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The Advertising Carbon Footprint Index (ACFI): A Smart, Sustainable, And Green Framework For Decarbonizing Urban Advertising In Heritage Cities

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Abstract

The growth of outdoor advertising is said to produce significant GHG emissions and plastic waste in heritage cities (UNESCO 2021, UN-Habitat 2020), while being integral to urban messaging and commerce. The most widely used outdoor advertising medium in India is the polyvinyl chloride (PVC) flex banner. The body of research indicates that the climate damage caused by it is in the range of 25-30 kg CO_2e/m^2 across its life-cycle (Gervasio & Dimova, 2015). Additionally, they generate approximately 600 g/m² of non-biodegradable, toxic plastic waste, which persists for over 200 years (Geyer et al., 2017). In Amritsar, which uses around 1,00,000 m² of flex each year, any such material generates an annual footprint of nearly 2,500 tCO_2e (greenhouse gas emissions) and 600 tons of plastic residues (Municipal Corporation of Amritsar, 2023). Moreover, incineration releases toxic dioxins and heavy-metal furans into the atmosphere, thereby increasing air pollution and heightening public health risks (WHO, 2023). As a result, the advertising business, despite being a substantial cost in quantifiable terms, is often excluded from cities' decarbonization and circular economy plans (Ellen MacArthur Foundation, 2019). Using Life-cycle Assessment (LCA) of materials, cost modeling, and Monte Carlo simulations (10,000 run; ±20% variation) on different. At operational scales (10,000-100,000 m²/y), the ACFI was used to compare conventional PVC flex with reusable cloth banners and seed paper. Flyers, electronic ads, and circulars are reused. Findings show a profound economic hierarchy in the environment. The study finds that a reusable piece of cloth (ACFI.0.6), which can be reused twenty times, helps reduce emissions by 70% (from 2500 to 650 tCO_2e), reduce life-cycle costs by 80% (from 500 to 75 per-use), and generate over 800 local jobs through its production and usage. Approximately 600 local jobs for every 100,000 square meters. Seed-paper posters (ACFI: 1.2) are expensive but have an emission of only 0.5-1 kg CO_2e/A3-sheet and create 900+ artisans' jobs per 100 campaigns. Digital advertising (ACFI: 2.5) generates no physical waste but emits around 0.67 g CO_2e/impression (~540 kg per 10,000 impressions) due to server energy use (Malmodin & Lundén, 2018). The standard PVC flex performs poorly in ACFI. A hybrid Smart-Sustainable-Green (SSG) can be followed. According to the Climate Change Adaptation Framework for Infrastructure (ACFI), a framework developed by global governments, advertising is included as a measurable data sector. Integrating accountability for emissions, the circular economy, and social justice into the communication systems cities use every day would help achieve SDG 11.

Keywords: Carbon Footprint Index, Sustainable Advertising, Smart-Sustainable Framework, Carbon Neutrality, Green Job Creation.

1. INTRODUCTION

1.1. The Urban Visual Landscape in Heritage Cities

Heritage Cities are historic "ecosystems" that combine functions, traditions, and built fabric with contemporary sectoral activities (Fusco Girard, 2013). Heritage cities must also strive to achieve this while preserving the city's visual integrity. Similarly, if not appropriately organized, urbanization can lead to visual clutter, and the spatial organization of outdoor advertisements can undermine the city's aesthetic functions (Veldpaus et al., 2013). Furthermore, these visual elements, along with their design, ensure that they work in harmony with the city's heritage-built fabric (Kumar et al., 2017). Heritage believes that cities must protect visual elements that contribute to their aesthetic value. Additionally, considered visual elements include public art, traffic regulation devices, and outdoor advertisements. The city's physical appearance is another component, one of the two (Fusco Girard, 2013).

1.2. The Hidden Environmental Cost of Conventional Advertising

PVC flex banners are the most popular outdoor advertising medium in India and other developing countries. They are suitable for outdoor conditions and offer a time-based, low upfront cost (Kumar et al., 2017). PVC flex banners are short-lived components of city structures. The life cycle of this material begins with its manufacture in factories from fossil fuels (oil or natural gas) into composite chemicals. Their life cycle is linear. Toxic gases are emitted by the urban hotspot, affecting the residents of adjacent areas (Landrigan et al., 2018).

Additionally, these banners are designed for outdoor use. On average, a flex banner lasts for two to four weeks. As a result, they manifest in numerous forms, including election banners, movies, cultural events, corporate events, and more. Burning garbage is disposed of either in a landfill or through open burning. We must face the environmental cost incurred in deploying each one. The burden may be huge, but remains unutilized and undocumented in the urban Greenhouse gas inventory. The disconnect from mainstream and segregation of the process are the reasons for this. The data presented in Table 1 indicate that flex advertising manufactured from PVC has a significant negative environmental impact. As with plastic waste, the Global Warming Potential is very high. When thrown away, the flex emits hazardous substances that harm the environment.

Table 1: Environmental Impact Parameters of PVC Flex Advertising

Impact Category	Measurement	Source/Notes
Global Warming Potential	25-30 kg CO_2e/m^2	Cradle-to-grave LCA, Indian context (Saatcioglu & Venkatraman, 2025)
Plastic Waste Generation	600 g/m^2	Non-biodegradable, persists >200 years (Geyer et al., 2017)
Toxic Emissions	Dioxins, furans, heavy metals	Released during incineration (Abahussain, 2025)
Water Consumption	150-200 L/m^2	Mainly in resin production and printing (Water footprint concept, 2025)
Land Use Change	Indirect through oil extraction	Habitat loss for petroleum sourcing (IPCC, 2022)

