Household energy transition and social status: evidence from large-scale heating renovation in China

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Abstract
Clean, low-carbon energy transition has been a global trend in pursuing climate mitigation and sustainable development, with residential heating being an essential component. Despite its substantial climate, environmental, and health benefits, the social impacts of residential energy transition are insufficiently understood. Based on a difference-in-differences design, we identify the causal effects of a large-scale clean heating policy on public perceptions of their social status in northern China. We find substantial improvement in individuals’ social status immediately following the heating renovation, which is robust over a set of empirical specifications but diminishes in the long term. The transition benefited not only those directly experiencing renovation but also others in the same areas. The improved social status was driven by perception of higher income and bettered health condition. The findings indicate a sustainable and inclusive transition of clean heating, and call for additional measures to maximize its social benefits.

1. Introduction
Residential sector accounts for 17% of final energy-related carbon emissions globally (IEA 2021), and plays an increasingly important role in climate mitigation in emerging economies (IPCC 2022). A major part of residential carbon emissions comes from energy use in heating and cooling, especially the combination of solid fuel—coal or biomass—and inefficient indoor devices for heating. Such a combination is widespread in developing countries, and causes not only climate impacts, but also serious consequences of indoor and outdoor air pollution, as well as health issues (Ebenstein et al 2017, Conibear et al 2018, Yun et al 2020). Countries like China are renovating its residential heating systems with natural gas and electricity on large scales (Carter et al 2020). Recent projection shows that this renovation could bring almost 50% mitigation in residential carbon emissions, 90% reduction in PM2.5, and 0.4 million avoided premature death annually (Zhao et al 2018, Zhou et al 2022).

Despite its substantial, multi-dimensional benefits, household energy transition is not necessarily socially inclusive and well accepted by the public. In settings of clean fuel adoption for cooking, the literature shows that with additional benefits of time saving, liberation of labor, and gender equity (Greenwood et al 2005, Krishnapriya et al 2021, Verma and Imelda 2022a), substantial barriers still exist and need to be addressed by campaigns (Jalan and Somanathan 2008, Hanna et al 2016, Afridi et al 2021). The case of heating renovation is associated with different sets of changes compared to cooking, and its social impacts are largely unknown. Evidence suggests that public support for China’s clean heating renovation may depend on factors such as subsidies, perceived welfare, and government implementation (Barrington-Leigh et al 2019, Zhang et al 2019, Xie and Zhou 2021, Yang and Zhao 2022). Its impact may also pertain to the country’s current endeavor for common prosperity and rural vitalization, requiring coordination between policy goals of environmental and social dimensions. Further research is needed to evaluate the overall status of the public after heating renovation and the inclusiveness of the sustainable transition, thereby informing decision-making and policy adjustment.
We focus on the impact of energy transition on public social status. Social status, often tied to individuals’ perception, is the belief about their location in a status order or perception of their place in the socioeconomic structure (Davis 1957). The interaction of energy switching and household variation in socioeconomic status has been well covered by the energy ladder and energy stacking model (Leach 1992, Masera et al 2000, Van der Kroon et al 2013). With improvement in socio-economic status, the former suggests discrete, consecutive preferences and choices for more advanced fuels, and the latter considers overlaps in preferences. The economic approach to energy transition shows an income-driven, energy-consumption preference ladder depending on technology cost, relative fuel prices, and energy access, commonly demonstrated in a modern society (Usmani et al 2017, Shupler et al 2021). Rather than one-way causality driven by economic status, however, the energy switch in rural or developing areas is actually a result of complex interactions among cultural, social, and economic factors (e.g. Srinivasan and Carattini 2020, Vyas et al 2021, Bonan et al 2022).

Despite considerable research of social influences on the choices of fuels and related technologies, the causal effect of the energy transition on social status is unclear yet important. Clean energy and modern fuels may be a ‘status symbol,’ which is related to the notion of ‘modernization’ for individuals or households, especially in rural areas (Masera et al 2000). Therefore, new technology infrastructure and related clean-fuel adoption foreshadow higher development levels, including a modern lifestyle, implying a direct positive effect on social status. Moreover, individuals’ acceptance of new products and services diffuses and affects their neighbors, often via social networks and social learning in rural areas (Banerjee et al 2013, 2019). This implies potentially an indirect spillover effect of energy transition. Both the direct and indirect effects, if causally identifiable, has important policy implications for clean energy transition in developing countries.

