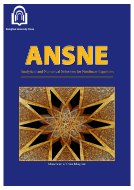

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Research article

Designing an Efficient and Incentive-Compatible Mechanism of Self-Adjusting in the Smart Power Grid

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Abstract

Given the increasing challenges in electricity supply and the necessity of optimizing energy consumption in public institutions, this article designs an efficient and incentive-compatible self-regulating mechanism in the smart electricity grid (based on mechanism design theory) to manage electricity consumption in public governmental institutions. Unlike existing mechanisms that rely on direct supervision or fixed quotas, our approach introduces a composite permitted ceiling that dynamically adapts to each institution's historical performance and operational constraints. The aim of this article is to design a mathematical model and create a mechanism through which agents (public governmental institutions) voluntarily and without coercion choose desirable and optimal consumption behavior. The proposed mechanism encourages agents to reduce consumption and adhere to the permitted ceiling without direct supervision. Our model achieves an improvement in energy balance compared to traditional fixed-ceiling approaches while maintaining voluntary participation. The proposed mechanism encourages agents to reduce consumption and adhere to the permitted ceiling without direct supervision. The proposed mechanism includes a composite permitted ceiling, mission coefficient, and a system of rewards and penalties that aligns with the interests of each institution and leads to the reform of consumption behavior.

Keywords: Game theory, Mechanism design, Players, Energy imbalance, Smart grid

Mathematics Subject Classification (2020): 91A10, 91B24, 90B50, 68M10

1 Introduction

One of the major challenges facing the development of the electricity industry for countries is achieving an optimal and balanced level of electricity production and consumption. On the one hand, due to inherent and technical limitations, electrical energy, unlike other types of energy such as water and gas, cannot be stored in large volumes; therefore, at any given moment, all electricity produced in a countrys electricity grid must be consumed, and there must always be a stable balance between electricity production and consumption; because storing more production than demand is not possible and becomes a waste of energy. On the other hand, producing less than demand also causes widespread blackouts for industries and other electricity users [1]. The most important problem that the electricity industry has faced in recent years is the imbalance in the supply and demand of electricity during peak consumption periods. A review of the macro indicators of the electricity sector in 2023 shows that although the nominal capacity of the country's power plants increased by 1.7 percent, the growth in electricity demand during peak times was 5.8 percent, and for this reason, the electricity imbalance has intensified and has become one of the country's serious issues. Therefore, in addition to increasing production, serious attention should be paid to management and optimization programs for electricity consumption. In the area of diversification of the electricity generation portfolio, there are also statistics indicating excessive reliance (more than 90 percent) of the country's electricity generation on fossil fuels. The imbalance of natural gas in the cold season, as well as the economic and environmental losses of liquid fuels, require greater attention to the development of non-fossil sources of electricity generation (especially renewable) and increasing the efficiency of thermal power plants [2]. Managing electricity consumption in public institutions is one of the strategic priorities in the country's energy policy. Due to the scope of their activities, the number of personnel, and numerous equipment, these institutions have a significant share in electricity consumption. In a situation where the electricity network is faced with production and distribution constraints, modifying the consumption pattern in this sector can have a significant impact on energy sustainability. However, implementing austerity policies requires mechanisms that are not only effective but also aligned with the real incentives of the institutions. Traditional methods based on direct control or fixed penalties have limited effectiveness and often encounter institutional resistance. In view of the above, it is necessary to use scientific methods to manage supply and demand in the smart electricity grid. For this purpose, various scientific methods have been used so far, one of the methods that has been widely used in the smart electricity grid in recent years is mechanism design theory. Mechanism design theory is a branch of game theory that studies the design of institutions and rules that help individuals achieve desired outcomes from their interactions. Mechanism design can be considered the reverse engineering of game theory or, equivalently, the art of