Incentives for green video streaming

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Introduction

In today's hyperconnected world, video streaming has become ubiquitous, but it comes with an often invisible cost: **energy consumption** and **carbon emissions**. We develop a framework that motivates ICT service consumers – focusing here on video streamers – to make more energy-conscious choices.

Our approach combines **behavioural incentives**, such as environmental points, peer recognition, and gamified challenges, with **economic incentives**. This creates a balanced mechanism that appeals to both environmentally conscious and self-interested users.

Environmental Points quantify the value of sustainable actions, such as selecting **lower video resolutions**, and can be redeemed for rewards or recognition. Over time, this mechanism encourages users to adopt greener habits, **reducing the overall energy and carbon footprint of digital services**.

Methodology

We introduce a **user acceptance model** [1] that captures how users respond to incentives. Key elements are illustrated below. Each user is characterized by a **personalized greenness factor** [3], reflecting environmental sensitivity, and a private **incentive threshold**, representing the minimum reward required to compensate for the perceived inconvenience of adopting energy-saving actions (e.g., selecting lower bitrate content).

The end-to-end energy consumption for user n is modeled as

$$E(x_n) = \sum_{t \in T} P(x_n, t)\Delta t,$$

with $P(x_n, t)$ equals $P_0 + \alpha x_n$ be the power model (P_0: static baseline power, α: bitrate-dependent scaling), and x_n the **reduction** in bitrates for user n, at time t.

Then, total session energy becomes,

$$E(x, t) = \sum_{n \in [N]} E(x_n)$$

leading to carbon emissions $CO_2(x, t) = \eta E(x, t)$, with $\eta = 0.388$kgCO_2/kWh, denoting the carbon intensity factor. Reducing bitrate directly lowers energy consumption and associated emissions.

The user utility U_n captures monetary incentives, environmental sensitivity, and–in the proposed extension–social welfare and gamification effects.

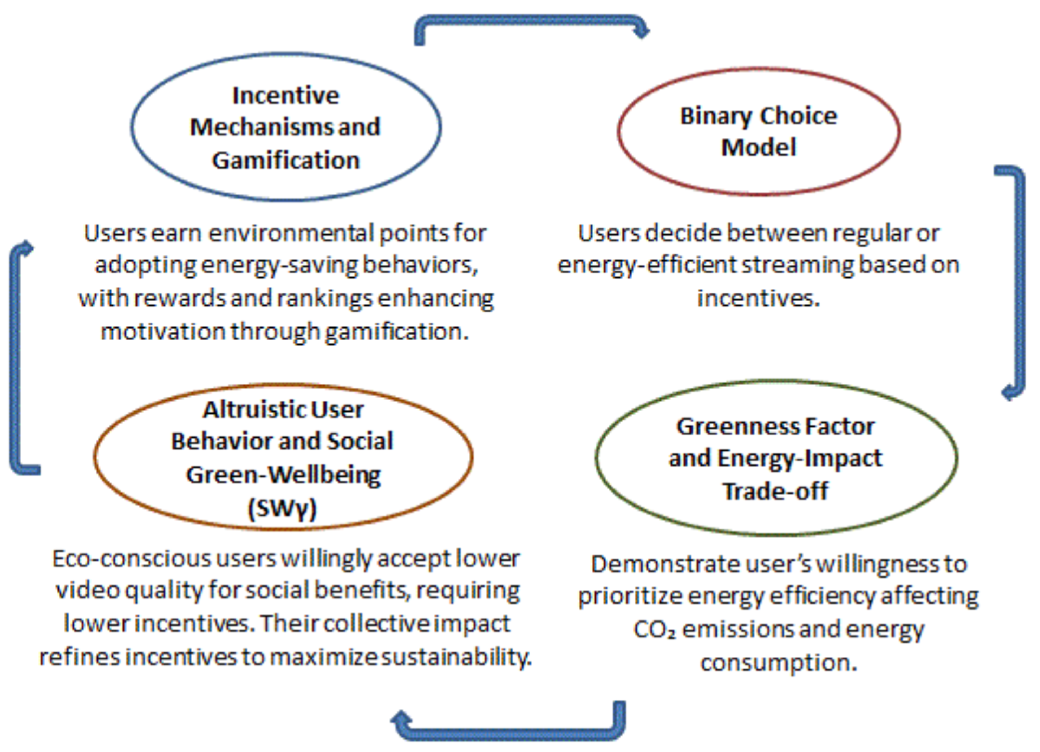

Figure 1: Effective user acceptance model for energy-efficient video streaming.