The empirical setting of our investigation is large-scale residential heating renovation currently ongoing in China. The renovation policy covers the whole northern China and aims to replace solid biomass and coal with cleaner electricity and natural gas for the majority of residential winter heating. The policy-driven renovation has the primary intention to reduce winter air pollution, with substantial carbon mitigation an obvious ancillary benefit. The devices and infrastructure put in place and life-style changes can help China proceed toward carbon neutral in the long term, given further decarbonization in energy production. The renovation, featuring rapid government implementation, also differs from most cases of clean cooking reported by previous research, which are laissez-faire in nature. Therefore, behavioral patterns of the public are no longer a consideration, and the observable changes can be mostly attributed to policy influences.

The causal effects of heating renovation on residential social status are identified by a difference-in-differences design, exploring the timing of local policy implementation and variation in the intensity of renovation in the initial stage from 2017 to 2020. The empirical strategy is applied to estimation for individual-level perception of social status from six waves of national survey during 2010–2020. The subjective measurement of social status reflects the individual’s relative position within the social hierarchy more accurately and promptly (Singh-Manoux et al 2005). Despite nontrivial cost increase for winter heating, our findings reveal a positive role of clean heating renovation in improving public perception of their social status. The estimated effects are robust over alternative empirical specifications and placebo tests. Further analysis shows that both those subject to household renovation and those not were better off, and the improved social status was driven by perceived higher income and bettered health conditions. The positive overall experience of the public with the heating renovation suggests that policy expansion for larger climate and environmental benefits would come with ancillary social benefits as well, especially in alignment with common prosperity and rural vitalization.

2. Research design

2.1. Research setting

The contribution of residential sectors to air pollution and carbon emissions is enormous and remains increasing in China, especially from inefficient combustion of fossil fuels in unregulated cooking and heating devices. The residential sector accounted for around 18% of China’s energy consumption but 69% organic carbon emissions in 2010 (Liu et al 2016). Heating-induced air pollution is estimated to cause the public to lose by 3.1–5.5 years of life expectancy (Chen et al 2013, Ebenstein et al 2017). Despite fast socio-economic transition of the past few decades, it did not diversify heating energy sources and increase clean energy use at the same pace. According to a nationwide rural residential energy-mix survey in 2012, heating energy was still dominated by coal and solid biomass, whereas cooking energy had been shifted to a mix of electricity, liquified petroleum gas, and conventional sources (Tao et al 2018). There are also substantial urban–rural differences in household heating energy use. The Chinese environmental exposure-related human activity patterns survey shows that solid fuels were mostly used for heating
in rural areas (Duan et al 2014). The evidence suggests either inertia of the households driven by norms and habits or lack of infrastructure that prevents progressive energy transition and calls for policy intervention.

In recent years, low-carbon, sustainable transition has become a central component in China's policy agenda. Since 2013, China has declared a war on pollution and taken aggressive measures, policies, and practices in improving air quality and promoting energy transition. In 2017, China announced a five-year plan to shift to clean heating energy in northern China. As the world’s largest campaign for clean heating renovation, this plan aims to switch households and businesses from coal to natural gas or electricity for winter heating, particularly in rural areas. This plan was intended for all northern China but with a main focus on Beijing, Tianjin, and 66 cities in five neighboring provinces initially between 2017 and 2020 (figure 1). By the end of 2020, 17.67 million households in northern China had switched to gas or electricity for heating in winter. But local implementation varied, even within the focused area. Among the 66 cities, the transition covered more than 480 households per 1000 rural population in some cities and fewer than 100 households in others, during 2017–2020.

Given substantive changes driven by the plan, evaluation of its impacts is not straightforward. On the one hand, it was promoted mostly in areas of serious air-pollution issues surrounding Beijing and Tianjin, where a series of other aggressive air-pollution control measures were also implemented. These pollution control measures would affect air quality and thereby health and social status of the residents, causing confoundedness in identifying the causal effects of heating renovation. On the other hand, heating renovation might have affected not only those with household renovation directly, but also those without renovation, because of improved air quality, amenity, and other local changes. Considering impacts on the latter group is important to a comprehensive understanding of the renovation.

2.2. Data source and sample
The main datasets used in our study come from two sources. First, to measure policy implementation for causal identification, we compose a dataset of local intensity of heating renovation across cities. We manually collect from city government reports, plans, and policies the number of households having completed the clean heating renovation each year. For the intensity of renovation, the accumulative number of households with completion of the renovation during China’s 13th five-year plan period of 2016–2020 is divided by the total rural population in each city. This variable indicates the probability of rural residents in a given city to experience clean heating renovation directly or indirectly.