designing game rules to achieve a specific desired outcome. The main focus of mechanism design is to create institutions or protocols that automatically and self-reinforcingly ensure the alignment and alignment of personal interests and public interests. In 1960, Horwich (Nobel Prize winner in Economic Sciences in 2007) first introduced the concept of mechanism. He also introduced the key concept of incentive compatibility in 1972, which allows the incentives of rational actors to be directly taken into account in planning and modeling, and extends the practical implementation of mechanisms to more fields [11]. The basic technique he uses in mechanism design to obtain specific information is to create a strategic game space among rational actors whose equilibrium of the static game is approximately the same as the desired outcomes of the policymaker or planner [25]. In fact, models based on mechanism design theory force players (executives) to do what the policymaker and planner want [4,7]. Gibbard (1973) first proposed the principle of disclosure, and then this principle was proposed in the most general form by Myerson [15–17]. In 1973, an applied framework for conducting empirical studies and applying Groves (1973) and quasi-Groves mechanisms was presented [8,9]. Satterwhite (1975) proved the impossibility of simultaneously achieving a social objective function with all the desirable characteristics desired by the planning institution, namely post-implementation efficiency, non-dictatoriality, and strategy-compatible incentive characteristics [20]. The concept of implementation was introduced by Maskin (2008; 1983) was introduced, and Baliga and Maskin (2003), Myerson (2008), and Appett and Gridel (2011) made great progress in mechanism design theory [6, 14–16]. Mechanism design theory has provided a very important tool for analyzing, modeling, and solving economic problems in the face of incomplete and asymmetric information of the centralized planning and policy unit and decentralized implementing agents [18]. Mechanism design theory expands the general and universal view of the centralized policy unit in the field of economic problems, and this broadening of vision enables the planner to consider incentive constraints as well as resource constraints [13,21]. Mechanism design theory is a great achievement and unexpected scientific breakthrough in modern economic analysis [27, 28]. This way of thinking theory It has changed the way economists, planners, and policymakers think about optimal institutions and regulations for achieving public desired outcomes (the extent to which goals are achieved) and has had a profound impact on policymaking and will continue to do so in the future [10, 16]. Despite its mathematical complexity, this theory has found its place in policymaking and planning [19,22]. The main focus of this theory is on designing, ensuring, and deploying institutions and rules that achieve public desired goals and outcomes by internalizing external side effects for executive agents [12, 23]. These mechanisms are designed, ensured, and deployed in such a way that, by creating sufficient internal incentives, honesty, truthfulness, and freely providing the best performance, they become the most productive as a result of implementing the dominant strategy of each executive agent (the only option of the actors) [3, 24]. In other words, in such mechanisms, no executive agent has an intrinsic motivation to not comply with the rules, and conversely, all executive agents have sufficient intrinsic motivation to fully comply with the rules. In this paper, the approach to designing a compatible incentive mechanism to guide the consumption behavior of public government institutions is examined; an approach that, by aligning individual interests and social goals, initiates behavior modification from within the institutions. Our research gap lies in the absence of self-adjusting mechanisms that simultaneously account for institutional heterogeneity and voluntary participation. Existing studies such as [13–15] focus on homogeneous agents or impose mandatory quotas, while our mechanism introduces a composite ceiling that adapts to each institution's unique characteristics. Unlike [16–18] which rely on centralized monitoring, our approach minimizes supervision costs while maintaining incentive compatibility through a carefully designed reward-penalty structure.

2 Mechanism Description

In this mechanism, a combined permissible ceiling is determined for the consumption of each executive agency. Agencies gain more benefits by observing the consumption ceiling and providing correct information. If an agency hides its mission information or does not reduce its consumption, then:

- it faces financial punishment
- it loses its managerial credibility
- it is placed in a lower performance ranking

As a result, the choice of optimal behavior (reducing consumption and providing correct information) will be in line with the real interests of the agency. This feature ensures the incentive compatibility of the mechanism. The parameters and structure of the model are shown below.

