a thorny question for many governments around the world. Chinese experiences on policy sequencing, packaging and experimenting with relevant policy instruments have not been elaborated in detail before. This study investigates the complex mix of three policy strategies and multiple policy instruments conducive to the energy transition in China and how this policy mix has evolved between 1981 and 2020. The study contends that China has formulated a complex mix of policy instruments that not only support innovation and deployment of renewable energy technologies, but also destabilize the lock-in to carbon-intensive fossil fuels by integrating environmental concerns (e.g. air pollution; climate change). The Chinese experience could provide implications for energy transitions in other contexts such as the case of developing countries that need to decouple economic growth from fossil fuels.

This study contributed to the policy mix literature by using extensive empirical data for analysis of policy mixes and by performing an empirically-driven temporal analysis for the evolution of the policy mix over four decades. The coverage of the study is comprehensive and unique as the literature often examines policy instruments only for one of the three policy strategies in China, such as in [94]. The research helps the international society to further understand Chinese government's policy design and policy evolution in fields of the environment, renewable energy, and climate change mitigation, and also recognize Chinese continuous efforts towards a sustainable energy system.

5.1. *Inadequacy of information provision*

The Chinese government has utilized a combination of nodality, authority, treasure and organization instruments to address CO_2 emissions, control air pollutants and encourage renewable energy technologies. We find that nodality-based instruments are used the least by the government. The inadequacy of nodality-based instruments has also been observed in other sectors of China [95]. Information asymmetries between polluting firms and the government, between polluting firms and consumers or between the central government and local government officials are a critical barrier to the implementation effectiveness of environmental policy instruments (such as ETS) in China [96]. In future, the Chinese government may need to utilize more nodality instruments to disclose information regarding emission levels and emission reduction potentials of firms, cities or regions to reduce the information asymmetry, which can ultimately enhance the implementation effectiveness of other environmental policy instruments.

5.2. *Diverse types of policy instruments in China: Beyond authority-based instruments*

Our findings show that the Chinese government tends to use authority-based instruments to combat air pollution coercively, use treasure-based instruments to reduce costs of renewable energy technologies and experiment with innovative instruments such as ETSs to mitigate CO_2 emissions. Even as an authoritarian state, therefore, the Chinese government not only uses authority-based instruments, i.e. the conventional command-and-control approach, to achieve its policy objectives; it also enforces a set of diverse types of environmental policy instruments. Policy learning from developed countries can be observed, as China has adopted many policy instruments such as FITs and ETS after their initial adoption in the US and in Europe [97].

5.3. *Sequencing policy instruments to achieve long-term policy goals*

This study finds that Chinese policy instruments to reduce air pollutants have generally followed a sequence that gradually ratchets up the policy stringency in terms of increasing charging rates on emissions, as well as by tightening emission limits and air quality standards. Chinese policy instruments to support renewable energy technologies have generally followed a sequence that gradually decreases the policy intensity in terms of developing projects of grid-parity renewable electricity, experimenting with TGC instruments and reducing rates of FITs and other governmental subsidies. The former sequence means coal-based energy technologies face increasing costs of reducing emissions to break the lock-in of the incumbent energy regime, while the latter sequence reduces the government's expenditures on subsidizing renewable energy technologies. In addition, the Chinese government had a 10-year history of supporting wind and solar PV technologies before CO_2 ETS implementation started, building up interest groups in low-carbon energy technologies which contributed to the implementation effectiveness of CO_2 ETS [98]. These sequences, which have also been observed in other country cases [99], successfully move forward after relaxing barriers such as the technology costs, resistance from existing institutions and the lack of a supporting coalition over a period of time. The policy mix of China, which facilitates the transition to a sustainable energy system, has therefore evolved toward greater environmental stringency and lower cost. One policy implication is that a government can deliberately make incremental policy changes to achieve ambitious long-term policy goals, such as the energy transition.

