

# Qualitative System Dynamics Analysis of LPG Subsidy Reform and Urban Gas Infrastructure Development

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## ABSTRACT

Indonesia's shift from liquefied petroleum gas (LPG) to city gas represents a vital move toward cleaner energy and long-term fiscal health, yet faces obstacles such as disjointed policies, limited infrastructure, and persistent user habits. This study adopts a qualitative system dynamics method to build a comprehensive view of the transition through a validated Causal Loop Diagram (CLD) encompassing three key areas: (1) subsidy policy, (2) consumer behavior, and (3) infrastructure development. The CLD of subsidy policy shows that price incentives alone are ineffective without synchronized infrastructure readiness and well-timed policies. The CLD of consumer behavior underscores the role of service quality, reliability, and satisfaction in maintaining adoption. Meanwhile, the CLD of system growth identifies technical, regulatory, and financial factors that influence the speed and fairness of infrastructure development. A combined CLD demonstrates how these areas interact—revealing, for instance, how pricing strategies impact user trust and behavior, or how satisfaction drives future demand. These findings highlight the need for integrated, rather than piecemeal, policy actions. The study proposes phased reforms in subsidies aligned with infrastructure rollout, improved residential access, and strategic public funding to accelerate city gas adoption. Although qualitative, the model offers a strong base for future simulations, policy experimentation, and deeper exploration of behavioral and institutional dynamics in Indonesia's energy shift.

**Keywords:** *Causal Loop Diagram (CLD), city gas adoption, Energy transition, LPG subsidy reform, system dynamics,*

## 1. INTRODUCTION

Energy subsidies have long been a central component of energy access strategies in low- and middle-income countries, particularly through the support of Liquefied Petroleum Gas (LPG) as a household fuel for cooking and heating. These subsidies are intended to make modern energy affordable, especially for low-income populations, and have enabled significant gains in clean energy access in urban and peri-urban settings. However, despite their positive impact, LPG subsidies often lead to unsustainable fiscal burdens, inefficient consumption patterns, and unintended consequences, particularly when subsidies are not well-targeted (Coady *et al.*, 2015; Gould & Urpelainen, 2018). As part of broader energy transition strategies, many governments are now seeking to gradually reduce these subsidies while promoting infrastructure-based alternatives such as piped natural gas or “city gas” systems. These systems offer long-term scalability and can reduce dependency on imported LPG, aligning with national goals for energy security and subsidy efficiency (IEA, 2021; Zhang, Wei, & Wu, 2019).

From a theoretical perspective, the transition from LPG to city gas can be understood through agency theory and asymmetric information, where governments, consumers, and service providers operate under divergent incentives and unequal access to information. Policy instruments such as subsidies and infrastructure investments are intended to align these incentives and correct market failures (Komives, Victor, & Heller, 2005), yet households may remain reluctant due to perceived risks or upfront connection costs, while service providers may delay network expansion without sufficient demand certainty (Miller & Mobarak, 2015). Despite this theoretical grounding, many evaluations of energy subsidy reform rely on static, output-based indicators—such as connection numbers or price changes—while overlooking the underlying causal mechanisms. This narrow focus fails to capture dynamic feedback, non-linearity, and time delays that shape transition outcomes, including unintended effects such as social

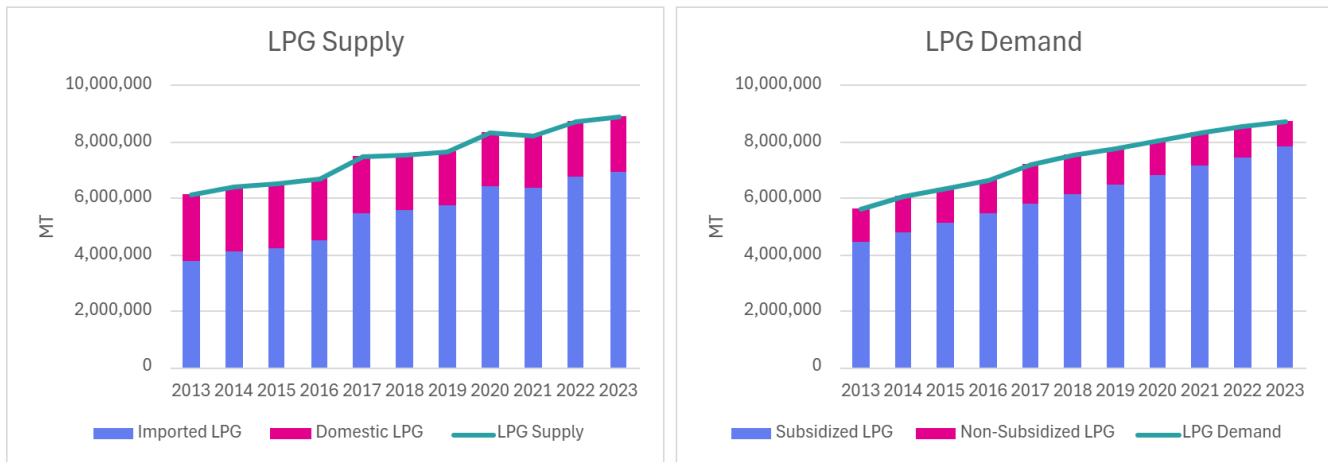


Figure 1 LPG Supply and Demand.

Source: Performance Report of the Directorate General of Oil and Gas (2023)

backlash or adoption inefficiencies when infrastructure readiness lags subsidy reduction. As a result, linear evaluation approaches often provide an incomplete assessment of policy effectiveness in complex energy transition systems (Serman, 2000; Cassidy *et al.*, 2021).

To address these limitations, a systems thinking approach is required—one that captures the interdependence of variables and the feedback structures that influence outcomes over time. Causal Loop Diagram (CLD) provides a powerful tool in this context, enabling the visualization of how subsidy policy, infrastructure readiness, consumer preferences, and institutional factors reinforce or balance each other in real-world systems. CLD is particularly valuable in contexts characterized by institutional complexity and evolving policy environments. By mapping causal relationships and identifying leverage points, CLD supports more nuanced and adaptive policy design (Rwashana *et al.*, 2014). Although CLD has been widely applied in health systems research and social policy (Cassidy *et al.*, 2021; Alonge *et al.*, 2017), its application to energy-related transitions has only recently begun to expand, particularly in studies examining systemic characteristics of gas transitions (Gürsan & de Gooyert, 2021).