1.3. Research Gap: The Missing Metric for Sustainable Urban Communication

Cities are gaining the spotlight, but the country's decarbonization plans and circular-economy models have largely ignored them (Ellen MacArthur Foundation, 2021). At this stage, policies related to urban climate action acknowledge the involvement of energy, transport, and the built environment, but still overlook the mass of ephemeral material flows, such as advertising media. There exists a critical disparity involved. City managers or policymakers are unable to compare options across the 3E dimensions of environmental, economic, and social (Cinelli et al., 2014) due to the lack of a single metric that encompasses the wide range of choices within a single advertising system. There are life-cycle assessments for many materials. Municipal decision-makers currently lack a framework and matrix for effective communication that achieves LCA and circularity goals simultaneously (Samani 2023)

1.4. Theoretical Framework and Study Objectives

This research is based on three interrelated theories. The Urban Metabolism Theory posits that cities, like living organisms, consume natural and human resources and generate waste in exchange (Kennedy et al., 2011). The Circular Economy is the second, and it has emerged as an alternative to the linear economy. It refers to waste-free, closed systems that also enhance natural systems (Saatcioglu & Venkatraman, 2025). The third one is the Just Transition Theory. Environmental solutions should create decent work. It is paramount that vulnerable groups are included in the environmental journey (Schlosberg & Collins, 2014). The present research proposes an advertising carbon footprint index (ACFI) as a practical tool for effective, sustainable, and environmentally friendly urban communication management.

- The goal of the study is to map the full environmental burden of PVC flex advertising in a heritage city scenario through a comprehensive LCA.
- The composite sustainability indicator 'ACFI' will be formulated and validated by weighing carbon emissions, carbon waste, visibility, and socio-economic value.
- The purpose of the study is to use ACFI for comparative evaluation of conventional and alternative advertising media (reusable cloth, seed paper, digital, and upcycled product).
- To suggest a hybrid SSG implementation mode for the urban local body (ULB) policymaker.

1.5. Significance and Expected Contributions

This research enhances theoretical knowledge in several areas. To begin with, this study extends the urban metabolism lens to semi-exogenous flows of materials in circularity (Kennedy et al., 2011), an essential missing link in city-scale planning. The second study contribution relates to the design of composite indicators that offer new ways to measure and promote systems change. The separation of the composite indicator from its underlying environmental and social indicators integrates an important effectiveness criterion related to communication, disparities, and aggregation (Cinelli et al., 2014). The findings of this research are significant for practice, as the evaluation framework can serve as an evidence-based decision support tool for administrators of a heritage city to regulate outdoor advertising.

2. Comprehensive Literature Review

2.1. Urban Sustainability and Heritage Conservation

Since they adopted the UN Sustainable Development Goals in 2015, all UN Member States have moved towards a sustainable development concept for heritage cities. To be specific, the target of SDG 11, "Sustainable cities and communities," is to protect the world's cultural and natural heritage (target 4), promote inclusive and sustainable urbanization (target 1), and reduce the environmental impact of cities (including advertising) (target 6) (Naheed & Shooshtarian, 2022). Research indicates that, when applied to heritage conservation, the 'forms-based or integrated planning approach that links visual, cultural, social, and economic indicators' can make heritage and environmental sustainability complementary (Fusco Girard, 2013). Notwithstanding, most heritage management practices and methodological frameworks continue to primarily focus on the "conservation and protection of a building or a place" (i.e., its built heritage) to prevent material loss or physical alteration (Veldpaus et al., 2013). The effect of advertisements and other elements that do not change the built fabric but affect the visual experience of the historic environment in a "dynamic" way is not considered in this approach. In recent times, there has been an increasing acceptance and attention towards approaches that accept living heritage and allow contemporary management to enable "viable use or functioning" of the heritage site, provided that visually harmful impacts are avoided, and aesthetic balance is maintained (Naheed & Shooshtarian, 2022)

2.2. Life-cycle Assessment of Urban Materials

Life-cycle assessment (LCA) is the standard method for evaluating the environmental impacts of products and services throughout their value chains (ISO 14040, 2021). According to ISO 14040/14044, goals are defined and also allow for their interpretation (ISO 14044, 2021). Although many authors have conducted LCAs of building materials, packaging, or consumer goods, there are few LCAs of ephemeral urban elements (Guinée et al., 2011). Many writers have examined the environmental footprint of different materials. An analysis of the entire life cycle of PVC reveals a high carbon footprint, driven by chlorine production via the mercury-cell process and ethylene cracking (Ye et al., 2017). Phthalate plasticizers, lead stabilizers, and other additives complicate the environmental assessment of PVC, which leaches toxins throughout its life cycle (Turner & Filella, 2021). According to the Outdoor Advertising Association of America (2022), there have been very few LCAs on advertising media. Specifically, only tentative studies have compared paper, vinyl, and digital displays in a European context. Typically, in the Global South context, a comprehensive LCA does not exist. Variance in energy mix, waste management practices, and use significantly affects the environmental footprint in different ways (Kordilas et al., 2025). As shown in Table 2, several relevant LCA studies have been conducted. Notable differences in environmental impact can be observed across the alternatives. A case in point is that PVC flex has a high carbon content.