2.1 Identifying Policymakers, Planners, Executive Agents and Stakeholders

Policymakers and planners in this mechanism include: the Islamic Consultative Assembly, the Ministry of Interior, the Ministry of Energy, the National Planning and Budget Organization, governorates, the Provincial Management and Planning Organization, the Regional Electricity Joint Stock Company and the Provincial Electricity Distribution Company. Given the large number of policymakers and for greater coordination, a committee called the Energy Allocation Committee can be formed, consisting of representatives of all policymakers. The task of this committee is to determine the macro policies and program management. The executive agents (actors) and beneficiaries are the institutions that operate in this mechanism and their consumption behavior is affected by the incentive system (incentives and punishments). The executive agents in this mechanism include public government and non-government institutions, which are the executive agencies at the national or provincial level.

2.2 Determining a Guaranteed Incentive System

Determining a guaranteed incentive system The lack of a guaranteed and effective incentive system to encourage and punish executive agencies is one of the obvious weaknesses of energy consumption management in the country. Encouragement and punishment act as tools for motivational adaptation in the design of the mechanism. Therefore, determining the incentive system plays a vital role in guiding the behavior of the agents in the theory of mechanism design. These rules must be such that the desired outcome is achieved even in situations where the actors pursue personal interests. In order to create sufficient internal motivation in the executive body to provide the best performance and achieve the highest income and, as a result, improve productivity and achieve the desired outcome of the policymaker, which is energy imbalance management, a table of incentives and penalties is presented below. An attempt has been made to make these policy rules such that rewards are attractive and penalties are avoidable. The policymaker can communicate these rules to all executive bodies in the form of a regulation, instruction or circular to ensure the implementation of the incentive system.

2.2.1 Incentive Compatibility Assumptions

The proposed mechanism is incentive-compatible under the following key assumptions:

- **Rationality of Agents:** Institutions act to maximize their utility based on available information,
- **Knowledge of Rules:** All agents are fully informed about the mechanism's rules, reward structure, and penalty scheme,

- **Absence of Collusion:** Institutions do not collude to manipulate the mechanism for mutual benefit,
- **Independent Consumption Decisions:** Each institution's consumption is independent and not influenced by external factors outside the mechanism,
- **Enforceable Contract:** The mechanism's rules and payments are legally binding and enforceable.

These assumptions are standard in mechanism design literature [19–21] and ensure theoretical incentive compatibility.

2.2.2 Incentive System

The proposed incentives for low-consumption or optimizing institutions are presented in Table 1.

Table 1. Proposed Incentives for Low-Consumption or Optimizing Organizations

Incentive Type	Incentive Description
Financial Reward	• Increased budget allocation (1% or more additional allocation for each 1% saving) • Allocation of credits (from the institution's savings) for distribution among staff (welfare, overtime, etc.) • Special credit allocation for energy optimization projects or purchase of new equipment
Budgetary Authority Increase	Priority in next year's budget allocation
Provincial and National Recognition	Inclusion of institution's name in official ministry reports of top performers or national/regional festivals (e.g., Shahid Rajaei Festival)
Energy Tariff Discount	Application of discount in electricity tariffs for future periods
Management Credit	Consideration of energy performance indicator in annual evaluation of institution managers

2.2.3 Penalty System

The proposed penalties for high-consumption and violating institutions that do not comply with the consumption ceiling are presented in Table 2.

2.3 Energy Use Intensity (EUI)

Energy use intensity in buildings is a measure that shows how much energy a building consumes per square meter of area for its normal operation:

$$EUI = \frac{x}{A},$$

where:

- x: Actual consumption of the institution (kwh),
- A: Area of the institution.

2.4 Mission Coefficient

The mission coefficient is one of the key components in the composite model for determining the permitted electricity consumption ceiling, which allows institutions to have a fairer consumption ceiling according to their type of activity and operational conditions. The Energy Allocation Committee can define this coefficient annually.