In line with this growing interest, energy transition research has increasingly emphasized the value of feedback perspectives in understanding how policy, infrastructure, and user behavior co-evolve over time. For instance, Zhang, Wei, & Wu (2019) documented how policy-driven shifts from LPG to city gas in China created regionally differentiated results depending on local enforcement, infrastructure availability, and consumer responsiveness. Gürsan & de Gooyert (2021) further demonstrated how natural gas transitions involve reinforcing and balancing effects that can create either bridge-like or lock-in dynamics, illustrating the broader relevance of qualitative system dynamics in energy transitions. Similar systemic modeling efforts in Liquefied Natural Gas (LNG) supply chains in China (Yin & Lam, 2022), Compressed Natural Gas (CNG) transport adoption in Iran (Shamsapour & Hajinezhad, 2021), and small-scale LNG development in Brazil (Costa *et al.*, 2024) reinforce the utility of feedback-based analysis in energy systems.

However, despite this body of work, research applying a systems perspective in LPG-to-city gas switching in Low- and Middle-Income Countries (LMICs) remains limited.

Existing studies in the Indonesian context primarily focus on descriptive assessments of program challenges rather than systemic dynamics. For instance, Sadiyah *et al.* (2021) identify barriers such as limited investment, licensing delays, infrastructure bottlenecks, and low customer satisfaction in Indonesia's city gas program, while Sugiyono & Adiarso (2021) assess natural gas infrastructure development mainly through the lens of national energy security and policy direction. Neither of these studies examines how these factors are connected within a broader feedback structure, leaving a clear gap for systems-oriented analysis. This gap underscores the need for a qualitative system dynamics approach that maps interdependencies among subsidy policy, infrastructure readiness, and consumer behavior to better understand transition pathways in the Indonesian setting.

This study aims to fill that gap by developing a qualitative system dynamics model that identifies the feedback dynamics underlying LPG subsidy reduction and city gas implementation, based on the case of Indonesia. The objectives are threefold: First, to map the causal pathways that influence switching behavior from LPG to city gas, particularly under subsidy reduction policies and varying conditions of infrastructure readiness, pricing differentials, and overall customer behavior. Second, to identify key feedback loops that shape the growth and stagnation patterns in city gas adoption. Third, to inform policymakers about the strategic leverage points where targeted interventions can amplify adoption, minimize system lock-ins, and ensure more effective and equitable transitions in energy access.

## 2. METHODS

This section outlines the methodological approach adopted to develop and validate the CLD for analyzing the transition from subsidized LPG to city gas in Indonesia. It begins by describing the study setting to contextualize the policy and infrastructure environment in which the transition takes place. The section then explains the data collection process, including the use of secondary data sources and primary data. Finally, it details the step-by-step procedure for constructing, integrating, and validating the CLD, ensuring methodological rigor, transparency, and alignment with system dynamics approach.

**Table 1** Characteristics of Experts Participating in FGD Sessions

Participant ID	Sector	Institutional Affiliation	Functional Role	Years of Experience	Notes
<b>Focus Group Discussion 1</b>					
P1	Government	Ministry of Energy and Mineral Resources (MEMR)	Policy Analyst – Downstream Oil & Gas	12	Involved in LPG subsidy policy development
P2	Government	Ministry of Energy and Mineral Resources (MEMR)	Energy Economist	9	Provides modeling input for household fuel policy
P3	State-Owned Enterprise	PT Perusahaan Gas Negara Tbk. (PGN)	Infrastructure Planning Manager	14	Oversees city gas network expansion programs
P4	State-Owned Enterprise	PT Perusahaan Gas Negara Tbk. (PGN)	Customer Operations Supervisor	8	Provides insights on consumer complaints and service reliability
P5	Planning Agency	Regional Infrastructure Development Agency	Project Engineer	10	Manages pipeline construction and area readiness assessments
<b>Focus Group Discussion 2</b>					
P6	Academia	National University	Lecturer/Researcher in Energy Policy	11	Specializes in household fuel transitions and behavioral aspects
P7	Research Institute	Energy Policy Research Institute	Senior Research Fellow	15	Conducts policy impact analysis on LPG and natural gas markets
P8	Civil Society	Consumer Advocacy Organization	Program Coordinator	7	Represents community perspectives and low-income household concerns

## 2.1 Study Setting

Indonesia provides a compelling case for system dynamics analysis of LPG-to-city gas transitions. Since the launch of the LPG conversion program in 2007, Indonesia has distributed over 70 million subsidized 3-kg LPG cylinders to households across the archipelago (World Bank, 2016). This program significantly reduced kerosene usage but has also led to a ballooning subsidy cost, estimated at over 50 trillion IDR per year (Ministry of Finance, 2022). Despite reforms, including the introduction of QR-code tracking and quota systems, the subsidies remain largely untargeted and regressive (Beaton & Lontoh, 2010; IESR, 2022). The trends illustrated in Figure 1 reinforce this situation. LPG supply and demand have continued to rise steadily over the past decade, with increasing reliance on imported LPG and persistent growth in subsidized consumption. These patterns highlight both the fiscal burden and structural vulnerability created by Indonesia's dependence on LPG, particularly as demand expands alongside population and economic growth.

In response, the government is piloting city gas networks in over 60 cities, supported by the Ministry of

Energy and Mineral Resources (MEMR) and state-owned gas companies. These networks offer piped natural gas at competitive, unsubsidized rates and are aimed at reducing fiscal dependency on LPG. However, adoption rates remain low, with households often hesitant to switch due to unfamiliarity, safety concerns, connection costs, and uncertain service quality (IESR, 2022). Figure 2 further illustrates this challenge: while city gas household customers and consumption continue to grow, the pace remains modest relative to LPG dominance. At the same time, a clear price distortion persists between subsidized LPG and city gas, creating a structural disincentive for households to transition. This distortion reinforces entrenched consumer behavior and complicates efforts to scale up city gas infrastructure. Meanwhile, urbanization trends and growing household energy demand increase the pressure to ensure infrastructure scalability and institutional readiness (Nugroho *et al.*, 2023).