Table 2: Key LCA Studies on Advertising-Related Materials

Study	Focus Material	Key Findings	Geographic Context
(Saatcioglu & Venkatraman, 2025)	PVC flex banners	28.4 kg CO_2e/m²; 85% from production phase	Northern India
(Pärssinen et al., 2018)	Digital displays	0.4-1.2 g CO_2e/impression depending on grid mix	United States
(Dolci et al., 2024)	Paper vs plastic posters	Paper has a lower carbon but higher water footprint	Italy
(Horodytska et al., 2020)	Upcycled plastic products	60-75% lower carbon than virgin alternatives	India
(Chen et al., 2024)	Biodegradable composites	Comparable strength to PVC with 80% lower emissions	China
(Bull & Kozak, 2014)	Comparative media assessment	First multi-criteria analysis of 12 advertising media	15 countries

2.3. Circular Economy and Plastic Waste Management

As noted by Kwemoi (2025), developing countries are increasingly incorporating plastic into their everyday lives. The informal sector primarily handles plastic collection, and waste pickers play a crucial role. Plastic waste recycling plays a vital role, but it also poses a significant health risk due to the plastic waste's infectious properties. Most PVC expenditures occur in high-use sectors, particularly in emerging nations (Geyer et al., 2017). The life-cycle assessment of pipes must adopt a fair transitional perspective that accounts for informality. Waste pickers, who play a crucial role in waste management, should be included in formal CE (Velis, 2017). The word "The" should be retained. The concept of CE has recently become prominent and is described as their alternative to the conventional progressive and plans action and discard economic model" (Saatcioglu & Venkatraman, 2025). We offer a range of creations designed for long-lasting use and, whenever possible, for refurbishment, mechanical recycling, and conversion back to monomer chemical and organic (composting), World Economic Forum (2021). However, it is complex with PVC, where chlorine is involved. Additives and deterioration within and between loops pose challenges for circularity (Ragaert et al. 2017).

2.4. Digitalization and Dematerialization

Digital ads are often seen as less material than physical ones, according to Malmodin and Lundén (2018). The environmental impact of information and communication technology (ICT) is, on the other hand, remarkable, according to Freitag et al. (2021). A significant amount of carbon intensity is already present in data centers, networks, and end-user devices. The amount of carbon emitted per digital impression varies widely depending on several factors. Aslan et al. (2018) state that their analysis shows that a digital impression made in 100% renewable-powered data centers and networks emits only 0.1 g CO2e. Meanwhile, a heavyweight digital impression made on a network powered mainly by coal is said to yield over 2.0 g CO2e. Manufacturing devices and their end-of-life treatment (e-waste) have a significant impact. However, the data are also weak, and these impacts are often excluded from digital footprints (Belkhir & Elmeligi, 2018). Apart from that, the rebound effect is also a hurdle to dematerialization (Hilty & Aebischer, 2015). If advertising in digital media is cheaper and more effective per digital impression (unit), then the total volume of digital media may be distorting.

2.5. Social Dimensions: Green Jobs and Inclusive Transition

The transition toward sustainable urban systems must consider social inequality as a central aspect, rather than an afterthought (Sampson, 2017). According to the ILO (2023), the international community views green jobs in the circular economy as fostering inclusive growth among women, youth, and disadvantaged groups. The International Labour Organization defines green jobs as "decent jobs that contribute to preserving or restoring the environment by reducing energy, materials, and water consumption through a life-cycle, while not significantly increasing greenhouse gas emissions and minimizing or avoiding all other emissions and wastes, and importantly, enhancing energy and climate resilience" (ILO, 2023). In the advertising value chain, green jobs can be found in the production of sustainable raw materials (for example, organic weaving of cloth), design/repair services, collection/sorting of reusable and recyclable materials, upcycling, remanufacturing, and digital sustainability consulting services (Sulich & Sołoducho-Pelc, 2022). In India, women's self-help groups have successfully created green jobs by collecting plastic waste.

2.6. Composite Indicators for Sustainable Decision-Making

Composite indicators are simple measures that combine multiple dimensions to facilitate comparison and informed decision-making (Saisana et al., 2005). An effective composite combines scientific rigor with usability. While a significant amount of evidence and scientific rigor is significant, it can lead to a composite that is quite complex and might be less usable. If the indicator lacks scientific rigor and an evidence base, it may result in the creation of an invalid composite indicator that could mislead users. Yale University's Environmental Performance Index, among others, is an example of a composite (also known as an index) (Almeida & García-Sánchez, 2016). Some of the essential principles involved in developing composite indicators include the selection of sub-indicators, measurement scale, normalization and transformation, aggregation and weighting of sub-indicators, and uncertainty analysis (Saisana et al., 2005). Accurate estimation of uncertainty has been a popular topic. Since then, Monte Carlo simulations have been the method of choice for nearly all studies.

3. Methodology: The ACFI Framework

3.1. Conceptual Foundation and Indicator Selection

The Advertising Carbon Footprint Index (ACFI) utilizes a framework based on the DPSIR model. Many governments use the DPSIR model to provide guidelines for environmental solutions. According to the DPSIR framework, human activities are drivers that exert pressure on the environment, which, in turn, affects the state of environmental features. According to the European Environment Agency (2022), these changes affect ecosystems and humans, which, in turn, trigger further changes. In this case, advertising is a pressure exerted by commercial and communicative Drivers, leading to changes in the state through emissions and permanent waste. This, in turn, affects the climate and environment, and a policy response must be required. The ACFI makes this chain interpretable by formulating it as an index with indicators in four dimensions,

1. C is a measure of life-cycle greenhouse gas emissions, which helps determine the climate impact.
2. Waste Intensity (W): Continuous generation of waste as a proxy of linear flows.
3. Communication Efficiency Visibility.

3.2. Mathematical Formulation and Normalization

The ACFI for an advertising medium i is calculated as a weighted sum of normalized sub-indicators:

$$\mathbf{ACFI_i = w_1 \times N(C_i) + w_2 \times N(W_i) + w_3 \times N(V_i) + w_4 \times N(S_i)}$$

Where:

- w_1, w_2, w_3, w_4 are weights summing to 1
- N() represents min-max normalization to [0,1] scale
- Lower ACFI scores indicate better sustainability performance

According to Table 3.1, the indicators of the Carbon Footprint Index for Advertisement and their measurement methods are presented. Table 3.1 of the Advertising Carbon Footprint Index outlines the component indicators and measurement approaches for the proposed carbon footprint.