Table 2. Proposed Penalties for High-Consumption or Violating Organizations

Penalty Type	Penalty Description
Financial Penalty	• Deduction from allocated credits (1% or more deduction for each 1% excess consumption) • Payment of amount for each percentage of excess consumption relative to permitted ceiling • Removal of energy tariff subsidies in case of violation for more than two years
Energy Budget Reduction	Reduction of allocated energy credits for the next year
Restriction on Purchasing High-Consumption Equipment	Prohibition on purchasing new equipment without energy efficiency approval
Mandatory Corrective Plan	Requirement to prepare and submit consumption reduction plan with specific timeline
Administrative Violation Report	Reporting violating institutions to supervisory bodies
Public Violation Report	Announcement of violating institutions' names in official reports or media

The mission coefficient is considered as a number between 0.8 and 1.2, determined based on the type of mission, operational sensitivity, and specific needs of each institution. This coefficient is applied as a multiplication in the average consumption or base ceiling to make the necessary adjustment. The proposed factors influencing the determination of the mission coefficient are presented in Table 3.

Table 3. Factors Influencing Mission Coefficient Determination

Mission Type/Activity	Description	Suggested Coefficient
Medical centers – Military centers – Emergency services (Fire department, Rescue, etc.)	24-hour activity, permanent readiness, critical and special equipment, high sensitivity	1.2-1.15
Data centers and Information Technology	Need for permanent cooling, active servers, information security	1.15-1.10
Government offices with standard working hours	Daily administrative activity, standard equipment	1.0
Educational centers (Schools and Universities)	Limited to specific hours, seasonal holidays, variable consumption	1.0-0.95
Cultural and Artistic centers	Limited to specific hours, variable consumption	0.95-0.90
Low-traffic administrative buildings	Low consumption, limited activity	0.95-0.80

2.5 Permitted Consumption Ceiling

Determining the permitted consumption ceiling for institutions plays a fundamental role in managing their energy consumption. Below, we present a composite model for determining the permitted electricity consumption ceiling that is fair, implementable, and motivating for institutions. This model consists of three main components and can be dynamically updated each year. The factors affecting this model and their weights are presented in Table 4.

Table 4. Components of the Composite Consumption Ceiling Model

Component	Description	Suggested Weight
Average consumption of past years	Main basis for calculating permitted ceiling	70%
Energy Use Intensity (EUI)	Consumption per square meter	20%
Seasonal or Mission Correction Coefficient	Adjustment based on activity type or season	10%

Note: Suggested weights can be changed by the allocation committee.
Method of Calculating Final Permitted Ceiling:

$$\begin{aligned}\text{Final Permitted Ceiling} = &(0.7\times\text{Annual Average Consumption})+\\&(0.20\times\text{Standard EUI}\times\text{Area})+\\&(0.10\times\text{Seasonal or Mission Correction Coefficient}).\end{aligned}$$

3 Mathematical Model

The agents in this mechanism are public entities that have private information about their consumption needs, reduction capacity, and mission type. The utility function of each agent is defined as follows:

$$U_i = V_i(x_i) - C_i(x_i) + R_i - P_i,$$

where:

- $V_i(x_i)$: Value of electricity consumption for institution i,
- $C_i(x_i)$: Cost of consumption reduction for institution i,
- R_i: Reward received if consumption is less than ceiling,
- P_i: Penalty if exceeding the ceiling,
- x_i: Actual consumption of institution i.

In the following, we will explain each of the above items.

3.1 Value of Electricity Consumption

In mechanism design, the goal is not only consumption reduction but consumption optimization. That is, a balance must be struck between lower consumption and the operational value of consumption. For example, there are companies that prefer not to have their electricity cut off but are willing to pay a higher price. This is because power outages cause them to lose significant added value and profit. In fact, the value of electricity consumption for these companies is very high. The value of electricity consumption for an institution $V(x)$ represents the amount of benefit or operational value that the institution obtains from electricity consumption. This value can depend on the following factors:

- Continuation of mission activities (e.g., operation of hospital equipment or sensitive equipment),
- Maintaining the quality of public services,
- Preventing disruption in daily activities,
- Ensuring the comfort of employees and clients...

Therefore, if $V_i(x_i)$ is high, the institution prefers to maintain the consumption pattern. On the other hand, if $V_i(x_i)$ is low, the institution has more incentive to reduce consumption.

$$V_i(x_i) = \gamma_i \times x_i \times r,$$

where:

- x_i: Actual consumption of the institution i,
- γ_i: Operational value coefficient for institution i,
- r: Electricity consumption tariff (Rials).