Beyond policy and adoption issues, the LPG-to-city gas transition also presents key challenges from an operations and supply chain management perspective. Efficient logistics for cylinder distribution, pipeline construction scheduling, network maintenance, and inventory



**Figure 2** City Gas Adoption and Price Distortions.

Source: Performance Report of the Directorate General of Oil and Gas (2023); Handbook of MEMR (2023)

management of piped gas are critical to ensure service reliability and cost-effectiveness, while bottlenecks in procurement, material handling, and coordination between state-owned and private entities can delay infrastructure rollout. Integrating demand forecasting, capacity planning, and real-time monitoring into the city gas supply chain is essential to manage fluctuations in household adoption and energy consumption. These operational and supply chain considerations directly influence investment prioritization, resource allocation, and the success of subsidy reform and adoption strategies, linking the CLD analysis to practical operations and supply chain management challenges. Given these dynamics, Indonesia represents an ideal context to explore the systemic interactions between subsidy policy, consumer behavior, infrastructure rollout, and institutional constraints. The application of a CLD framework to this case is expected to provide insight into how different actors, variables, and policies interact to accelerate—or hinder—the progress toward a robust and sustainable city gas system.

## 2.2 Data Collection

This study draws on qualitative data from secondary and primary sources to support the development and validation of the CLD. Secondary data informed the initial model structure, while primary data from Focus Group Discussions (FGDs) were used to refine and validate causal relationships and feedback loops. The following subsections describe the data sources and collection procedures.

### 2.2.1 Secondary Data

This study utilized qualitative secondary data to inform the initial development of the CLD examining Indonesia’s transition from subsidized LPG to city gas through a systematic review of peer-reviewed journals, government policy documents, and reports from international organizations and industry stakeholders. These sources—including MEMR policy documents, reports from the International Energy Agency (IEA), and evaluations by the Institute for Essential Services Reform (IESR) and the World Bank—provided insights into the evolution of LPG subsidy policies, infrastructure rollout challenges, and behavioral factors influencing household energy transitions. Grey literature, such as consultancy reports, regulatory guidelines, and press releases from state-owned gas enterprises, e.g., PT Perusahaan Gas Negara Tbk. (PGN), was also reviewed to

capture operational perspectives and implementation bottlenecks. Extracted data were categorized into thematic clusters and translated into causal linkages and feedback loops, establishing the theoretical grounding of the CLD while identifying critical actors and variables for subsequent primary data collection

### 2.2.2 Primary Data

The CLD developed from secondary sources was further refined and validated through primary data collection involving two rounds of FGD. Participants were selected using purposive sampling to ensure representation from diverse stakeholder groups with relevant institutional expertise, technical roles, and direct involvement in LPG subsidy reforms and city gas development. The first FGD included participants from MEMR, PGN, and related infrastructure planning agencies, while the second group consisted of individuals from civil society, academia, and energy policy research institutes (see Table 1). FGD sessions were conducted fully online to ensure accessibility for geographically dispersed experts. Each session was facilitated by experienced moderators using a semi-structured guide tailored to the CLD validation objectives. The guide was designed to systematically review each subsystem and causal mechanism, allowing participants to confirm, critique, and refine variable relationships, feedback loop functions, and system constraints relevant to policy implementation. The guiding questions used during both FGDs are presented in Table 2. The conversations were recorded, transcribed verbatim, and coded using a thematic approach to extract stakeholder feedback. A combined inductive–deductive coding strategy was employed: deductive codes were derived from predefined CLD subsystems and feedback loops, while inductive codes emerged from unanticipated stakeholder inputs during discussion. Coding definitions were iteratively refined in a codebook, and consistency was ensured through cross-checking between two coders, with discrepancies resolved through consensus. These inputs were critical in refining the model structure—adjusting polarities, adding feedback loops, and ensuring contextual relevance to the Indonesian energy landscape. Ethical approval and informed consent were collected from all participants prior to each FGD session.

**Table 2** FGD Guiding Questions for CLD Validation

CLD Subsystem	Aspect Evaluated	Guiding Questions
Subsidy Policy	Price Incentive Dynamics	1. Does the increase in city gas connections realistically influence usage volume in your experience? 2. How accurate is the relationship between usage volume, incentives, and final city gas pricing? 3. Does a wider LPG–city gas price gap strongly affect household switching in practice?
	Integrated Service Expansion	1. Does improved service integration affect customer awareness and sign-up decisions? 2. Are there additional channels or actors influencing customer acquisition not shown here?
	Subsidy Adjustment	1. Is it realistic that increased city gas use motivates LPG subsidy reduction? 2. Could political or social pressures weaken this loop? 3. What safeguards or transitional mechanisms typically accompany subsidy cuts?
	LPG Supply and Demand Pricing Sensitivity	1. Does reduced LPG demand meaningfully reduce imports in practice? 2. How responsive are domestic production and imports changing LPG demand?
Customer Perspectives	Service Quality	1. Do price incentives genuinely influence long-term customer retention? 2. How sensitive are customers to tariff variations?
	Reliability and Risk	1. How accurate is the link between service quality, customer satisfaction, and switching back to LPG? 2. Are any other experience-related variables missing?
	Investment	1. Do subsidy cuts create perceived risks or social tensions affecting service reliability? 2. How strongly does perceived reliability influence switching behavior?
System Growth	Access Regulation	1. Is ROI a primary driver of new connection approvals? 2. What additional factors influence investment decision-making?
	Construction and Area Readiness	1. How is demand regulated when registered customers exceed service capacity? 2. Are waitlists or prioritization systems common?
	Gap	1. How significant are area readiness issues (land, permits, infrastructure) in slowing or constraining new network construction?

### 2.3 CLD Development

The CLD was developed through four sequential methodological steps grounded in system dynamics principles (Forrester, 1961; Sterman, 2000), as illustrated in Figure 3 (Cassidy *et al.*, 2021; Tomoaia-Cotisel *et al.*, 2017). CLD methodology was selected for its ability to qualitatively capture complex interdependencies and feedback mechanisms among technical, economic, and behavioral factors in energy transition systems (Meadows, 2008; Black, 2013). Step 1 focused on problem definition, using secondary data from a structured literature review and initial stakeholder input to identify three core problem domains—subsidy policy, customer perspectives, and system growth—which define the analytical boundaries of the LPG-to-city gas transition. Step 2 involved the development of individual CLDs within each domain, where causal links and feedback loops were constructed separately to capture distinct stakeholder logics and causal pathways. These two steps directly address Objective 1 by mapping how subsidy reduction, infrastructure readiness, pricing differentials, and customer behavior influence switching decisions.

Step 3 integrated the three individual CLDs into a single initial integrated CLD by linking cross-domain variables and feedback mechanisms, supporting Objective 2 through the identification of key reinforcing and balancing loops shaping growth and stagnation in city gas adoption. Step 4 focused on validation and triangulation through follow-up focus group discussions and structured comparisons with regulatory and policy documents, addressing Objective 3 by ensuring the CLD reflects operational realities and highlights strategic leverage points for policymakers. This multi-step CLD development process

ensured both conceptual clarity and contextual relevance (Luna-Reyes *et al.*, 2019; Andersen *et al.*, 2012).