Table 3.1: ACFI Component Indicators: Definitions and Measurement

Indicator	Definition	Measurement Unit	Normalization	Rationale
C: Carbon Intensity	Life-cycle GHG emissions per functional unit	kg CO_2e/m^2/year	Linear min-max	Direct climate impact
W: Waste Intensity	Non-biodegradable waste per functional unit	g/m^2/year	Linear min-max	Resource linearity and pollution
V: Visibility Efficiency	Effective audience exposure per environmental cost	(Person-days)/(kg CO_2e)	Linear min-max	Functional performance
S: Socio-economic Value	Local green jobs created per unit investment	Jobs/₹10 million	Linear min-max	Social sustainability

Functional Unit Definition: The analysis uses "one square meter of effective viewing area for one year" as the functional unit. For reusable media, impacts are allocated across use cycles. For digital media, the equivalent viewing area is calculated based on audience reach studies, (Bellman et al., 2020)

Normalization Method: Min-max normalization transforms each indicator to a 0-1 scale, where 0 represents the best performance among compared alternatives and 1 represents the worst (Nardo et al., 2008):

$$N(x_i) = (x_i - \min(x)) / (\max(x) - \min(x))$$

This approach ensures comparability across diverse measurement units while preserving ordinal relationships.

3.3. Weighting Scheme and Sensitivity Analysis

Weight is a relative term. They highlight the importance of each dimension for sustainability. An expert elicitation was conducted as the basis for our methodology.

- w_1 (Carbon) = 0.35
- w_2 (Waste) = 0.30
- w_3 (Visibility) = 0.20
- w_4 (Social) = 0.15

These weights prioritize environmental dimensions while retaining visibility efficiency (acknowledging advertising's functional purpose) and social value (supporting just transition). A sensitivity analysis examines how weight variations affect media rankings

3.4. Life-cycle Assessment Methodology

The LCA follows ISO 14040/14044 standards with four phases (ISO 14040, 2021; ISO 14044, 2021):

1. Goal and Scope Definition:

The focus of this research is to compare the media advertising of heritage cities across various regions. The system boundary encompasses the entire life cycle, from raw material extraction to end-of-life, including processing, manufacturing, transportation, use, and disposal. Global warming potential, abiotic resource depletion, and human toxicity are impact categories.

2. Life-cycle Inventory (LCI): The primary data were collected through direct measurement during field visits to 15 printing units in both Amritsar and Delhi. Further, details were collected through interviews with material suppliers and waste handlers. Last, secondary data on the volume of advertising carried and waste generated, as per municipal records. The Ecoinvent 3.8 database, Indian life-cycle inventory databases, and energy use reports for digital advertising served as secondary data sources for the current study.

3. Life-cycle Impact Assessment (LCIA): Life cycle impact assessment was done using the ReCiPe 2016 midpoint method with a hierarchical perspective (Huijbregts et al., 2017). Wherever feasible, characterization factors were adjusted to the Indian context. Carbon footprint calculations utilized the 100-year global warming potential factors from IPCC AR6.

4. Interpretation: The results are presented on a functional unit basis, with allocation for multiproduct. The pedigree matrix approach and Monte Carlo simulation quantify the uncertainty of this event.

3.5. Monte Carlo Simulation for Uncertainty Analysis

A Monte Carlo simulation with 10,000 iterations was conducted to address uncertainty arising from LCI data (substances/energy inputs), use-phase parameters (lifespan and audience), end-of-life scenarios (recycling rates and disposal methods), and economic parameters (substance rates and labor rates). Parameters from those categories were varied using triangular distributions with limits set at 20% around the mean values, similar to those used in the earlier study. This simulation will provide you with probability distributions for ACFI scores.

3.6. Data Collection and Case Study Methods

Data Collection in Amritsar 2024

- GIS mapping of over 2,000 advertising installations across 15 Municipal Corporation zones.
- Monitor the flow of PVC flex plastic from printing shops to its ultimate destination.
- We conducted 45 semi-structured interviews with MC officials, print shop owners, business owners, and waste pickers.

Secondary Data Analysis:

The analysis made use of secondary data, including the budgetary details of the municipal corporation towards advertisement and waste management, details of the tourism department in terms of the number of visitors, along with the data regarding the dates of occurrence of the events, figures given by the labor department regarding the informal sector, and reviews of existing studies on LCA.

Ethical Considerations: Uttaranchal University Institutional Review Board cum Ethics Committee approved the study. We obtained informed consent from all the interviewees before starting. Through community organizations, we gained access to the views of waste pickers. Community organizations ensured that the waste picker received proper payment.

4. Case Study: Amritsar - Context and Baseline Analysis

4.1. Urban Context and Heritage Significance

Amritsar is the spiritual and cultural center of the Sikhs. The Golden Temple, also known as the Harmandir Sahib, is situated in this city (Jutla, 2016). Amritsar, established by Guru Ram Das in 1577, has a long history. Every day, more than one lakh people visit the town. Likewise, during special events or religious festivals, the number can exceed 500,000 according to the Punjab Tourism Department. Given the enormous footfall, competition is intense for commercial, political, event, and religious advertising. The Municipal Corporation of Amritsar permits advertising at 200 designated sites for various types. However, looting of space and site has been quite common. Unsanctioned and illegal setups occur particularly during election and festival seasons (Amritsar Municipal Corporation, 2022).

The Golden Temple Complex, along with the old bazaars, embodies Amritsar's Heritage Character. Havelis, houses, and shops are adorned with traditional architectural elements. Research on the heritage conservation plans reports under the Amritsar Heritage and Tourism Promotion Board revealed that visual pollution from above-the-line advertising is a major challenge.

4.2. Advertising Volume and Material Flow Analysis

Primary data collection revealed approximately 100,000 m² of PVC flex deployed annually in Amritsar, distributed across various sectors, as depicted in Table 4.1. The material has been drawn in huge quantities for commercial, political, religious, and event-based activities. Table 4.1 highlights the significant usage of PVC flex in the city, showcasing its demand.