The exact value of γ_i should be determined by the specialized energy committee by examining the exact mission of the institution. The higher $V_i(x_i)$ is, the more important electricity consumption is for the institution. For example, electricity consumption for a hospital is much more important than for an institution with ordinary administrative activity. Therefore, the designed mechanism will not only be fairer but also more realistic and implementable. The suggested value for γ_i are presented in Table 5.

Table 5. Suggested Operational Value Coefficients by Mission Type

Mission Type/Activity	Suggested Coefficient
Medical centers – Military centers – Emergency services (Fire department, Rescue, etc.)	4-6
Data centers and Information Technology	3-5
Government offices with standard working hours	2-3
Educational centers (Schools and Universities)	1.5-2.5
Cultural and Artistic centers	1.5-2.5
Low-traffic administrative buildings	1-2

3.2 Cost of Consumption Reduction

This part of the mathematical model plays a crucial role in realism, as it shows that reducing consumption-free. The cost of reducing consumption, $C_i(x_i)$, represents the expense incurred by institution i to reach consumption level x_i. These costs may include:

- Cost of upgrading or replacing high-consumption equipment,
- Reduction of working hours or restriction of activities,
- Reduction in heating or cooling,
- Decrease in service quality or client satisfaction,
- Need for staff training or behavior change...

The consumption reduction cost is important because:

- It shows that consumption reduction is not always desirable unless rewards exceed costs,
- It indicates that institutions will only reduce consumption when it is truly cost-effective,
- It helps the incentive-compatible mechanism maintain a balance between savings and operational mission.

The consumption reduction cost is obtained from the following relation:

$$C_i(x_i) = \delta_i \times (x_i^{base} - x_i),$$

where:

- δ_i: Cost rate of consumption reduction per kWh saved for institution i (in Rials),
- x_i^{base}: Base consumption ceiling for institution i,
- x_i: Actual consumption of institution i.

Note: The cost rate of electricity consumption reduction, denoted by δ_i in the model, is one of the most sensitive parameters because it directly determines whether the entity is willing to reduce its consumption or not. If this rate is too high, entities resist; if it is too low, operational realities are ignored. A logical value for this coefficient should be set such that:

- Consumption reduction is economically viable,
- Entity behavior is guided towards optimization,
- The operational mission of the institution is not disrupted.

The electricity consumption reduction cost rate should be determined by the Energy Allocation Committee. This rate should be adjusted based on the electricity tariff, the institution's budget, and mission sensitivity, and set as a percentage of the actual electricity consumption rate. For example, the suggested coefficient can be as per the table Table 6:

Table 6. Suggested Consumption Reduction Cost Coefficients (δ_i) (Monetary unit e.g., Thousand Rials per kWh reduced)

Mission Type/Activity	Suggested Coefficient
Medical centers – Military centers – Emergency services (Fire dept., Rescue, etc.)	80000–120000
Data centers and Information Technology	60000–100000
Government offices with standard working hours	40000–70000
Educational centers (Schools and Universities)	30000–60000
Cultural and Artistic centers	30000–60000
Low-traffic administrative buildings	20000–50000

Agents are assumed to be rational and self-interested, making decisions based on maximizing their utility.

Example 1. Assume a institution has a base consumption ceiling 10,000 kWh and its actual electricity consumption is 8,000 kWh per month. If the consumption reduction cost rate is 40,000 Rials, then:

$$C_i(x_i) = \delta_i \times \left(x_i^{base} - x_i\right) = \mathbf{40000} \times (\mathbf{10000} - \mathbf{8000}) = \mathbf{80,000,000}.$$

This means the institution has incurred a cost of approximately 80,000,000 Rials for reducing consumption by 2,000 units.