#### 2.3.1 Step 1: Problem Definition

The first step involved problem definition through the identification of key problem domains relevant to the LPG-to-city gas transition. Using secondary data from a structured literature review and initial stakeholder engagements, we identified three major problem domains: (1) Subsidy Policy, (2) Customers Perspectives, and (3) System Growth. This step established the conceptual boundaries and domain structure upon which subsequent CLDs were built. The identification of these domains provided the foundation for all subsequent modeling activities and justified the development of three individual CLDs.

#### 2.3.2 Step 2: Individual CLD Development

Building on the defined problem domains, the second step involved developing individual CLDs using a synthesis of structured literature review findings and initial stakeholder engagements. Guided by Kim & Andersen (2012), cause–effect relationships relevant to the LPG-to-city gas transition were extracted and coded into three individual CLDs—Subsidy Policy, Customers Perspectives, and System Growth—with variables linked based on their consistency and frequency across sources. Each CLD captured a distinct stakeholder logic, including policymakers managing Reduction of LPG Subsidy Policy, infrastructure providers responding to Customer Acquisition signals, and households evaluating switching decisions through Perceived Reliability and Perceived Safety. The CLDs were constructed using Vensim software, and purposive text analysis of documents and stakeholder notes enabled the inclusion of both tangible variables (e.g., price levels,

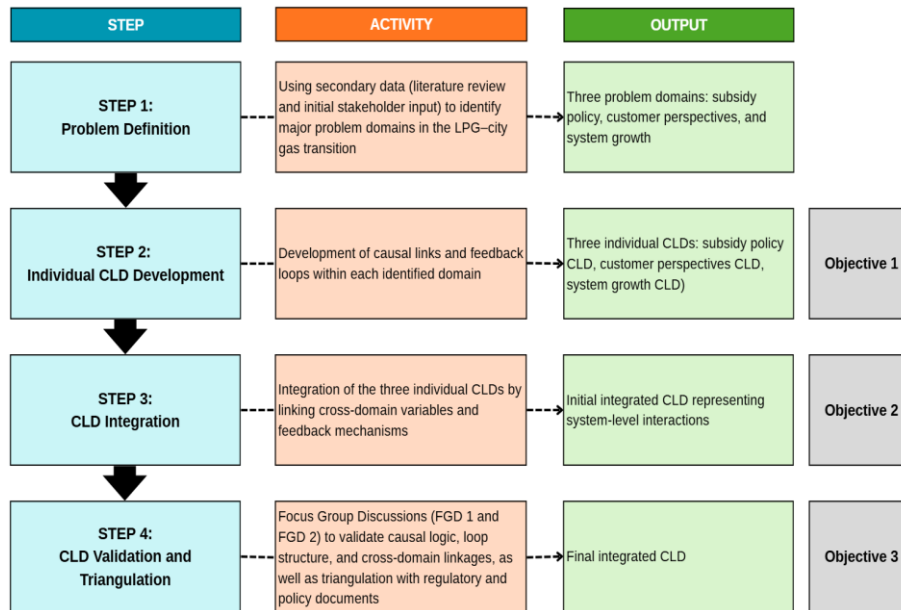


Figure 3 Research Methodology.

connection rates) and intangible influences (e.g., perceived reliability, service convenience) shaping behavioral and policy outcomes (Waterlander *et al.*, 2021).

2.3.3 Step 3: CLD Integration

The third step involved integrating the three individual CLDs into a single initial integrated CLD. This synthesis followed a stepwise process in which each CLD was compared to identify overlapping variables, feedback loops, and complementary structures. One CLD was selected as an anchor structure, while others were merged by refining existing feedback loops or introducing additional variables and causal links. Throughout this integration process, particular attention was paid to maintaining feedback logic coherence, adjusting link polarity when needed, and eliminating redundancy without losing meaningful distinctions. This step directly supported Objective 2 by revealing system-level reinforcing and balancing loops that drive city gas adoption dynamics, consistent with the approach outlined by Tomoiaia-Cotisel *et al.* (2017). The resulting output was an initial integrated CLD representing system-level interactions.

2.3.4 Step 4: CLD Validation and Triangulation

The final step was validating the integrated CLD to ensure that key stakeholder perspectives and system behaviors were accurately represented (Coyle, 2000; Coyle & Exelby, 2000). This was achieved through two follow-up FGDs involving additional participants not included in the initial modeling phase. Each FGD reviewed the integrated CLD and provided feedback on whether the relationships and feedback loops reflected their real-world experience. The FGD, in particular, generated substantive validation feedback that led to refinements across all three subsystems—subsidy policy, customer perspectives, and system growth. Structural adjustments were made where important variables or links were missing, or where feedback loops required clarification.

Key validation insights confirmed that infrastructure readiness must precede LPG subsidy reduction (strengthening balancing loop B1), clarified interactions

between price differentials, behavioral inertia, and switching costs (refining loops R1 and B2), and identified social trust and perceived service reliability as critical moderators of customer retention (reinforcing loops R3, B5, and B6). Stakeholders also highlighted delayed feedback effects of excess LPG allocation and import management on domestic production sustainability (loops B3 and B4), as well as practical constraints related to area readiness, regulatory rigidity, and return-on-investment considerations shaping investment-driven construction (R5) and construction capacity limits (B8). In addition, triangulation with updated regulatory documents, policy briefs, and implementation guidelines enhanced model robustness and policy relevance (Barlas, 1996; Vennix, 1996; Luna-Reyes & Andersen, 2003), resulting in a validated, policy-relevant CLD capturing multi-level dynamics in Indonesia’s clean energy transition.

3. RESULT

This section presents the results of the integrated CLD analysis. The findings are organized into four subsections that reflect the main structural domains of the system: subsidy policy dynamics, customer perceptions and adoption behavior, infrastructure and connection system development, and the final integrated CLD. Figure 4 provides a high-level sector map of the LPG-to-city gas transition, illustrating the three main subsystems—Subsidy Policy, Customer Perspective, and System Growth—and their reinforcing and balancing interactions. This overview helps contextualize the detailed discussion of individual feedback loops presented in each subsequent subsection. Each subsection explains the dominant feedback mechanisms, stakeholder insights, and their implications for the transition from subsidized LPG to city gas in Indonesia.