Second, individual-level observations, including perceived social status, come from the China Family
Panel Studies (CFPS). The CFPS is a biennial, nationwide micro-level survey of individuals and households covering 126 cities in China (Xie and Hu 2014). We use all the six waves of the CFPS from 2010 to 2020. To avoid confoundedness introduced by other policies, our analysis focuses on the 66 cities at the prefecture-level with similar air-pollution control measures, excluding Beijing and Tianjin because of their uniqueness. Of the 66 cities, the CFPS covers 39. We therefore restrict the sample to these 39 cities. Given the cognitive decline in older adults, our sample is also restricted to adults of age 18–65. The sample includes a total of 41,341 individual-level observations, with 7597 in 2010 (18.38%), 8259 in 2012 (19.98%), 7644 in 2014 (18.49%), 7359 in 2016 (17.80%), 5948 (14.39%) in 2018, and 4534 (10.97%) in 2020.

The main outcome of interest is the responses to the question: how do you evaluate your social status in the local areas? The answer is a five-scale discrete variable, from 1 (extremely low) to 5 (extremely high). We also collect individual-level variables that relate to social status, including self-perceived income status, health status, confidence to the future, life satisfaction, and happiness, as well as other personal characteristics, including age, gender, and marriage status.

In addition, we control city-level social and economic variables, including population, population density, per capita GDP, and industrial structure, from the China City Statistical Yearbook. In order to avoid the influence of extreme values in the data, all numerical data were truncated, replacing the values out of the first and 99th percentiles with the values of the first and 99th percentiles, respectively. The summary statistics are shown in Table 1.

### Table 1. Variables, measurements and descriptive statistics.

| Variable                  | Measurement                              | N   | Mean  | SD   | Min  | Max  |
|---------------------------|------------------------------------------|-----|-------|------|------|------|
| Social status             | Score 1–5, from low to high              | 39,388 | 2.894 | 0.997 | 1    | 5    |
| Probability of renovation | Number of households renovated in 13th FYP period per rural population | 32,537 | 0.221 | 0.132 | 0.002 | 0.555 |
| Income status             | Score 1–5, from low to high              | 36,497 | 2.493 | 1.007 | 1    | 5    |
| Health status             | Score 1–7, from low to high              | 33,406 | 5.507 | 1.179 | 1    | 7    |
| Confidence to the future  | Score 1–5, from low to high              | 39,468 | 4.034 | 1.016 | 1    | 5    |
| Life satisfaction         | Score 1–5, from low to high              | 39,517 | 3.722 | 1.036 | 1    | 5    |
| Happiness                 | Score 0–10, from low to high             | 24,922 | 6.574 | 2.509 | 0    | 10   |
| Age                       | Age at time of survey                     | 41,341 | 42.357 | 13.330 | 18   | 65   |
| Gender                    | Male = 1, No = 0                         | 41,215 | 0.470 | 0.499 | 0    | 1    |
| Marriage                  | Married = 1, Unmarried = 0               | 41,212 | 0.133 | 0.339 | 0    | 1    |
|                           | Cohabitation = 1, No = 0                 | 41,212 | 0.832 | 0.374 | 0    | 1    |
|                           | Bereaved spouse = 1, No = 0              | 41,204 | 0.021 | 0.144 | 0    | 1    |
| Population size           | Population size (10,000 people), Log     | 41,204 | 6.344 | 0.483 | 4.850 | 7.122 |
| Population density        | Population density (Number of people per Km²), Log | 41,204 | 8.314 | 0.643 | 6.952 | 9.509 |
| Per capita GDP            | GDP per capita, Log                      | 41,204 | 10.522 | 0.459 | 9.555 | 11.610 |
| Industrial Structure      | Share of the secondary sector in GDP (%)  | 39,388 | 48.984 | 8.928 | 32.700 | 69.740 |

