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GREEN ENERGY TRANSITION TOWARDS DECARBONISED AND SUSTAINABLE UNESCO HERITAGE TOURISM

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ABSTRACT

Transitioning to low carbon tourism demands that heritage places balance decarbonization with conservation responsibilities, visitor experiences, institutional coordination and rising demand. This study focuses on green energy transition in UNESCO World Heritage tourism in Tamil Nadu with the integrated Governance – Retrofit – Demand (GRD) framework. The framework explores retrofit feasibility, institutional governance and demand-side behaviour as factors influencing visitor support and considers awareness as a direct and moderating factor. A descriptive analysis, reliability test, correlation, regression, site comparison and PLS SEM are applied using a respondent level data set of 330 respondents in Mahabalipuram, Great Living Chola Temples, Nilgiri Mountain Railway and Western Ghats. Constructs had high internal consistency from 0.914 to 0.930 (Cronbach, 1951). Overall support was significantly predicted by retrofit feasibility ($\beta = 0.355$, $p < 0.001$), institutional governance ($\beta = 0.293$, $p < 0.001$), and demand-side behaviour ($\beta = 0.318$, $p < 0.001$), explaining 47.8% of the variance. PLS-SEM further confirmed significant effects of RF→OS ($\beta = 0.251$, $p < 0.001$), IG→OS ($\beta = 0.285$, $p < 0.001$), and DB→OS ($\beta = 0.321$, $p < 0.001$). Awareness had no significant direct effect ($\beta = 0.069$, $p = 0.086$) but did significantly moderate the relationship between RF and OS ($\beta = 0.157$, $p = 0.002$). The results indicate that the integrated heritage-energy governance approach is required in Tamil Nadu, encompassing technical retrofitting, institutional coordination, demand management and effective visitor communication

KEYWORDS: green energy; renewable energy; UNESCO World Heritage; heritage tourism; decarbonization; institutional governance; retrofit feasibility;

INTRODUCTION

Tourism is becoming more vulnerable to the impacts of climate change and at the same time driving up energy use, mobility demand, infrastructure pressure, and emissions. In heritage destination areas, decarbonization measures are more complex, as they need to fit the conservation requirements, visitor expectations, landscape constraints and institutional responsibilities. UNESCO World Heritage sites thus offer a valuable context for the study of energy transition without eroding the cultural, ecological and experiential values that make it possible for heritage sites to be attractive. (IPCC, 2022; UNESCO World Heritage Centre, 2023)

Tamil Nadu offers a unique context as it hosts World Heritage sites with a variety of spatial, architectural, ecological and transport traits. The Great Living Chola Temples are major temple complexes and surrounding communities, the Nilgiri Mountain Railway is heritage transport and hill tourism, and the Western Ghats are a natural-heritage setting, where ecological sensitivity is at the heart of the experience. These differences lead to different technical, institutional and demand side conditions for the transition to green energy. The UNESCO World Heritage Centre (2024)

The question of whether renewable technologies can be installed is not a policy challenge. Reducing environmental impacts can be achieved via solar photovoltaic systems, efficient lighting, water-saving solutions, electric mobility, waste-management solutions and building retrofits, which require maintenance, institutional coordination, visitors, financing, communication, and compatibility with heritage management needs. The decarbonization of Heritage needs a 'system' approach, not a 'technology' approach. (IEA, 2024; UNESCO World Heritage Centre, 2015, 2023)

Another question has to do with visitors. Tourism demand may place further strain on heritage resources but at the same time it can be a catalyst in energy transitions by, for example, adopting energy-efficient mobility, using resources responsibly, agreeing to green infrastructure, and supporting low-carbon destination policies. Knowledge is thus key, but knowledge is not necessarily action. The question is whether visitors have the contextual information and understanding to make sustainability knowledge actionable. (UNESCO World Heritage Centre, 2015, 2023; IPCC, 2022)

Given this background, this study proposes and experiments a Governance – Retrofit – Demand (GRD) framework for UNESCO heritage tourism. Retrofit feasibility (RF) is a technical and operational feasibility of introducing or improving for green energy and efficiency measures. The institutional governance (IG) is defined as coordination, policy implementation, monitoring, maintenance and institutional credibility. Demand-side behaviour (DB) refers to the level of behavioural support from visitors for responsible resource use and low carbon tourism practices. The overall support (OS) is the support for a decarbonized and sustainable transition for heritage-tourism. Visitor awareness (AW) is directly included as a contextual variable and as a moderator.