3.3 Reward Function

The reward function is defined as a combination of a savings reward and an efficiency reward:

$$R_i = r \times \alpha_i \times \max\left(\mathbf{0}, x_i^{\max} - x_i\right) + \theta \times \max\left(\mathbf{0}, EUI_{std} - EUI_i\right) \times A_i,$$

where:

- r: Electricity consumption tariff (Rials),
- $x_i^{\max}$: Consumption ceiling for institution i (kWh),
- x_i: Actual consumption of institution i (kWh),
- α_i: Mission coefficient for institution i,
- θ: Energy efficiency reward coefficient for institution i,

- EUI_{std}: Standard Energy Use Intensity (kWh/m^2),
- A_i: Built area of institution i's building (m^2),
- EUI_i: Energy Use Intensity of institution i (kWh/m^2), calculated as $EUI_i = \frac{x_i}{A_i}$.

3.4 Penalty Function

The penalty function is also defined as a combination of a penalty for lack of savings and a penalty for inefficiency:

$$P_i = r \times \beta_i \times \max\left(\mathbf{0}, x_i - x_i^{\max}\right) + \phi \times \max\left(\mathbf{0}, EUI_i - EUI_{std}\right) A_i,$$

where:

- β_i: Penalty coefficient for institution i,
- ϕ: Energy efficiency penalty coefficient for institution i.

3.5 Final Utility Function

Considering the above, the final utility function for each agent is defined as follows:

$$\begin{aligned} U_i =& V_i\left(x_i\right) - C_i\left(x_i\right) + \left\{r \times \alpha_i \times \max\left(\mathbf{0},\ x_i^{\max} - x_i\right) + \theta \times A_i \times \max\left(\mathbf{0},\ EUI_{std} - EUI_i\right)\right\} \\ & - \left\{r \times \beta_i \times \max\left(\mathbf{0},\ x_i - x_i^{\max}\right)\ + \phi \times A_i \times \max\left(\mathbf{0}, EUI_i - EUI_{std}\right)\right\}. \end{aligned}$$

The above utility function shows:

- The institution gains operational value from electricity consumption (first part),
- It simultaneously incurs consumption reduction costs (second part),
- If the institution's consumption is below the ceiling, it receives a reward (third part),
- If the institution's energy intensity is below the standard, it receives an efficiency reward (fourth part),
- If the institution's consumption exceeds the ceiling, it is penalized (fifth part),
- If the institution's energy intensity exceeds the standard, it is subject to an inefficiency penalty (sixth part).

Example 2. To demonstrate the practical performance of the proposed mechanism, a numerical simulation for a hospital is conducted. Assuming the simulation pararmeters are according to Table 7. Also assuming that for this hospital actual consumption is $x_i = 80,000$ kWh, then:

Initial Indicators Calculation:

$$EUI_i = \frac{x_i}{A_i} = \frac{80,000}{2,000} = 40 \text{ kWh/m}^2,$$
$$EUI_{std} - EUI_i = 50 - 40 = 10 \text{ kWh/m}^2.$$

Utility Function Components Calculation:
1. Operational Value of Consumption (V_i):

$$\begin{aligned} V_i &= \gamma_i \times r \times x_i \\ &= 1.3 \times 10,000 \times 80,000 = 1,040,000,000 \text{ Rial}. \end{aligned}$$

Table 7. Simulation Parameters

Parameter	**Symbol**	**Value**	**Unit**
Area	A_i	2,000	m^2
Base consumption ceiling	x_i^{base}	100,000	kWh
Permitted Consumption Ceiling	x_i^{max}	90,000	kWh
Standard Energy Use Intensity	EUI_{std}	50	kWh/m^2
Electricity Tariff	r	10,000	$Rial/kWh$
Operational Value Coefficient	γ_i	1.3	–
Consumption Reduction Cost Rate	δ_i	15,000	$Rial/kWh$
Mission Coefficient	α_i	1.2	–
Energy Efficiency Reward Coefficient	θ	500	$Rial$

2. Consumption Reduction Cost (C_i):

$$\begin{aligned} C_i &= \delta_i \times (x_i^{base} - x_i) \\ &= 15{,}000 \times (100{,}000 - 80{,}000) = 300{,}000{,}000 \text{ Rial.} \end{aligned}$$