2.3. Empirical strategy

We adopt a difference-in-differences design, exploring differences before and after the policy implementation and variation in the intensity of heating renovation across cities. Different from a standard difference-in-differences, our treatment is a continuous variable, which allows us to restrict comparison within cities of heating renovation. This strategy helps to avoid potential confoundedness from other policies in comparisons between cities with and without heating renovation in a standard difference-in-differences setting. The estimation follows:

\[
Y_{i\text{ct}} = \text{Prob}_{D_{t,2017}} \cdot \beta + X_{i\text{ct}} \cdot \gamma + Z_{i\text{ct}} \cdot \eta + \mu_{i} + \theta_{t} + f_{t}(t) + \epsilon_{i\text{ct}},
\]

where \(Y_{i\text{ct}}\) is the perceived social status of individual \(i\) in household \(f\), city \(c\), and year \(t\); \(\text{Prob}_{D_{t,2017}}\) is the probability of household heating renovation, or policy intensity, reflecting the probability for an individual to experience renovation in a city; \(D_{t,2017}\) is a time dummy variable with one for years after 2017 and zero otherwise; \(X_{i\text{ct}}\) is a set of individual-level covariates; \(Z_{i\text{ct}}\) is a set of city-level covariates; \(\mu_{i}\) is household fixed effects, capturing time-invariant household features; \(\theta_{t}\) is year fixed effects, capturing any economic, social and political shocks universally affecting the sample...
area; $f_c(t)$ allows city-specific time trends in robustness checks; $\varepsilon_{igt}$ is the error term. The coefficient of interest is $\beta$, which measures the additional changes in the outcome after policy implementation in cities with more intensive renovation compared to those with less renovation.

To assess the identification strategy of parallel trend and show dynamic effects of clean heating renovation, we estimate a more flexible version of (1) in an event study style:

$$Y_{igt} = \sum_{t=2010}^{2020} \text{Prob}(D_i)\beta + X_{it}\gamma + Z_{at}\theta + \mu_f + \theta_i + f_c(t) + \varepsilon_{igt}, \quad (2)$$

where $D_i$ is a set of dummy variables indicating the year, and $\beta$ provides estimation for each year. Because the policy is implemented mostly in rural areas, we apply both strategies to the rural sample for estimation, and to the urban sample—on whom there should be no effect—to test the validity of the identification strategy.

### 3. Results

#### 3.1. Main effects

Table 2 shows that the household clean energy transition induces a significant improvement in public perception of their social status in northern rural China. We begin with the most parsimonious model (1), and then incrementally add individual controls, city controls, and household and year fixed effects in the following models (2) to (4). Based on the estimated coefficient from the most restrictive specification in column (4), the city with largest renovation (0.4846 in Langfang) had its rural residents have 0.146 unit higher in social status than the city with smallest renovation (0.0036 in Rizhao). This is a 5% improvement compared to the mean value of social status in our samples (2.894).

While both rural and urban residents are affected by potential confounding factors of other air pollution control policies, the clean heating renovation is almost exclusively targeting rural residents. This is exactly the estimation results from our identification strategy. As a placebo, model (5) shows that urban residents are not affected by the renovation. All of these models consistently suggest a positive causal effects of heating renovation on the perceived social status of the public.

To test the plausibility of the parallel trend assumption and estimate dynamic effects, figure 2 plots the event-study estimates with 90% confidence intervals. There is no evident pre-trend in residents’ social status before the policy implementation. Afterwards, it shows that the renovation improved public perception of their social status immediately, but the improvement diminished two years later, suggesting saturation in perception. This dynamic effect implies that the public has a positive overall experience with the heating renovation, which is conducive to policy implementation, although psychological experience returns to the normal level in the long term.

#### 3.2. Robustness checks

To confirm the estimated effects, a series of robustness checks are performed to address concerns for the empirical strategy, presented collectively in table 3. First, the unit of clean heating renovation is households, on which level the heterogeneity may affect individuals’ self-evaluation of social status. We therefore cluster the standard errors at the household level and report them in square brackets in column (1). Second, changes in rural population affect the policy treatment variable being constructed as in section 2. Alternatively, we keep it fixed by using rural population in 2016 as the benchmark in column (2). Third, measurement error of the treatment variable reflecting the probability of renovation is considered. We discretize it by constructing a dummy variable for high and low degrees of renovation in column (3). The results are robust and consistent.

Additional controls are also added to equation (1) for estimation. Local weather conditions could affect public perception, and contaminate the baseline estimations. To address it, we add city-level weather conditions, including wind speed, hours of sunshine, temperature, humidity, and precipitation, in column (4). Column (5) considers city-specific social economic changes that may affect the outcome by adding a specific time trend to each city. Results are robust across different specifications.

Finally, we test the possibility that our estimation is a result of pure chance or other omitted variables by a set of 500 placebo tests. Each test randomly assigns the treatment levels across cities, and performs estimation following column (4) of table 2 again. Results presented in figure 3 show that the estimated actual effect is much larger than all the placebo effects, confirming a real effect from renovation.