3.1 Changes in Subsidy Policy

The discussion around accelerating the transition from LPG to city gas centered on a systemic understanding of subsidy policy (Figure 5). Participants consistently

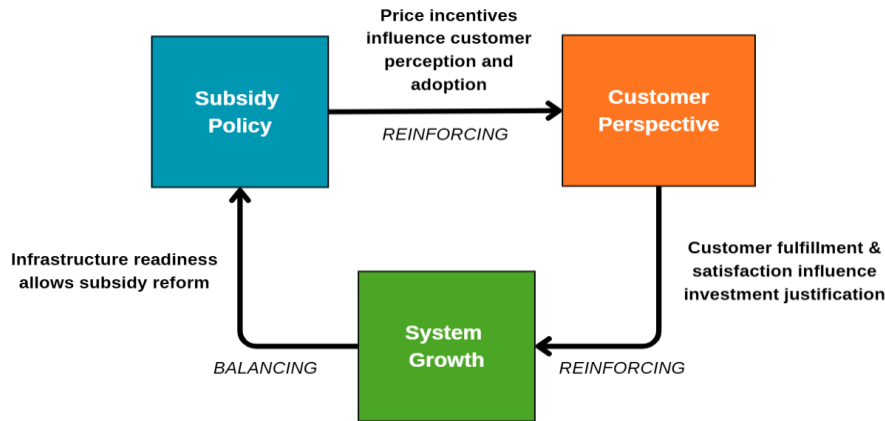


Figure 4 High-level Map of the LPG-to-City Gas Transition.

emphasized the need to prioritize infrastructure before altering existing subsidies. This is grounded in the belief that any move to reduce LPG subsidies (as reflected in balancing loop B1) must be accompanied by a solid and accessible city gas infrastructure. Without it, users may face limited options and resist the change. One participant insightfully remarked, *“It would be more comfortable to reduce the subsidy only after making sure that the city gas is truly available.”* This highlights how infrastructure readiness serves not only as a physical prerequisite but also as a trust-building mechanism, supporting efforts to rebalance the energy subsidy structure.

Building on this, participants stressed that infrastructure alone is not enough—economic signals also matter. When discussing how to encourage behavioral shifts, they noted that price differences between LPG and city gas strongly influence household decisions. If city gas becomes relatively cheaper—whether by adjusting LPG base prices or reevaluating the subsidy scheme—the reduced price gap provides a strong incentive for consumers to switch. This dynamic is captured in reinforcing loop R1, where rising LPG prices due to subsidy cuts push households to explore more affordable alternatives. As one participant put it, *“People respond to what hits their wallet. If LPG is more expensive, they’ll look for alternatives.”*

Yet, the effectiveness of price signals is closely tied to infrastructure and service delivery. The presence of integrated services, strategic partnerships, and neighborhood-wide outreach campaigns was seen as crucial to increase adoption. As these services improve, awareness grows, customer acquisition becomes easier, and more households connect to the city gas network—illustrating the reinforcing loop R2. A stakeholder noted, *“If people see that others in the neighborhood are using city gas, they’re more likely to sign up too.”* This peer influence creates a ripple effect, reinforcing the uptake of city gas and justifying continued investment in infrastructure expansion.

Despite these incentives, behavioral inertia and practical barriers continue to slow the transition. The balancing loop B2 illustrates how factors such as the perceived inconvenience of switching, lack of awareness, and upfront costs limit the effectiveness of pricing strategies. This is especially pronounced in remote or underserved areas. Participants emphasized the importance of targeted incentives to mitigate these challenges, including temporary

subsidies for installation costs or flexible payment plans. These measures help reduce psychological and financial barriers to change. Further amplifying the switch, participants discussed the establishment of LPG-free zones as a structured push to accelerate the transition (also connected to B1). These zones limit or gradually phase out LPG availability in certain areas, nudging consumers toward adopting city gas. However, this policy approach must be implemented carefully. Without proper readiness—both in infrastructure and public acceptance—it risks backlash or even energy access disruption. Thus, enforcement must be accompanied by education, community engagement, and clear rollout timelines.

Shifting focus to the broader LPG ecosystem, the discussion revealed downstream effects of declining LPG usage. As more households switch, overall LPG consumption falls, reducing the effectiveness of existing subsidies. This is illustrated in balancing loop B3, where lower usage weakens the rationale for high subsidy allocations, creating room for reallocation or removal. However, if not properly adjusted, this can result in excess LPG allocation, where the government continues supplying volumes no longer matched by demand. One participant commented, *“The government is paying for gas that no one is using—it’s a waste.”*

This inefficiency connects directly to domestic production sustainability. When imported LPG is used to cover the excess, domestic producers may lose their market share, discouraging investment and reducing production rates—captured in balancing loop B4. A participant observed, *“When imports keep coming in to cover the excess, local producers are pushed aside.”* Over time, this dynamic undermines national energy resilience and creates artificial dependence on external sources. The reduced incentive to produce domestically could leave the system more vulnerable to global price volatility or supply chain shocks. Controlling subsidized LPG allocation, therefore, not only supports a smoother energy transition but also safeguards the long-term viability of domestic production. In sum, participants underscored the need for a holistic approach—combining infrastructure readiness, economic incentives, behavioral nudges, and production sustainability—to ensure that the transition from LPG to city gas is both effective and equitable.