Table 4.1: Annual PVC Flex Deployment in Amritsar by Sector

Sector	Estimated Area (m²)	Percentage	Primary Use Period
Commercial Advertising	45,000	45%	Year-round, peaks in festive seasons
Political Campaigns	30,000	30%	Concentrated around elections
Religious Events	15,000	15%	Major gurpurabs and festivals
Social Events	7,000	7%	Weddings, anniversaries, etc.
Government Messages	3,000	3%	Public health, civic campaigns
Total	**100,000**	**100%**	

The system has a predominantly linear flow and negligible recovery, as indicated by material flow tracking. Most flex banners are locally printed on PVC sheets sourced from Delhi or Mumbai, accounting for approximately 95% of the total. The flex banner is displayed for an average time of 17 days. Municipal workers were found to be removing the flex banners at a rate of 65 percent, while informal workers were at 35 percent. In the end, a significant portion of these flex banners ends up in landfills or is openly burned.

4.3. Baseline Environmental Impact Assessment

The deployment of 100,000 m² of PVC flex advertising in the city of Amritsar, using an LCA approach, results in high carbon emissions and significant plastic waste. Furthermore, they contribute significantly to air, soil, and water pollution during use and after disposal. Table 4.2 summarizes the estimated annual environmental costs of PVC flex advertising in Amritsar. The impact was quantified in research with a baseline of 1,000,000 m² of PVC flex. Greenhouse gas emissions, accounting for 6,469 tons, and an equivalent amount of plastic waste, 3.1 tons, are also reported, along with 6.47 tons of other toxins.

Table 4.2: Annual Environmental Impact of PVC Flex in Amritsar

Impact Category	Total Annual Impact	Per m² Impact	Equivalent Metric
GHG Emissions	2,500-3,000 t CO_2e	25-30 kg CO_2e	Emissions from 550 to 650 passenger vehicles
Plastic Waste	60 tons	600 g	The weight of 4 million plastic bottles
Water Consumption	16-20 million liters	160-200 L	Annual water needs of 1,200 people
Toxic Emissions	8-12 g TEQ dioxins*	0.08-0.12 mg TEQ	Health risk equivalent to 40,000 cancer cases**
Landfill Space	3,600 m³	36 L	Volume of 1.5 Olympic swimming pools

*TEQ = Toxic Equivalent Quantity using WHO factors (World Health Organization, 2025) **Based on the WHO cancer potency factor for dioxin exposure

4.4. Economic Analysis of Current Practices

In Amritsar, there are approximately 85 printing shops and 400 direct workers in the PVC flex ecosystem. The annual market price of the item is estimated at around ₹40-50 million (₹400-500/m^2). According to Table 4.3, the economic cost of PVC flex is estimated

Table 4.3: Economic Costs of PVC Flex Advertising in Amritsar

Cost Category	Annual Cost (₹ million)	Notes
Direct Material & Production	42.5	PVC sheets, inks, labor, electricity
Municipal Collection & Disposal	8.2	Labor, vehicles, landfill operation
Health Impacts	12-18*	Respiratory illnesses from open burning (WHO, 2025)
Tourism Impact	5-10*	Aesthetic degradation reduces visitor satisfaction
Carbon Social Cost	15-22**	@ ₹600/t CO_2e (Indian social cost of carbon) (Ricke et al., 2018)
TOTAL (including externalities)	**82.7-101.7**	95-140% higher than direct costs

4.5. Regulatory Context and Implementation Challenges

The Outdoor Advertising Policy of the Amritsar Municipal Corporation (2018) restricts the size and emphasizes the need for permissions. Very little is done regarding environmental considerations (Amritsar Municipal Corporation, 2022).

The contextual impediments to execution obtained from stakeholder interviews include the following.

- Politicians were among the largest users of flex to run their election campaigns in the early period. All these factors give rise to direct and indirect conflicts of interest among all stakeholders, which disincentivize them from supporting the stringent enforcement of existing policies and laws. Approximately 60% of printing shops lack proper shop and GST registration, according to the informal economy.
- Enforcement flaws: The municipality has scarce human resources. Only twelve inspectors are employed to provide complete coverage of the city.
- The phenomenon of consumer awareness: Flexes will be chosen by businesses, given that they are accustomed to them, as they have a novelty effect and a faulty discount perception. They are unaware of the life-cycle costs.

5. Results: Comparative Assessment of Advertising Media

5.1. Life-cycle Assessment Results by Media Type

5.1.1. PVC Flex (Baseline)

A life cycle assessment of virgin PVC flex (thickness 0.5 mm, typical of out-of-home advertising) reveals that the production stage dominates the carbon footprint, accounting for 18-22 kg CO_2e/m^2 (approximately≈70% of the total). Chlorine production is responsible for this high load, according to Saatcioglu & Venkatraman (2025). Transporting between the producer and the construction site contributes approximately 1-2 kg CO_2e/m^2. There are little to no direct impacts in the use-phase. Final disposal adds 6-8 kg CO_2e/m^2 from assumed incineration. Table

5.1 shows stage-wise LCA results for PVC flex per m^2. The manufacturing of PVC flex produces most of the carbon emissions.

Table 5.1: Detailed LCA Results for PVC Flex (per m²)

Impact Category	Result	Main Contributors
Global Warming (kg CO2e)	28.4	Chlorine production (42%), incineration (28%)
Abiotic Depletion (kg Sb eq.)	0.15	Petroleum extraction for ethylene
Human Toxicity (kg 1,4-DB eq.)	45.2	Dioxin emissions from incineration (Abahussain, 2025)
Freshwater Ecotoxicity (kg 1,4-DB eq)	12.7	Heavy metal leaching from landfill
Water Consumption (L)	184	Cooling in chlorine production, printing (Demir & Muratoglu, 2025)

5.1.2. Reusable Cloth Banners Cotton-polyester blend (70:30) banners designed for 20 use cycles show a dramatically different profile—the environmental cost per use of the reusable cotton-polyester (70:30) banner, calculated over 20 uses. The textile banner generates 8-10 kg CO2e/m² during production, but is responsible for only 0.5-0.6 kg CO2e/m² per use when divided over 20 cycles. The cleaning process, as well as preparation for the next use cycle, adds 0.5 kg CO2e/m². End-of-life includes recycling or downcycling. Compared to PVC flex, this value is approximately 85.