This study aims to answer the following question: How much does the technical feasibility,

institutional governance, and demand-side behaviour collectively explain decarbonization-oriented support at the UNESCO World Heritage properties of Tamil Nadu, and what are the implications for a Tamil Nadu-level heritage-energy policy framework?

The study aims to have three objectives. The research question will be focused on **RO1**: What is the relationship between retrofit feasibility, institutional governance and demand side behaviour in the green-energy transition in UNESCO World Heritage tourism. **RO2**: To determine the influence of retrofit feasibility, institutional governance and demand side behaviour on the support of decarbonized and sustainable heritage tourism. **RO3**: To explore how the visibility of visitors influences support for green-energy transition, and how this moderates the relationship between the retrofit feasibility and total support.

This study has three contributions. Conceptually, it links explanations of both technical and institutional and demand-side approaches in one heritage-tourism context. In practice, it is applied to four different contrasting UNESCO heritage landscapes in Tamil Nadu on an empirical basis. In practice it is translating the results into a governance-driven approach that brings energy transition into the equation of conservation, visitor management, infrastructure maintenance and destination communication. (UNESCO World Heritage Centre, 2015, 2023)

LITERATURE REVIEW

Green energy and tourism decarbonization

Tourism decarbonization is more than just boosting the supply of renewable electricity. It includes energy efficiency, electrification, low carbon mobility, resource use, waste reduction and consumption shift. The impacts of renewable-energy technologies on tourism depend on how well they are integrated in the system and on their performance. In heritage contexts, feasibility of interventions is further constrained by visual integrity, structural conservation, archaeological sensitivity and restrictions on the alteration of the historic fabric. (IPCC, 2022; IEA, 2024) Research on sustainable tourism is increasingly aware of the need for destinations to make a systemic transition from isolated environmental projects. Technical success in an energy intervention can result in short-term benefits but not long-term ones if the intervention is poorly maintained. Likewise, gains in efficiency are counterbalanced by rising numbers of visitors or level of consumption. This leads us to a need to consider supply and demand side issues.

Heritage conservation and renewable energy retrofit

The retrofit challenges are unique for heritage properties. Historic buildings can also have protected facades, sensitive materials, archaeological layers or strict regulations on physical changes. The design of renewable-energy infrastructure must, therefore, be based on conservation principles instead of being a generic engineering response. In certain environments, alternatives such as off-site renewable

generation, inconspicuous renovations, energy-efficient lighting, passive cooling, smart monitoring, and mobility interventions might prove to be more compatible options than tangible structural changes. (UNESCO World Heritage Centre, 2015, 2023) In this study retrofit feasibility is therefore considered as perceived practicality of implementing energy and efficiency measures considering operational and heritage restrictions. The construct is more than just technical availability, but also implementation practicality, compatibility, maintenance, and perceived feasibility within the destination context.

Institutional governance in heritage-energy transition

The stakeholders in heritage tourism are numerous, such as heritage authorities, tourism departments, local governments, tourism managers, infrastructure agencies, transport companies, businesses, communities, and visitors. Decentralized tasks can lead to a disconnect between policy making and policy action. Governance is therefore important as it is in many ways a cross-institutional process. (UNESCO World Heritage Centre, 2015) Good governance can be achieved through clear accountability for energy performance, regular monitoring, maintenance arrangements, communication, funding agreement and stakeholder engagement. Institutional credibility can also shape visitors' willingness to support sustainability efforts as visitors are more likely to be responsive if the green claims are consistent, visible, and credible. (UNESCO World Heritage Centre, 2015)