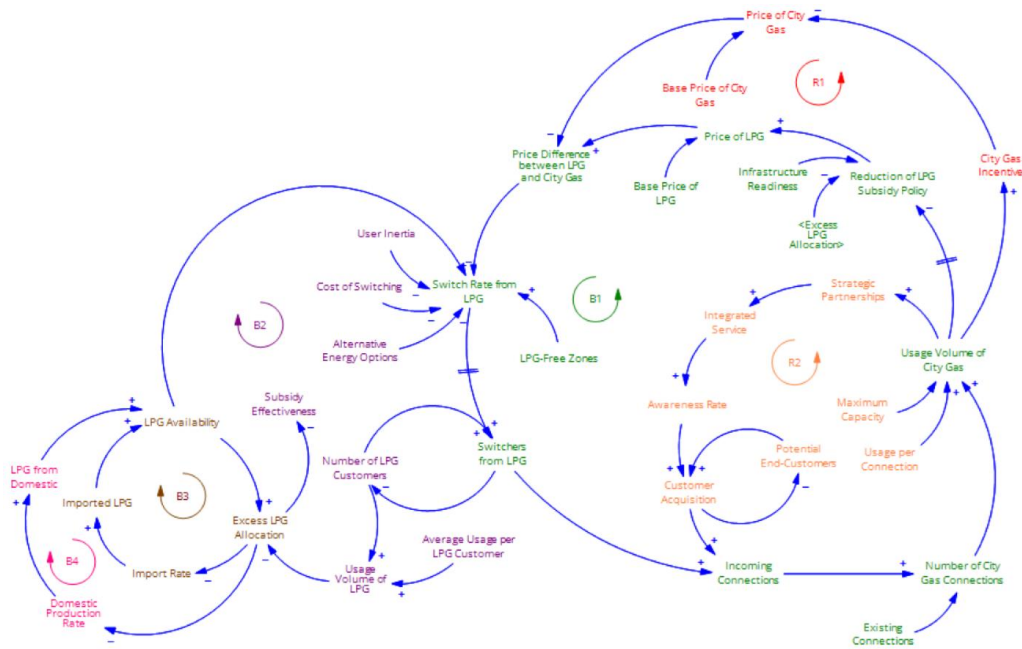


Figure 5 Changes in Subsidy Policy.

### 3.2 Changes in Customer Perceptions and Adoption Behaviors

Customer experience stands out as a central factor in the sustainability of city gas usage (Figure 6). The analysis indicates that when users perceive the system as reliable and safe, their overall satisfaction increases, which in turn fosters continued use. As one participant noted, “Perception of safety... if the pipeline leaks, it could explode,” emphasizing the importance of trust in the system's integrity. Another shared, “Price isn’t a big issue... it’s more about how easy it is to use,” highlighting that convenience often outweighs cost in decision-making. This self-reinforcing pattern forms feedback loop R3, where positive experiences enhance perceptions, leading to stable and continued adoption.

Service quality factors—such as responsiveness, ease of use, and convenience—also emerged as significant contributors to user satisfaction. A participant explained, “Lower-middle-class households are quite interested in city gas because of how easy it is to use.” Another remarked, “Imagine being hungry at midnight and not being able to cook because the LPG ran out,” underlining city gas reliability advantage. Still, dissatisfaction remains a threat: “If they have to pay and don’t want to... they’ll just switch to firewood,” a warning of how unmet expectations can prompt users to abandon the system altogether. This dynamic corresponds to loop B5, where a dip in customer fulfillment increases the switch rate and weakens system performance.

Price sensitivity and government incentives also play strategic roles. One respondent observed, “They’re cutting subsidies and reducing LPG circulation,” showing how policy shifts shape behavior. However, concerns persist: “If they reduce LPG and shift to city gas... don’t let the budget increase too much,” reflecting fears over rising costs. This describes loop B6, in which policies act as levers for adoption—but if not carefully balanced, “Lower-income groups... with these reductions, there could be social unrest,” underscoring the risks of misaligned policy and pricing.

Finally, the number of active users and new connections is influenced by a complex interplay of pricing, service quality, and customer experience. When satisfaction is high, switch rates decline, and retention improves—particularly when users feel safe and well-served. As one respondent concluded, “If they can keep it affordable and improve service, I’ll definitely keep using city gas.” The interwoven feedback loops of R3, B5, and B6 reveal the delicate balance between technical reliability, effective policy, and user-centered service delivery.

### 3.3 Development of Infrastructure and Connection Systems

The expansion of city gas infrastructure is a critical pillar in Indonesia’s energy transition strategy, as reflected in Figure 7. Development across Indonesia’s diverse geography poses substantial challenges, particularly in areas with complex terrain (captured in reinforcing loop R5). As highlighted in the FGD, “Areas with rivers, bridges, and railways increase CAPEX,” indicating how natural and built environments can drive up capital expenditure. Another participant added, “The construction type differs... costs are high,” underscoring that technical approaches must adapt to local conditions. Even with a nationally fixed pricing policy, regional economic feasibility varies: “City gas prices are set the same but economic viability differs because of topography.”

This disparity impacts investment decisions. This dynamic corresponds to loop R5, where participants emphasized the need for economic support mechanisms to maintain investor confidence. One pointed out, “For every expense, business entities need projected returns,” highlighting the importance of profitability. Another remarked, “The subsidized price of IDR 7,000 is a burden for business entities,” revealing that even with government support, margins remain tight. Without additional incentives, investment approval is challenging: “If there’s no support, it’s hard to get investment approval,” and “There must be economic price compensation to the business entities.” On





**Table 3** Feedback Loops

CLD	Subsystem	Feedback Loop	Loop Type	Mechanisms	Reference	Expert Opinion
CLD Subsidy Policy	Price Incentive Dynamics	Incoming Connections → Number of City Gas Connections → Usage Volume of City Gas → City Gas Incentive → Price of City Gas → Price Difference between LPG and City Gas → Switch Rate from LPG → Switchers from LPG → Incoming Connections	Reinforcing (R1)	Growth in connections increases usage and incentives, which raises city gas price, increases the LPG–city gas price gap and promotes switching.	Andadari <i>et al.</i> , 2014; Sovacool, 2016	<i>“People respond to what hits their wallet. If LPG is more expensive, they’ll look for alternatives.”</i>
	Integrated Service Expansion	Incoming Connections → Number of City Gas Connections → Usage Volume of City Gas → Strategic Partnerships → Integrated Service → Awareness Rate → Customer Acquisition → Incoming Connections	Reinforcing (R2)	More connections improve service integration and awareness, boost customer acquisition, and thus further increase connections.	Toft <i>et al.</i> , 2017	<i>“If people see that others in the neighborhood are using city gas, they’re more likely to sign up too.”</i>
	Subsidy Policy Adjustment	Incoming Connections → Number of City Gas Connections → Usage Volume of City Gas → Reduction of LPG Subsidy Policy → Price of LPG → Price Difference between LPG and City Gas → Switch Rate from LPG → Switchers from LPG → Incoming Connections	Balancing (B1)	Rising city gas use justifies subsidy cuts, increasing LPG price and the price gap, which drives switching—but social pressures may counteract this.	Sovacool, 2016	<i>“It would be more comfortable to reduce the subsidy only after making sure that the city gas is truly available.”</i>
	LPG Usage and Availability	Switch Rate from LPG → Switchers from LPG → Number of LPG Customers → Usage Volume of LPG → Excess LPG Allocation → Import Rate → Imported LPG → LPG Availability → Switch Rate from LPG	Balancing (B2)	Decline in LPG use leads to surplus, which lowers import demand and availability, thereby slowing switching.	Imelda & Verma, 2021; Moeletsi & Palamuleni, 2020	<i>“Targeted incentives... temporary subsidies for installation costs or flexible payment plans.”</i>
	LPG Import Regulation	LPG Availability → Excess LPG Allocation → Import Rate → Imported LPG → LPG Availability	Balancing (B3)	Higher LPG availability leads to reduced imports, stabilizing overall supply.	Kusdiana, 2023	<i>“The government is paying for gas that no one is using—it’s a waste.”</i>
	Domestic LPG Production Control	LPG Availability → Excess LPG Allocation → Domestic Production Rate → LPG from Domestic → LPG Availability	Balancing (B4)	Surplus LPG reduces domestic production rate, which balances availability over time.	Purwosaputra <i>et al.</i> , 2022	<i>“When imports keep coming in to cover the excess, local producers are pushed aside.”</i>