#### 3.3. Heterogeneity between individuals with and without renovation

We now turn to the question whether those directly with renovation and others in the same local area both experienced improvement in social status. By referring to and comparing fuel types of the same household from CFPS 2016 and CFPS 2018, those who switched from conventional to cleaner fuel can be differentiated from those who remained using the same types of fuel, clean or unclean. A small set of respondents who switched from clean to conventional fuel, usually because of relocation, is excluded from the analysis.
Table 2. Effects of the clean heating renovation on social status.

|                      | Rural sample | Urban sample |
|----------------------|--------------|--------------|
|                      | (1)          | (2)          | (3)          | (4)          | (5)          |
| Prob,D_{i>2017}      | 0.744***     | 0.726***     | 0.624***     | 0.304**      | 0.070        |
|                      | (0.066)      | (0.065)      | (0.075)      | (0.154)      | (0.152)      |
| Individual controls  | Y            | Y            | Y            | Y            | Y            |
| City controls        | Y            | Y            | Y            | Y            | Y            |
| Household FE         | Y            | Y            | Y            | Y            | Y            |
| Year FE              | Y            | Y            | Y            | Y            | Y            |
| Observations         | 17,151       | 17,150       | 17,150       | 16,961       | 13,543       |
| Adjusted $R^2$       | 0.009        | 0.032        | 0.035        | 0.190        | 0.193        |

Note: Individual-level controls include age, gender, and marriage status. City-level controls include population (log), population density (log), GDP per capita (log), and industrial structure. Columns (1)–(4) show the estimated results for rural residents aged 18–65, while column (5) shows the estimated results for urban residents aged 18–65. The robust standard errors are clustered at the individual level. FE = fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Figure 2. Event study estimation.

Note: Dots indicate point estimates and bars indicate 90% confidence intervals.

Table 3. Robustness tests of renovation effects on rural social status.

|                      | (1)          | (2)          | (3)          | (4)          | (5)          |
|----------------------|--------------|--------------|--------------|--------------|--------------|
| Prob,D_{i>2017}      | 0.304*       | 0.344**      | 0.159***     | 0.307*       | 0.322*       |
|                      | [0.162]      | [0.168]      | [0.044]      | [0.162]      | [0.176]      |
| Individual controls  | Y            | Y            | Y            | Y            | Y            |
| City controls        | Y            | Y            | Y            | Y            | Y            |
| Household FE         | Y            | Y            | Y            | Y            | Y            |
| Year FE              | Y            | Y            | Y            | Y            | Y            |
| Weather conditions   | Y            | Y            | Y            | Y            | Y            |
| City time trends     | Y            | Y            | Y            | Y            | Y            |
| Observations         | 16,961       | 16,578       | 15,624       | 16,961       | 16,961       |
| Adjusted $R^2$       | 0.190        | 0.187        | 0.216        | 0.190        | 0.190        |

Note: Individual-level controls include age, gender, and marriage status. City-level controls include population (log), population density (log), GDP per capita (log), and industrial structure. The baseline specification is based on column (4) of Table 2. Column (1) has standard errors clustered at the household level. Column (2) uses the initial rural population in 2016 to construct the treatment variable. Column (3) replaces the intensity for treatment with a dummy of high- or low-level of renovation. Column (4) controls weather conditions, including mean wind speed, cumulative hours of sunshine, mean temperature, mean humidity, and cumulative precipitation. Column (5) controls for city-specific time trends. Except Column (1), other models’ robust standard errors are clustered at the individual level. FE refers to fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 
Figure 3. Placebo test.
Note: The estimation specification follows column (4) of table 2. The grey dashed line shows the estimated actual effects. Each red dot represents an estimated placebo effect and its density.

Table 4. Heterogeneity in social status effects by sample of fuel switch.

|                          | Not switched sample | Switched vs. not switched |
|--------------------------|---------------------|---------------------------|
|                          | (1)                 | (2)                       |
| *Prob,*$D_{t>2017}$*     | 0.358***            | −0.054                    |
| ($0.177$)                | ($0.044$)           |                           |
| $D_{\text{switched}}, D_{t>2017}$ |                     |                           |
| Individual controls      | Y                   | Y                         |
| City controls            | Y                   | Y                         |
| Household FE             | Y                   | Y                         |
| Year FE                  | Y                   | Y                         |
| Observations             | 12,542              | 19,930                    |
| Adjusted $R^2$           | 0.184               | 0.178                     |

Note: FE refers to fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

We first apply the estimation specification of column (4) in table 2 to the sample who remain using the same fuel type. As the treatment variable reflects the probability or intensity of treatment, the specification cannot be applied to those with clean fuel switch, who are treated with certainty. Column (1) of table 4 shows that for those who remain using the same fuel and experience heating renovation only indirectly by locating in the area, the effect on social status improvement is significant and not any smaller. We further compare those who switched to cleaner fuel and those who did not, based on a difference-in-differences estimation with 2017 the treatment year, in column (2). It shows that the two groups are not statistically different in their self-evaluation in social status changes. Both specifications suggest that the heating renovation benefited not only those who experienced renovation directly, but also those who enjoyed the spillovers as neighbors.