Demand-side behaviour and visitor participation

Visitors affect the environmental impacts of heritage tourism by their travel, energy and water consumption, waste practices, shopping and tolerance for sustainability initiatives. Demand-side management can thus be considered a behavioural alternative to infrastructure investment. These include public and shared transport, walking and cycling, electric mobility, responsible water usage and waste segregation, as well as the acceptance of sustainability-oriented visitor guidelines and the reduction of single use materials. (IPCC, 2022; UN Tourism, 2024) Demand management is especially important because technological improvements may be offset by an increase in visitors or visitor consumption. However, if a transition framework does not consider the behaviour of visitors, it can overestimate the impact of technical interventions.

Awareness and the actionability gap

Often, awareness is assumed to lead to sustainable behavior, while awareness does not necessarily result in adoption or support. Visitors might be familiar with the concepts of renewable energy but not have any detailed knowledge of feasibility, cost, reliability or maintenance or benefits at destination. The present study thus does not assume that awareness is always determination. (IPCC, 2022) This viewpoint reflects an actionability gap – the disconnect between the recognition of the need for green energy and the level of confidence, understanding and context that enable practical transition actions.

The moderation hypothesis predicts that the relationship between retrofit feasibility and overall support will be stronger when awareness is high.

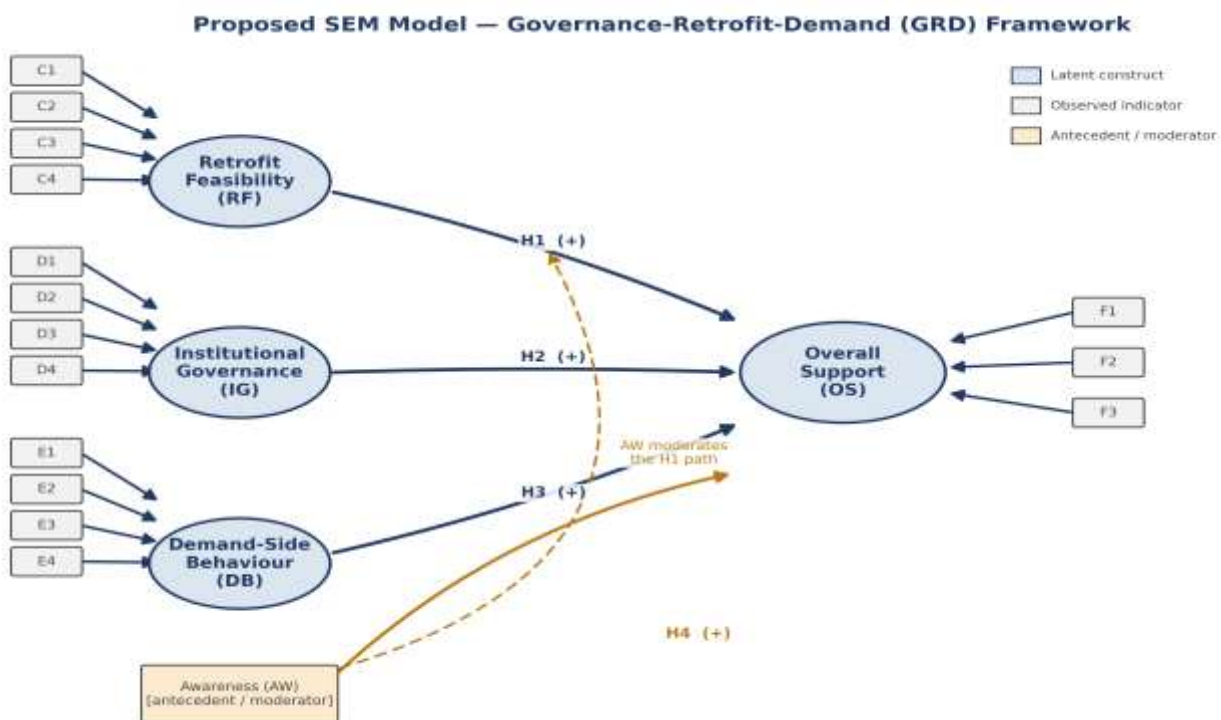
Research Gap

Three gaps inspire this study. First, heritage-energy research tends to divorce the technical from the visitor and governance questions. Second, research in tourism often explores environmental attitudes and awareness without making explicit linkages with the feasibility of tourism infrastructure. Third, research on UNESCO heritage tourism in the Global South is still relatively scarce, especially on a multi-dimensional level that incorporates retrofit feasibility, institutional government, behaviour of visitors and awareness. The present study tries to overcome these gaps by using an integrated empirical model applicable to Tamil Nadu. (UNESCO World Heritage Centre, 2023; IEA, 2024)

Conceptual Framework and Hypotheses

The Governance–Retrofit–Demand approach brings together three complementary pathways. Retrofit feasibility (technical and operational); institutional governance (coordination and implementation); demand-side behaviour (visitors and consumption). All of these intersect in the overall support for green-energy transition in heritage tourism. The construct of awareness is featured both in the context of the RF and as a moderator in the RF–OS relationship.

Figure 1. Governance–Retrofit–Demand conceptual framework



The proposed GRD model is shown in figure 1. RF and IG are given as complementary determinants of OS and DB is given as a determinant of OS. AW is specified as a direct contextual variable and as a moderator of the RF→OS relationship. The model thus links technical feasibility, institutional coordination and demand management oriented towards visitors instead of focusing on heritage decarbonization as a technology-only process.

H1: Retrofit feasibility has a positive effect on overall support for green-energy transition in UNESCO heritage tourism.