3. Savings Reward (R_{i1}):

$$\begin{aligned} R_{i1} &= r \times \alpha_i \times \max(0, x_i^{max} - x_i) \\ &= 10{,}000 \times 1.2 \times (90{,}000 - 80{,}000) = 120{,}000{,}000 \text{ Rial.} \end{aligned}$$

4. Energy Efficiency Reward (R_{i2}):

$$\begin{aligned} R_{i2} &= \theta \times A_i \times \max(0, EUI_{std} - EUI_i) \\ &= 500 \times 2{,}000 \times 10 = 10{,}000{,}000 \text{ Rial.} \end{aligned}$$

5. Total Reward (R_i):

$$R_i = R_{i1} + R_{i2} = 120{,}000{,}000 + 10{,}000{,}000 = 130{,}000{,}000 \text{ Rial.}$$

6. Penalty (P_i):

$$P_i = 0 \text{ Rial} \quad (\text{No excess consumption or inefficiency}).$$

Final Utility Function:

$$\begin{aligned} U_i &= V_i(x_i) - C_i(x_i) + R_i - P_i \\ &= 1{,}040{,}000{,}000 - 300{,}000{,}000 + 130{,}000{,}000 - 0 \\ &= 870{,}000{,}000 \text{ Rial.} \end{aligned}$$

Note: The numerical simulation presented in Table 7 is illustrative rather than an empirical validation. The purpose is to demonstrate the mechanism's behavior under controlled parameter values.

This structure ensures that consumption below the ceiling leads to rewards and consumption above the ceiling leads to penalties, while the mission information of each entity is incorporated through α_i. Also, if the energy intensity is below the standard, a reward is given, and vice versa. The coefficients θ and ϕ can be changed based on the social planner's policies and the Energy Allocation Committee's decisions. These coefficients act like tuning knobs for institution behavior. The higher their value, the more significant the role of energy intensity in institution decision-making becomes.

Considering the electricity tariff rate in Iran in 2025 for public institutions, which is between 10000 and 20000 Rials, these coefficients can be set between 2% to 15% of the public institution tariff, making them both incentivizing and implementable. Therefore, the Table 8 is suggested:

Table 8. Suggested Energy Efficiency Reward and Penalty Coefficients (Rials)

Mission Type/Activity	**Efficiency Reward (θ)**	**Inefficiency Penalty (ϕ)**
Medical centers – Military centers – Emergency services (Fire dept., Rescue, etc.)	500–1000	200–500
Data centers and Information Technology	500–1000	200–500
Government offices with standard working hours	1000–2000	1000–1500
Educational centers (Schools and Universities)	1000–2500	1200–1800
Cultural and Artistic centers	1000–2500	1200–1800
Low-traffic administrative buildings	2000–3000	1500–2000

Example 3. Assume a institution with an area of 1000 m^2, a standard energy intensity of 200 kWh/m^2, and an actual energy intensity of 150 kWh/m^2. If the energy efficiency reward coefficient $\theta = 1000$ Rials, then the institution's energy efficiency reward is:

$$\text{Efficiency Reward} = \theta \times A_i \times \max\left(0, EUI_{std} - EUI_i\right) = 1000 \times 1000 \times 50 = 50{,}000{,}000,$$

this means the institution receives a reward of 50 million Rials.

Note: The penalty coefficient β_i is the financial or credit penalty applied per unit of electricity consumption exceeding the permitted ceiling for institution i. It can be determined based on grid sensitivity in the region or season, the institution's consumption history in previous years, the percentage deviation from the consumption ceiling, etc.

The factors influencing the determination of the penalty coefficient are presented in Table 9.

Table 9. Factors Influencing Penalty Coefficient β_i

Factor	**Explanation**
Organization Mission Type	Critical institutions like hospitals should have a milder coefficient.
Organization Financial Capacity	Organizations with limited budgets should not face heavy penalties.
Severity of Deviation from Ceiling	If consumption is far above the ceiling, the coefficient should increase progressively.
Macro Energy Policies	During periods of electricity shortage, the coefficient should be set more strictly.
Organization's Past Behavior	If the institution has a history of high consumption, the penalty coefficient can be higher.