Altruism. To move beyond purely selfish behavior, we incorporate **social characteristics** into user decision-making. We utilize the social well-being function SW [4], representing average welfare, and allow each user to consider a weighted combination of personal utility U_n and social welfare. We refer to this extension as *altruistic behavior* [1].

Gamification. Independently of altruistic behavior, we introduce a second extension based on **gamification** [2]. Users are ranked into top-K and bottom-M lists according to their energy reduction and carbon footprint performance. We then construct a **serious-game** mechanism based on these rankings to promote peer comparison and competition, transforming passive participation into active engagement, similarly to [5].

Users in the top-K list receive an additional reward H, while users in the bottom-M list incur a penalty $-H$. The H value is derived from socio-cultural characteristics independently from the environmental points. Within a **Stackelberg game** formulation, the streaming provider – acting as the strategic leader – optimizes both incentive levels and game parameters to maximize network-wide energy savings under budget constraints.

Environmental points accumulated by user n over a period Δt are proportional to the **energy saved**, that is $E(0) - E(x_n)$.

Main Objectives

1. Users voluntarily reduce traffic (and energy) by switching to greener options.
2. Align self-interested participant behaviour with collective environmental goals.

Results

Synthetic data. To evaluate the proposed mechanisms, we designed a synthetic data generator producing a population of $N = 1000$ heterogeneous users with different streaming behavior, environmental awareness, and responsiveness to incentives. Each user selects a high bitrate option from $\{2000, 3000, 4000, 5000\}$ kbps, and a low bitrate option from $\{300, 600, 1200, 1500\}$ kbps. Further, the provider offers incentives sampled from $r_n \sim \mathcal{N}(\mu, \sigma^2)$.

Gamification. Provider strategy space $K, M \in \{0, 10, 50, 100, 150, 200\}$, $\mu \in \{1, 2, 3, 4, 6\}$, $\sigma \in \{0.5, 1, 2, 3\}$.

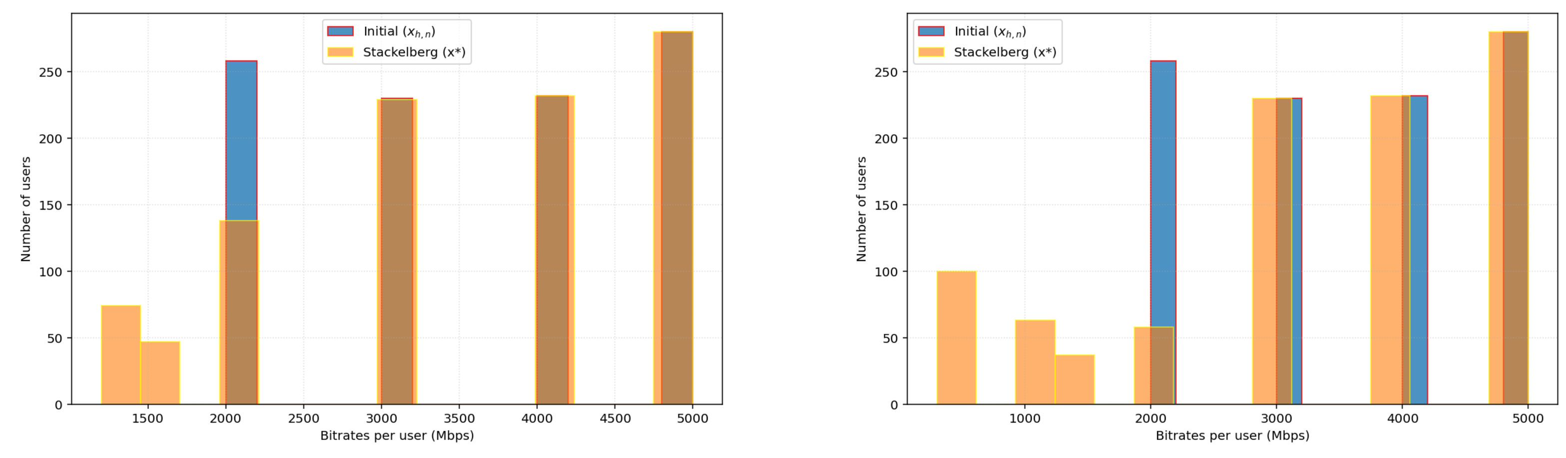

Figure 2: Provider offers total incentives up to 1 monetary unit. Social reward $H = 1$ (left), and $H = 1000$ (right).