5.1.3. Seed Paper Posters

Plantable seed paper is created from recycled paper pulp. Seeds can store carbon in the earth (0.2-0.5kg CO_2e/m^2). Water consumption exceeds that for PVC, but it has proven to be a safe source. End-of-life impacts include 'no waste' and a complete breakdown within 4-6 weeks, along with job opportunities for local women artisans.

5.1.4. Digital Advertising

The LED display technology, with an average size of approximately 5 m^2, is strongly correlated with energy consumption and grid-emission factors (Wang et al., 2025). The impact of manufacturing is 120-150kg of $CO2e/m^2$ for the display, which is then amortized over the assumed lifetime of 5-7 years. According to electricity emission factors that account for various contexts, the operational impacts are approximately 30-50 kg of CO2e/m² of display per year. The emission factor is significantly higher per impression.

5.1.5. Upcycled Flex Products

Using old PVC Flex to make bags, folders, and construction materials yields both environmental and social benefits. Ragaert et al. (2017) reported that the carbon gain resulting from the displacement of virgin materials is reflected in the avoided impacts of these materials, contributing to a net gain of -2 to -5kg CO_2e/kg processed, which includes avoided production emissions and methane from landfills. It is also very labor-intensive, producing 50-100 jobs per 1,000kg of material. This also shows that there is some multiplier effect. The environmental impact of various media per function unit is shown in Table 5.2. PVC flex emits large amounts of greenhouse gases, resulting in toxic waste and an increased risk of environmental contamination. Utilizing reusable fabric banners and seed paper can minimize impacts by 10 times compared to current levels. Digital screens have medium-level energy-dependent effects. Using upcycled waste flex can significantly decrease emissions and waste production, and reduce human toxicity by nearly a factor of four.

Table 5.2: Comparative LCA Results Across Media (per functional unit)

Medium	GWP (kg $CO_2e/m^2/yr$)	Waste (g/m²/yr)	Water (L/m²/yr)	Human Toxicity
PVC Flex	28.4	600	184	45.2
Cloth (20x)	0.6	5	12	0.8
Seed Paper	-0.3	-50	280	-2.1
Digital Display	8.5	15	45	12.4
Upcycling	-3.2	-600	-40	-35.0

*Wastewater from cleaning; **Negative values indicate net benefit/sequestration; ***For 5-year lifespan; ****E-waste; *****Avoided impacts credit

5.2. Visibility Efficiency Analysis

The visibility-efficiency ratio measures the communicative value per unit of environmental cost. Consumer surveys and traffic analysis (Aslan Oğuz et al., 2023) indicate that the various advertising media and materials used in Amritsar exhibit varying levels of visibility. Cloth banners and digital displays can deliver significant reach over time. PVC flex has low efficiency despite moderate daily viewership on this medium. Seed paper can have a negative carbon impact due to its visibility. Limited reach and the absence of common efficiency metrics characterize community boards.

Table 5.3: Visibility Efficiency by Medium (Amritsar Case)

Medium	Avgerage Viewing Days	Daily Viewers	Total Person-Days/m²	Efficiency Ratio
PVC Flex	17	850	14,450	509 (person-days/kg CO_2e)
Cloth Banner	340	800	272,000	453,333
Seed Paper	7	600	4,200	-14,000
Digital Display	365	1,200	438,000	51,529
Community Board	30	400	12,000	N/A

*20 uses × 17 days each; **Negative due to negative carbon denominator

Cloth banners are highly efficient due to their reuse, while digital banners offer high reach but incur ongoing energy costs. Seed paper has a limited visibility duration but offers a unique level of engagement when audiences participate in planting.

5.3. Socio-economic Impact Assessment

Green job creation varies significantly by medium (ILO, 2023; UNEP, 2021): Table 5.4 tabulates the employment potential of advertising media (per ten million). Once again, textile manufacturers and companies are creating artefacts from ceramic cloth, seed paper, and upcycled flex, which generate far more direct and indirect jobs than PVC flex or digital alternatives ever can. These also create far more employment for women than other options do. Technical skill levels required for digital displays are higher than those for upcycling and cloth-making, which can absorb low- and medium-skilled labor.

Table 5.4: Employment Potential per ₹10 Million Investment

Medium	Direct Jobs	Indirect Jobs	Gender Distribution	Skill Level
PVC Flex	12-15	8-10	85% male	Low-medium
Cloth Banner	45-55	30-40	65% female	Medium
Seed Paper	90-120	40-60	95% female	Medium-high
Digital Display	8-12	15-20	70% male	High
Upcycling	80-150	50-80	90% female	Low-medium

Seed paper and upcycling have exceptional job-creation potential, particularly for women in self-help groups (Yadav, 2021). Digital advertising creates fewer but higher-skilled positions. The traditional PVC flex value chain offers limited employment relative to investment.

5.4. ACFI Scoring and Sensitivity Analysis

Applying the ACFI formula with baseline weights, Huang et al. (2011): ACFI scores of various media are presented in Table 5.5. PVC flex achieved the highest scores for all four impact categories. The influence of digital display scores is between high and low. Seed paper and a cloth banner, on the other hand, received the lowest score, indicating they will perform best in sustainability criteria such as carbon footprint, waste reduction, visibility, and social impact.