For example, the coefficient β_i can be considered within the range $[1,3]$, or it can be defined based on a function of several variables:

$$\beta_i = \beta_0 + \varepsilon_1 \times d + \varepsilon_2 \times r + \varepsilon_3 \times h,$$

where:

- β_0: Minimum base coefficient (e.g., 1),
- d: Percentage deviation from the ceiling,
- r: Grid sensitivity in the region or season,
- h: institution's consumption history in past years,
- ε_i: Weights adjusted by the supervisory entity.

Example 4. Assume a institution has consumed 20% more than its ceiling, is located in a high blackout risk area, and has a history of high consumption. If $\beta_0 = 1$, $\varepsilon_1 = 0.5$, $\varepsilon_2 = 0.3$, $\varepsilon_3 = 0.2$, then:

$$\beta_i = 1 + 0.5 \times 0.2 + 0.3 \times 1 + 0.2 \times 1 = 1.6,$$

this means for every kWh consumed above the ceiling, the institution must pay a penalty of 1.6 times the tariff.

3.5.1 Key Points for Greater Mechanism Effectiveness

- **Transparency:** Criteria and calculation methods must be clear to all institutions,
- **Proportionality:** The level of incentive or penalty should be proportional to the deviation from the consumption ceiling,
- **Continuity:** This mechanism should be implemented annually to have a long-term effect,
- **Flexibility:** Possibility for review under special circumstances (e.g., emergency missions or structural changes).

3.5.2 Model Advantages

- **Justice-oriented:** Larger institutions or those with specific missions will have more appropriate ceilings,
- **Incentivizing:** As energy intensity decreases, the permitted ceiling also decreases, encouraging institutions to optimize,
- **Flexible:** Coefficients can be adjusted based on annual policies,
- **Comparable:** institution performance can be analyzed based on common indicators.

4 Conclusion

This paper has designed an efficient and incentive-compatible self-regulating mechanism for managing electricity consumption in public governmental institutions. Our main contribution lies in introducing a composite permitted ceiling that dynamically adapts to each institution's unique characteristics while maintaining incentive compatibility. The incentive-compatible mechanism proposed in this article serves as an effective tool for managing electricity consumption in public institutions. This mechanism is designed such that:

- Institutions provide their information honestly (due to the fair mission coefficient),
- They naturally move toward consumption reduction (because rewards are tangible and penalties are effective),
- They automatically choose desirable behavior (without coercion, but through interest alignment).

In the proposed mechanism, even if institutions pursue solely their own interests, they still choose to optimize electricity consumption because:

- The permitted ceiling is fair,
- Rewards are attractive,
- Penalties are avoidable,
- Their information is properly considered.

Therefore, the proposed mechanism can optimize consumption behavior and play an effective role in the country's energy policy-making. With precise design, transparent implementation, and continuous monitoring, this mechanism can reform the consumption behavior of institutions and help achieve national goals in the energy sector.

Policy Relevance:

The mechanism offers a practical solution for energy imbalance challenges without requiring intensive supervision or mandatory quotas. It can be implemented in various sectors including healthcare, education, and public administration.

Limitations:

- The mechanism assumes rational agents and perfect information, which may not always hold in practice
- The illustrative numerical example has not been validated with empirical data.
- The model does not account for external factors such as weather conditions or equipment failures.

Directions for Future Research:

- Empirical validation using real consumption data from participating institutions.
- Extension to heterogeneous agent populations with different risk preferences.
- Integration with renewable energy sources and storage systems.
- Investigation of collusion resistance and robustness against strategic behavior.
- In conclusion, this mechanism represents a significant step toward sustainable and efficient energy management in the smart grid context.

Authors' Contributions

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data in the paper are available from the corresponding authors upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest.

Ethical Considerations

The authors have diligently addressed ethical concerns, such as informed consent, plagiarism, data fabrication, misconduct, falsification, double publication, redundancy, submission, and other related matters.

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