**Table 3** Feedback Loops (Cont'd)

CLD	Subsystem	Feedback Loop	Loop Type	Mechanisms	Reference	Expert Opinion
CLD Customer Perspectives	City Gas Pricing Dynamics	Number of City Gas Connections → Usage Volume of City Gas → City Gas Incentive → Price of City Gas → Switch Rate from City Gas → Number of City Gas Connections	Reinforcing (R3)	Price incentives tied to higher usage encourage adoption, reducing switching and reinforcing customer base.	Mugauina <i>et al.</i> , 2020; Khosrowpour <i>et al.</i> , 2018	<i>“Price isn’t a big issue... it’s more about how easy it is to use.”</i>
	Customer Experience Feedback	Number of City Gas Connections → Usage Volume of City Gas → Customer Fulfillment → Switch Rate from City Gas → Number of City Gas Connections	Balancing (B5)	Poor user experience reduces fulfillment and increases the likelihood of switching and balancing growth.	Kumar <i>et al.</i> , 2020; Claudy <i>et al.</i> , 2015	<i>“If they have to pay and don’t want to... they’ll just switch to firewood.”</i>
	Perceived Service Reliability	Number of City Gas Connections → Usage Volume of City Gas → Reduction of LPG Subsidy Policy → Social Conflict → Perceived Reliability → Quality of Service → Customer Fulfillment → Switch Rate from City Gas → Number of City Gas Connections	Balancing (B6)	Subsidy cuts can trigger conflict, undermining reliability and fulfillment, leading to customer churn.	Sovacool, 2016; Wang <i>et al.</i> , 2019	<i>“Lower-income groups... with these reductions, there could be social unrest.”</i>
CLD System Growth	User Base Expansion	Incoming Connections → Number of City Gas Connections → Switch Rate from City Gas → Potential Returning Customers → Incoming Possible Customers → Possible Connections → Registered Customers → Incoming Connections	Reinforcing (R4)	Growth in connections increases potential re-engagement and expands the pool of new users.	Graziano & Gillingham, 2015	<i>“Now we lay pipes first, then socialize.”</i>
	Investment-Driven Construction	Incoming Connections → Return on Investment → Investment Approval → Connection Construction → Incoming Connections	Reinforcing (R5)	Increased connections improve ROI, driving further investment and network growth.	Dhakal <i>et al.</i> , 2019; Koengkan <i>et al.</i> , 2020	<i>“For every expense, business entities need projected returns.”</i>
	Access Gap Regulation	Incoming Possible Customers → Possible Connections → Registered Customers → Not Served → Incoming Possible Customers	Balancing (B7)	Unserved customer buildup pressures the system, requiring demand regulation.	Lopez-Bernabeu <i>et al.</i> , 2023	<i>“Once an area is centrally managed, LPG can disappear—there’s no other option but city gas.”</i>
	Construction Capacity Limit	Connection Construction → Areas Ready for City Gas → Target Gap → Connection Construction	Balancing (B8)	Construction is constrained by area readiness and planning targets, limiting overexpansion.	Nakata <i>et al.</i> , 2011; Jones & Pye, 2014	<i>“The national development plan targets 40 new cities that can immediately use city gas.”</i>

infrastructure readiness (Rogers, 2010; Pachauri & Rao, 2013; Moeletsi & Palamuleni, 2020). Reinforcing feedback through public awareness and customer acquisition, captured in R2 (Integrated Service Expansion), can accelerate adoption when infrastructure readiness and multi-stakeholder collaboration are present (Toft *et al.*, 2017).

In parallel, the customer perspectives CLD highlights how user experiences and perceptions shape both adoption and retention. Customer fulfillment—driven by perceived safety, service reliability, and ease of use—functions as a central leverage point within R3 (City Gas Pricing Dynamics), where higher usage volumes reinforce price responsiveness and loyalty (Kumar *et al.*, 2020; Claudy *et al.*, 2015). Negative experiences, including aesthetic disruption and ambiguous pricing, weaken this reinforcing process and activate B5 (Customer Experience Feedback), increasing churn and constraining growth (Bertsch *et al.*, 2017; Wang *et al.*, 2019). Moreover, B6 (Perceived Service Reliability) illustrates how subsidy reductions, when poorly sequenced, can trigger social conflict that undermines perceived reliability and customer fulfillment, particularly among lower-income groups (Sovacool, 2016). Conversely, positive customer experiences strengthen R3 by reducing switching rates, increasing usage volumes, and enabling economies of scale that justify further infrastructure investment and service improvements (Khosrowpour *et al.*, 2018).

Meanwhile, the system growth CLD captures the institutional and technical dynamics underlying infrastructure expansion. Connection construction lies at the core of R5 (Investment-Driven Construction), where higher returns on investment stimulate investment approval and further network expansion (Dhakal *et al.*, 2019; Koengkan *et al.*, 2020). From an operations and supply chain management perspective, this involves scheduling construction, managing procurement of materials, coordinating multiple contractors, and ensuring timely pipeline installation to meet projected demand. Complementing this, R4 (User Base Expansion) shows how growing connections increase visibility and social legitimacy, reinforcing adoption through word-of-mouth and socialization effects (Graziano & Gillingham, 2015). However, these reinforcing dynamics are constrained by balancing loops such as B7 (Access Gap Regulation) and B8 (Construction Capacity Limit), which reflect inequities in coverage, regulatory rigidity, and physical construction limits (Jones & Pye, 2014; Lopez-Bernabeu *et al.*, 2023; Nakata *et al.*, 2011). Managing these constraints requires careful planning of resource allocation, inventory management, and operational coordination to prevent bottlenecks and ensure efficient infrastructure rollout.