3.4. Mechanism analysis
It is still puzzling how the clean heating renovation improves public perception of their social status. To further explore the underlying mechanisms, we examine different dimensions of individual perceived social relevance that may contribute to their self-evaluation of social status. The estimation follows the same baseline specification of column (4) in table 2. Table 5 shows that rural residents’ self-evaluation of their income status and health status are significantly improved following the large-scale heating renovation, while confidence to the future, life satisfaction, and happiness are unchanged.

The confirmed mechanisms echoes previous research findings. Increased income status is consistent with evidence that fuel switch in cooking alters household production and reduces the associated time burden (Afridi et al 2022, Verma and Imelda 2022b). Improved health status is consistent
Table 5. Renovation effects on different dimensions of social status.

|                      | Income status | Health status | Confidence to the future | Life satisfaction | Happiness |
|----------------------|--------------|--------------|--------------------------|------------------|-----------|
|                      | (1)          | (2)          | (3)                      | (4)              | (5)       |
| Prob, $D_{t > 2017}$ | 0.474        | 0.508        | 0.063                    | −0.016           | −0.327    |
|                      | (0.161)      | (0.242)      | (0.140)                  | (0.141)          | (0.339)   |
| Individual controls  | Y            | Y            | Y                        | Y                | Y         |
| City controls        | Y            | Y            | Y                        | Y                | Y         |
| Household FE         | Y            | Y            | Y                        | Y                | Y         |
| Year FE              | Y            | Y            | Y                        | Y                | Y         |
| Observations         | 15 624       | 14 551       | 17 001                   | 17 026           | 10 570    |
| Adjusted $R^2$       | 0.216        | 0.330        | 0.194                    | 0.210            | 0.561     |

Note: The main specification is based on column (4) of table 2. FE refers to fixed effects. **$p < 0.01$, *$p < 0.05$, *$p < 0.1$.

with lower exposure and premature death (Meng et al. 2019, Zhao et al. 2021, Zhou et al. 2022). Both mechanisms suggest that the policy could in fact improve the actual welfare of the public.

4. Conclusions and policy implications

Clean, low-carbon energy transition can bring considerable carbon mitigation, pollution reduction, and health benefits, and is a key component of the United Nations’ Sustainable Development Goals and national climate policies. It is essential for China to achieve its carbon peaking and carbon neutrality target in particular. Our main finding reveals that the ongoing large-scale clean heating renovation implemented in northern China led to immediate, significant improvement in rural residents’ perception of their social status. The positive overall experience of the public with the heating renovation suggests that further policy expansion would be generally welcome and come with ancillary social benefits as well.

Additional findings provide three implications. First, evaluation and design of the heating renovation policy should consider the social dimension and for a broad population. The findings suggest that the policy benefited not only those with renovation at home, but also those not experiencing renovation directly. Such broad-scope benefits complement China’s policy goal for common prosperity and rural vitalization. In light of the increasingly important discussions of environmental justice, our research delivers a positive message to the global endeavor for sustainable, inclusive transition. It also suggests that evaluating the social impacts of the renovation should be considered, for both households expected to experience transition and a broader population.

Second, supportive measures accompanying the heating renovation should be considered. While the perception of social status improved immediately following the renovation, it faded away after two years. Psychological perception can get saturated through time. Therefore, to secure the social benefits of renovation may need other associated measures that can turn improvement in subjective perception into objective well-being.

Third, heating renovation is associated with changes in labor supply and medical resource allocation. The findings indicate that the increased social status was driven by perceived higher income and better health conditions. On the one hand, gains in the two dimensions are positive messages that can be used to promote residential heating renovation and improve policy acceptance. On the other hand, job training programs and employment opportunities should be created to ease individuals’ transition as they are freed from household production; the supply and distribution of medical services can also be adjusted to accommodate improved health conditions. The household heating renovation appears to be an important dimension that links to other dimensions of China’s modernization.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors declare no competing interests.

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