H2: Institutional governance has a positive effect on overall support for green-energy transition in UNESCO heritage tourism.

H3: Demand-side behaviour has a positive effect on overall support for green-energy transition in UNESCO heritage tourism.

H4a: Visitor awareness has a positive direct effect on overall support for green-energy transition.

H4b: Visitor awareness positively moderates the relationship between retrofit feasibility and overall support.

METHODOLOGY

Research design and study context

A quantitative cross-sectional study is employed regarding the relationship between retrofit feasibility, institutional governance, demand-side behaviour, awareness and overall support. The four UNESCO heritage settings under consideration are Mahabalipuram, Great Living Chola Temples, Nilgiri Mountain Railway and Western Ghats in Tamil Nadu. These settings offer examples of variation in built heritage, transport heritage and natural heritage.

Sample and study dataset

This study employs a respondent-level data set with 330 observations. 83 respondents from Mahabalipuram, 83 from the Great Living Chola Temples, 82 from the Nilgiri Mountain Railway, 82 from the Western ghats. The responses regarding visitor awareness of the use of green energy were coded as binary, with 120 respondents indicating that they were aware (36.4%) and 210 respondents indicating that they were not aware (63.6%).

Table 1. Distribution of respondents by study context

Study context	n	Share (%)
Mahabalipuram	83	25.2
Great Living Chola Temples	83	25.2
Nilgiri Mountain Railway	82	24.8
Western Ghats	82	24.8

Total	330	100.0
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Source: Author's analysis of the study dataset (n = 330).

Measures

The questionnaire operationalized the main constructs with Likert-type statements. The four measures of retrofit feasibility (RF), four measures of institutional governance (IG), four measures of demand-side behaviour (DB), and three measures of overall support (OS). Visitor Awareness (AW) was used as a contextual variable. The statements on the "Respondent" side were crafted to be simple and yet still conceptually precise at the construct level.

Data analysis

The analysis was carried out in descriptive statistics, internal-consistency reliability, bivariate correlation, multiple regression, site comparison, and measurement and structural assessment of PLS-SEM. The internal consistency of the survey was assessed using Cronbach's alpha. Composite reliability (CR) and average variance extracted (AVE) were examined for construct quality. The discriminant validity was evaluated using HTMT. Standardized path coefficients, t-statistics and p-values were used to evaluate structural relationships. AW×RF was used to investigate the proposed moderation effect. (Cronbach, 1951) The analytical approach was formulated in such a way that the empirical tests were in keeping with the conceptual model. The structural model offers construct-level assessment of the hypothesized pathways and awareness interaction, and regression offers a transparent multivariate assessment of the three principal determinants. (Hair et al., 2022)

RESULTS

Respondent awareness

Of the 330 respondents, 120 (36.4%) indicated awareness of green energy, whereas 210 (63.6%) did not. The distribution in this case shows that it is not equally distributed among the study sample and thus should be specifically addressed in the structural model.