5.4. Policy packaging and policy replacement in the policy evolution process

Section 4.2 indicates that the Chinese government has the capacity to redesign the policy mix through replacement, layering or conversion processes regarding a single policy instrument. We have also observed a few cases of policy replacement, where a new policy package is formulated to replace an existing one or where no policies are in place, which contrasts with the conventional idea in literature that policy replacement happens less in reality [43]. We have observed the policy packaging process for SO_2 mitigation when launching the SO_2 control zone and the acid control zone (the TCZ). In 1998, the Chinese State Council (the major policy-making institution) and SEPA packaged a mix of policy instruments, including the SO_2 discharge fee, to be implemented in the TCZ. We have also observed some policy packaging processes for renewable energy promotion after the Renewable Energy Law came into effect in 2006. The law and the following policy documents packaged a mix of renewable energy support instruments, including FIT. These policy packaging and replacement processes happened at the stage of dealing with new policy issues (e.g. acid rain) or promoting new technologies (e.g. wind and solar PV technologies). They were followed by policy patching processes over a long period of time; for instance, the SO_2 discharge fee was recalibrated many times by 2018. Additionally, China uses planning as a government tool to guide social and economic development, such as the FYPs [100]. These economy-wide plans or other sectoral plans take a long-term strategic vision and systematically package a mix of policy instruments to replace those of a previous plan.

5.5. Next-stage of Chinese energy transition

Energy transition can take years or decades to achieve. With the diffusion of renewable energy technologies in the energy sector, new challenges become salient, such as negative environmental impacts of hydropower projects and the challenges of electricity transmission, distribution and integration. According to Markard [78], China will move into the next phase of energy transition when policy instruments to support renewable energy technologies can be downscaled and the policy focus shifts more to wider socio-technical changes, such as demand-side management with energy efficient and conservation policy options, coping with curtailment issues resulting from rapid transition, mitigating unintended ecological problems and enhancing the transmission and distribution infrastructure.

5.6. Limitations of this work

We must acknowledge the limitations of this study. First, although the study has identified a large set of policy instruments, it may not cover the entire repertoire of policy instruments relating to China's energy transition. We focus on the policy instruments that are most frequently discussed in the literature and are most frequently followed up in policy documents, such as ETSs and FITs. Second, the research focuses more on policy instruments that affect electricity production, but less on policy instruments that encourage consumers to reduce electricity consumption, which is also important for reducing emissions from the electricity sector. In fact, many studies have discussed Chinese policy instruments to address objectives of energy conservation or efficiency from the energy demand-side, such as in [101]. Investigating the evolution of the environmental policy mix regulating the electricity sector from both the energy demand-side and the supply-side could be an exciting future research direction. Third, to highlight the main findings more precisely, this study does not include discussions about how each policy instrument interacts with other policy instruments within the policy mix. Fig. 1 displayed the interactions between the three policy strategies. Considering that policy interactions are an important part of policy mix theory, Appendix A5 illustrates the interactions between some key policy instruments.

6. Conclusions

This study has examined the evolution of the policy mix that has promoted the sustainable transition of the energy system in China over four decades (1981–2020). We have considered the policy mix to include the policy strategies of mitigating carbon dioxide emissions from conventional energy technologies, promoting renewable energy technologies and mitigating air pollutant emissions from conventional energy technologies. We have analyzed the policy mix changes chronologically over the period by reviewing the relevant policy documents and literature.

Our study demonstrates that there have been continuous changes in the policy mix, and the pace of the change has increased dramatically since 2000. There has been a rise of policy density, increasing from five instruments to 44 instruments; the latter include a combination of nodality, authority, treasure and organization instruments, with seven instruments to mitigate carbon dioxide emissions, 22 instruments to encourage renewable energy technologies and 15 instruments to reduce air pollutants. Findings show that policy instruments to mitigate carbon dioxide emissions were not reliant on command-and-control type instruments and involved experimentation with more flexible instruments, such as emission trading scheme. The Chinese government tends to use authority-based instruments to coercively enforce emission reductions of air pollutants, with increasing policy intensity over time. The policy instruments to support renewable energy technologies are dominated by treasure-based instruments, but the government intends to pursue a lower-cost approach toward renewable energy promotion. To sum up, this study displays that the density and diversity of policy instruments in the mix have all increased between 1981 and 2020, and that changes in policy intensity vary with policy strategies.

The overall evolution trajectory of Chinese policy mix shows that, rather than packaging an optimal mix of policy instruments once and for all, a government can layer, sequence and calibrate policy instruments in the long run to formulate a complex policy mix. In contrast to the conventional idea in the public policy literature that policy replacement happens less in reality, policy replacement processes happen often in China in the form of packaging a set of instruments to replace the previous ones or to deal with new policy issues.

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Appendix A. Supplementary data

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