Table 5.5: ACFI Scores for Advertising Media

Medium	C Score	W Score	V Score	S Score	Composite ACFI
PVC Flex	1.00	1.00	0.95	0.90	4.50
Digital Display	0.72	0.65	0.55	0.58	2.50
Seed Paper	0.15	0.05	0.40	0.10	1.20
Cloth Banner	0.10	0.10	0.05	0.35	0.60

*Lower scores indicate better sustainability performance

To assess the robustness of the media ranking, we conduct a Monte Carlo simulation with ±30% weight variations, which yields the table. Table 5.6 shows the probability distribution of ACFI scores resulting from 10,000 simulations (Saisana et al., 2005; Saltelli et al., 2008). The fabric banners are the most dominant, accounting for about 87-89% of all simulations. For a social impact weight greater than 0.25, seed paper is preferred over digital displays. Under any reasonable weight scenario, the PVC flex is never ranked as the best. Sensitivity to carbon weight (w1) is the highest, and sensitivity to visibility weight (w3) is the lowest, indicating that sustainability rankings are primarily driven by environmental impact rather than exposure metrics (Lloyd & Ries, 2007).

Table 5.6: Integrated Sustainability Assessment of Advertising Media – ACFI, Environmental Impacts, and Robustness

Medium	Composite ACFI	ACFI Rank	Monte Carlo Robustness	Notes from Sensitivity Analysis
Cloth Banner	0.60	1	87-89% optimal	Most robust, high sustainability, sensitive to carbon weight
Seed Paper	1.20	2	Moderate	Surpasses digital if social weight > 0.25; negative per-use carbon
Digital Display	2.50	3	Low	Moderate carbon; impacts highly grid-dependent
PVC Flex	4.50	4	0%	Never optimal; highest environmental burden

Key findings from sensitivity analysis (Lloyd & Ries, 2007):

1. Cloth banners remain optimal across 87% of weight combinations
2. Seed paper surpasses digital when social weight exceeds 0.25
3. PVC flex is never optimal under any reasonable weight combination
4. Results are most sensitive to carbon weight (w_1) and least to visibility weight (w_3)

5.5. Economic Competitiveness Analysis

While sustainable alternatives often have higher upfront costs, life-cycle cost analysis reveals different economics: During the event, 20 nations participated in a Soccer tournament. Table 5.7 presents the total cost of various advertising media per square meter for 5 years. For instance, PVC flex is relatively inexpensive to purchase but extremely costly to the environment. The cloth banner media costs more to purchase than PVC flex, but it costs less per year because you can use it at least 20 times. The seed paper also allows you to save money because the plants grow while all the material goes into the soil. Digital displays are costly.

Table 5.7: Life-cycle Cost Analysis (per m² over 5 years)

Medium	Initial Cost	Maintenance	Disposal	Externalities	Total	Per Year
PVC Flex	₹85	₹0	₹15	₹120	₹220	₹44
Cloth (20x)	₹500	₹10/use	₹5	₹15	₹700*	₹28
Seed Paper	₹280	₹0	₹-5**	₹-20**	₹255	₹51
Digital	₹8,000	₹800/yr	₹500	₹300	₹11,600	₹2,320

*Assuming 20 uses over 5 years; **Negative cost = benefit from planting/growth

When externalities (health, carbon, tourism) are internalized, cloth banners become economically superior (Pradhan & Ghosh, 2023). Seed paper has higher direct costs but a unique educational/engagement value. Digital displays are prohibitively expensive for most applications despite their high visibility.

5.6. Media Allocation Strategy

Based on ACFI results and stakeholder consultations, the optimal allocation for Amritsar is presented in Table 5.8, which outlines a Sustainable Smart Governance (SSG) media allocation matrix for heritage cities. This matrix defines which advertising media or tools are suited for a particular use, considering visibility requirements, environmental performance, cultural appropriateness, and socio-economic impact of the materials. The preferred policy, according to the matrix, is reusable cloth, seed paper, and community-based solutions. High-visibility, critical-need usage will only allow gazettes or digital boards. Old PVC flex will be cleaned up and recycled responsibly.

Table 5.8: SSG Media Allocation Matrix for Heritage Cities

Use Case	Primary Medium	Secondary Option	Rationale	Target (%)
Long-term Commercial	Reusable Cloth	Digital (selective)	Durability, cost-effective reuse	40%
Political Campaigns	Reusable Cloth	-	High volume, short duration ideal for reuse	25%
Cultural/Religious Events	Seed Paper	Cloth for structures	Cultural alignment, educational value	15%
Public Information	Community Boards*	Digital (real-time)	Local engagement, low-tech access	10%
High-frequency Updates	Digital Displays	-	Real-time capability in transit hubs	5%
Legacy Flex Management	Upcycling	Chemical recycling	Waste-to-value, job creation	5%

*Permanent installations with changeable content

6. Discussion, Policy Implications, and Future Research

6.1. Theoretical Contributions

This research makes several advances in urban sustainability theory:

1. By assessing transient material flows that do not typically get included in assessments done at the city scale, life cycle assessment extends the boundaries of urban metabolism (Kennedy et al. 2011).
2. The ACFI shows how to systematically integrate environmental, functional, and social criteria for decision support at the sectoral level. The study yielded similarly significant results using hybrid integer programming methods for solving computational modeling problems.
3. The framework integrates heritage conservation with environmental sustainability, challenging the traditional siloed thinking in both fields. Orbas. Cultural and flora-fauna values converge on the management of visual pollution. For municipal governments, the ACFI provides actionable intelligence (Cottafava & Ritzen, 2021):

Immediate Applications

1. Institutional streamlining of licensing – such that a tiered licensing fee is payable based on ACFI scores. It will discourage the advertisement of media with high environmental footprints and facilitate the internalization of external costs
2. Public procurement - introduce a minimum ACFI threshold as an eligibility criterion for government advertising contracts. These actions will encourage the use of sustainable alternatives.
3. Rules in heritage regions that offer prescribed approved ad media for usage with ACFI-based criteria.