When integrated, the three CLDs reveal cross-domain feedback mechanisms that would be difficult to observe in isolation. For example, the price differential driving R1 in the subsidy policy CLD also feeds into customer perceptions of fairness and satisfaction in R3 (Mugauina *et al.*, 2020). Similarly, infrastructure expansion driven by R5 improves service reliability and customer fulfillment, which then strengthens R3 and dampens churn through B5, feeding back into system growth. These interactions highlight how operations and supply chain management activities—such as logistics, network maintenance, and real-time monitoring—directly influence system dynamics and policy outcomes.

These interactions demonstrate how interventions in subsidy design, service quality, or infrastructure rollout propagate across domains, potentially amplifying or undermining policy outcomes if feedback effects are not anticipated (Heiskanen & Matschoss, 2017; Sari, 2024; Claudy *et al.*, 2015).

Compared to non-system dynamics approaches, the findings offer more explicitly dynamic insights by revealing how policy, infrastructure, and user behavior co-evolve through reinforcing and balancing feedback loops. While prior studies on LPG-to-city gas transitions document bridge-like or lock-in dynamics (Zhang, Wei, & Wu, 2019; Gürsan & de Gooyert, 2021), most empirical evaluations rely on static indicators or isolated drivers. In the Indonesian context, existing studies emphasize descriptive barriers (Sadiyah *et al.*, 2021) or macro-level policy directions (Sugiyono & Adiarso, 2021) without mapping how these factors interact within feedback structures. By explicitly linking R1–R5 and B1–B8 across subsidy policy, customer perspectives, and system growth, the integrated CLD reveals time delays, cross-domain effects, and unintended consequences that linear or output-based methods typically overlook (Sterman, 2000; Cassidy *et al.*, 2021).

In conclusion, the transition from LPG to city gas must be understood as a multi-layered process shaped by interacting policy, consumer, infrastructure, and operations and supply chain management feedback. Effective transformation depends on reinforcing positive loops—such as R2, R3, and R5—while carefully managing balancing constraints embedded in B1, B5, and B8. Reforming subsidies to strengthen price signals, improving service experiences to stabilize customer fulfillment, ensuring infrastructure rollouts align with institutional capacity, and coordinating operational and supply chain activities are all critical. Recognizing the feedback-rich structure of the integrated CLD enables policymakers to identify strategic leverage points, anticipate systemic risks, and design interventions that reinforce rather than destabilize the transition pathway.

## 5. CONCLUSION AND RECOMMENDATIONS

This study explored the transition from LPG to city gas in Indonesia through a system dynamics lens, resulting in the development of CLD that integrates policy, customer behavior, and infrastructure development. The analysis identified 13 significant feedback loops—five reinforcing and eight balancing—that capture the complex interdependencies within the system. The findings highlight that economic incentives, such as subsidy reduction, are only effective when complemented by infrastructure readiness and strategic customer engagement. Additionally, customer fulfillment, shaped by perceived safety, service quality, and convenience, plays a critical role in stabilizing the system and reducing the likelihood of switching away from city gas. Infrastructure growth, while essential, remains limited by financial, technical, and regulatory constraints. The integrated CLD also underscores the importance of policy alignment across sectors, showing how pricing policies, infrastructure access, and service reliability mutually influence one another.

Based on the integrated CLD, five primary leverage points emerge. First, LPG subsidy design and sequencing constitute a high-impact leverage point within balancing loop B1, where phased and conditional subsidy reform—implemented only when infrastructure readiness thresholds are met—can reduce social conflict and stabilize price signals. Second, infrastructure readiness functions as a structural leverage point influencing multiple loops (R2, R4, and R5), as network availability directly conditions switching behavior, customer fulfillment, and investment attractiveness. Third, customer fulfillment—shaped by perceived safety, service reliability, and convenience—represents a behavioral leverage point embedded in reinforcing loop R3 and balancing loop B5, where improvements can simultaneously enhance retention, reduce churn, and strengthen demand-side stability. Fourth, regulatory classification of city gas as a basic public utility act as an institutional leverage point affecting access gaps and construction bottlenecks (B7 and B8), with regulatory rigidity currently constraining reinforcing growth dynamics. Fifth, the reinvestment of fiscal savings from reduced LPG subsidies into city gas infrastructure operates as a financial leverage point that strengthens investment-driven construction (R5) while alleviating long-term subsidy burdens.

Accordingly, the following policy recommendations are grounded in the CLD analysis and reinforced by expert feedback, ensuring that each recommendation aligns with the identified structural, behavioral, institutional, and financial leverage points. First, it is recommended that the government implement LPG subsidy reforms in a phased and conditional manner, ensuring that reductions are aligned with measurable infrastructure readiness to avoid social backlash. Second, infrastructure expansion should be accelerated through strategic public-private partnerships, especially in urban housing developments where integration with residential gas networks can be most effective. Third, customer adoption can be supported by offering temporary incentives such as connection fee subsidies, awareness campaigns, and bundled utility services to mitigate switching barriers. Fourth, regulatory frameworks should be revised to classify city gas as a basic public utility and remove outdated constraints on distribution models. Fifth, fiscal savings from reduced LPG subsidies should be redirected to finance city gas development, capitalizing on its potential for operational efficiency and domestic energy resilience.

Despite its strengths, the study has several limitations. First, the analysis is based primarily on qualitative modeling, which, while insightful, does not quantify the magnitude of feedback interactions or time delays within the system. Second, the model is highly contextualized to Indonesia's energy landscape, limiting its generalizability to other regions with differing institutional or geographic profiles. Third, while stakeholder perspectives were included, the study may not fully capture the experiences of marginalized groups such as rural communities or informal urban populations who often face distinct challenges in accessing clean energy.

Future research can build on this foundation in several ways. First, there is a need to develop quantitative system dynamics models based on the validated CLD to simulate long-term policy outcomes and test the sensitivity of system

responses. Second, incorporating geospatial and demographic data into future modeling efforts could improve understanding of how location-specific factors influence infrastructure rollout and user adoption. Third, longitudinal studies should be conducted in pilot areas to evaluate the real-world impacts of policy changes and infrastructure expansion on household energy behavior. Fourth, further investigation into equity and inclusion dimensions is essential to ensure that the transition to city gas does not exacerbate existing inequalities but instead supports universal and just energy access.

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENTS

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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