Stackelberg eq. for $H = 1$: $(K^*, M^*, r_n^*) = (200, 10, \mathcal{N}(1, 1))$, meaning that 94 users switch (9.4%) and energy reduction ≈ 10 kWh.

Stackelberg eq. for $H = 1000$: $(K^*, M^*, r_n^*) = (200, 10, \mathcal{N}(1, 0.5))$, meaning that 200 users switch (20%) and energy reduction: ≈ 44.4 kWh.

Remark. With a highly constrained budget, **social rewards dominate monetary incentives**: larger H nearly doubles adoption.

From Ultra-HD to Full-HD. Each user streams at 20 Mbps (**Ultra-HD / 4K**) with a greener alternative of 5 Mbps (**Full-HD / 1080p**). Experiment settings: offered incentives $\sim \mathcal{N}(3, 4)$ and $H = 1000$. The maximum achievable reduction is $\approx 75\%$.

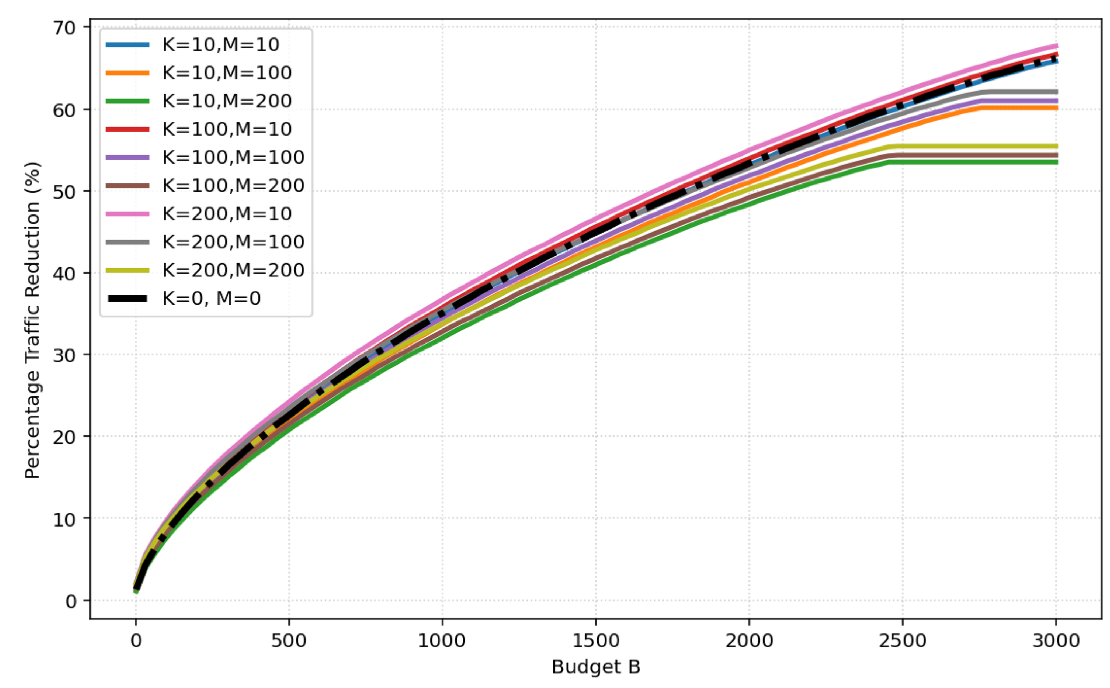

Figure 3: Traffic reduction from Ultra-HD (4K) to Full-HD (1080p).

The proposed mechanism achieves up to 67.2% traffic reduction, corresponding to a reduction of **more than** $3\times$ and nearly 90% of the achievable theoretical maximum.

Remark. Combining **monetary incentives and social rewards** can realistically motivate users to shift from **4K to 1080p** under high-demand conditions.

Conclusions

- Enables proactive, application-level control of energy consumption.
- A **data-driven, personalized, and scalable incentive strategy** can substantially improve the sustainability of video-streaming systems while controlling provider costs.
- Monetary incentives alone are insufficient, **social motivation amplifies budget efficiency** and enables greener behavior at lower cost.
- Additional experiments, see in [2], with larger budgets show diminishing returns from monetary incentives.

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