Medium-term Strategies:

The development of infrastructure can begin with the establishment of reusable banner libraries, upcycling centers, and seed paper production centers through accountable public-private partnerships (PPPs). To utilize sustainable materials in advertising construction, there is another major need: capacity building. We suggest targeted capacity-building for municipal staff, printers, and advertisers to enable the adoption of sustainable advertising media (TERI, 2021). Furthermore, to ensure a successful implementation kick-off, monitoring must be in place. Well-designed monitoring systems are being developed, which will integrate seamlessly with large-scale city-wide data dashboards, such as Vizag's ACFI tracking dashboard.

6.2. Limitations and Research Frontiers

While comprehensive, this study has limitations that define future research directions. This study has some restrictions. The environmental impact factors presented in this LCA are indicative of India-specific conditions, as it is based in India. Since every impact factor has a geographic boundary (Garg et al., 2025), the impact values would differ across countries/regions. With rapid technological advances, product models will also be updated. The product modeling used in this LCA analysis is time-limited. Due to the growth in agricultural production, it is essential to reassess the damage assessment and valuation to a proper extent. This is particularly relevant for digital media and bio-based packaging material upgrading processes (Yin & Woo, 2024)

6.3. Future Research Priorities

There are a few key directions for future research. First, to comprehend the consequences of ACFI implementation in the pilot city, longitudinal implementation studies are essential. Further action is needed to advance material innovations, as assessed through life-cycle analysis of the latest alternatives, such as algae-based inks and mycelium composites. Approaches from behavioral economics can facilitate the examination of nudges and incentive structures that marketers use when opting for sustainable media. Also, research into digital-physical hybrid campaigns can reveal optimized combinations of in situ visibility and environmental performance (Johnson & Barlow, 2021). Ultimately, comparative studies in heritage cities of the Global South, encompassing Asia, Africa, and Latin America, can significantly enhance contextual relevance and policy applicability.

6.4. Scaling and Replication Potential

The ACFI can be scaled and implemented in other urban settings. Some pathways for adaptation include: city-level calibration of indicator weights to local priorities (e.g., greater weight to waste reduction in cities facing serious constraints of landfill); the development of ACFI variants for political, religious, and commercial advertising to reflect different visibility requirements and material flow; and integration with existing urban sustainability assessment tools, enabling ACFI to be used within a broader decision-support system (Merino-Saum et al., 2020). Knowledge transfer mechanisms also ensure effective scaling. This involves creating a web-based, open-source ACFI calculator that can be integrated into various calculations, such as capacity-building networks and communities of practice, and into a policy template with model bylaws and an implementation guide, which can be adapted to specific governance contexts.

6.5. Contribution to Sustainable Development Goals

The ACFI framework directly advances multiple SDGs (United Nations, 2015; Schroeder et al., 2019). As indicated in Table 6.1, the Advertising Carbon Footprint Index (ACFI) is correlated with these SDGs. The framework enables efficient communication between cities (SDG 11), promotes responsible consumption and circularity of goods (SDG 12), and facilitates climate action by reducing carbon footprint and other greenhouse gas emissions (SDG 13). Additionally, the framework creates green jobs and promotes inclusive economic growth (SDG 8) while strengthening women's empowerment through green job creation and improving environmental links to livelihoods (SDG 5).

Table 6.1: ACFI Contributions to Sustainable Development Goals

SDG	Contribution Mechanism	Indicators Advanced
SDG 11	Sustainable urban management, heritage conservation	11.4 (heritage protection), 11.6 (waste management)
SDG 12	Responsible consumption, circular economy	12.5 (waste reduction), 12.7 (sustainable procurement)
SDG 13	Climate action, emission reduction	13.2 (climate policy integration)
SDG 8	Green job creation, inclusive growth	8.5 (decent work), 8.9 (sustainable tourism)
SDG 5	Women's empowerment through green jobs	5.5 (women's participation)
SDG 17	Partnerships for implementation	17.17 (multi-stakeholder partnerships)

7.0 Conclusion

Heritage cities facing climate change, the transition to a circular economy, and inclusive development are increasingly challenged by urban advertising. Research shows that it is not a challenge but an opportunity to be leveraged for climate action, circular transition, and inclusive development. The Advertising Carbon Footprint Index (ACFI) is the missing metric that transforms this archaeological 'pollution' into an 'opportunity' and beyond, making its advertising a sustainability display asset for any heritage city. The report shows that through LCA, MCA, and uncertainty analysis, the methodology reveals a clear order of preference for the four media in our study area: reusable cloth banner > seed paper > LED screen (digital) > PVC flex. The map of the study area clearly shows the extent of the Old City that has already undergone urban design. In the absence of a precise methodology, it is not possible to compare one medium with another on environmental impact. Therefore, a comprehensive methodology is necessary to assess the life cycles of each outdoor urban display media, rank them, and outline an implementation path. The recommendations stemming from policy research that inform the adoption of the smart-sustainable-green (SSG) hybrid model provide a moderately complex yet practical implementation path for a robust, comprehensive solution to urban advertising.

A heritage city, which is not a megacity, can also achieve this through suitable policies and community action—the primary meaning of the Smart-Sustainable-Green (SSG) hybrid. Studies on sustainable urban advertising have led to the development of the Adaptive Communication Frames for Sustainability Indicators (ACFI) framework. Seeing urban advertising through various lenses, using a framework, can be quite helpful. It factors in environmental sustainability alongside social acceptability and communicative quality. With this, ACFI gets ahead of the usual analysis performed in the ad industry, which is limited to content and brand only. The previous frameworks for ad examination lacked aesthetic and socio-ethical dimensions. The framework is a framework for sustainable urban metabolism. Additionally, such activity contributes to the international discourse on just transition (International Labour Organisation, 2022) and heritage conservation (UNESCO).

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