Table 2. Construct descriptive statistics and internal consistency

Construct	Items	Mean	SD	Cronbach's α
Retrofit Feasibility (RF)	4	3.002	0.891	0.930
Institutional Governance (IG)	4	2.993	0.892	0.923
Demand-Side Behaviour (DB)	4	3.027	0.885	0.926
Overall Support (OS)	3	2.998	0.914	0.914

Source: Author's analysis of the study dataset (n = 330).

Descriptive results indicate that the means of all four constructs are near the midpoint of the scale and that all Cronbach's alphas are above the accepted levels of reliability. The results offer solid grounding

for further construct-level analysis.

Measurement model

Indicator loadings were high, and construct reliability was good for the measurement assessment. Composite reliability ranged from 0.945 to 0.950, and AVE ranged from 0.812 to 0.853. (Hair et al., 2022)

Table 3. Measurement-model assessment

Construct	Loading range	CR	AVE
RF	0.906–0.915	0.950	0.827
IG	0.890–0.916	0.945	0.812
DB	0.893–0.912	0.948	0.819
OS	0.921–0.927	0.946	0.853

Source: Author's analysis of the study dataset (n = 330).

Indicator loadings are all significant and CR and AVE values show good internal consistency and convergent validity.

Correlation analysis

Table 4. Correlation matrix

Variables	RF	IG	DB	OS
RF	1.000	0.346	0.222	0.527
IG	0.346	1.000	0.230	0.489
DB	0.222	0.230	1.000	0.464
OS	0.527	0.489	0.464	1.000

Source: Author's analysis of the study dataset (n = 330).

The correlation results show positive correlations between main constructs. RF has the strongest bivariate association with OS ($r = 0.527$), followed by IG ($r = 0.489$) and DB ($r = 0.464$). The lower intercorrelations among the explanatory constructs support their conceptual distinctiveness.

Multiple regression

Overall support was predicted by the multiple regression model ($R^2 = 0.478$; adjusted $R^2 = 0.474$). All three main predictors were statistically significant.

Table 5. Multiple regression predicting overall support

Predictor	B	SE	B	t	p
RF	0.364	0.044	0.355	8.224	<0.001
IG	0.301	0.044	0.293	6.787	<0.001
DB	0.329	0.043	0.318	7.644	<0.001

Source: Author's analysis of the study dataset (n = 330).

RF, IG, and DB each have positive and statistically significant coefficients. The regression results hence support H1, H2 and H3, and suggest that overall support is related to a combination of technical, institutional, and behavioural conditions.

Site comparison

Table 6. Site-wise overall support

Study context	OS Mean
Great Living Chola Temples	2.920
Mahabalipuram	2.996
Nilgiri Mountain Railway	3.073
Western Ghats	3.004
Overall	2.998

Source: Author's analysis of the study dataset (n = 330).

There were no statistically significant differences across the four study contexts on the overall level of support ($F = 0.387$, $p = 0.763$; $\eta^2 = 0.004$). A small effect size shows that that site membership explained a very small percentage of the overall support.

Discriminant validity

Table 7. HTMT ratios

Construct pair	HTMT
RF-IG	0.372
RF-DB	0.240
RF-OS	0.572
IG-DB	0.249
IG-OS	0.533
DB-OS	0.506

Source: Author's analysis of the study dataset (n = 330).

The HTMT values are below the commonly used thresholds, which provides for discriminant validity among the four reflective constructs.

Structural model and hypothesis testing

Table 8. Structural paths and hypothesis testing

Hypothesis	Path	β	t	P	Result
H1	RF $\rightarrow$ OS	0.251	4.708	<0.001	Supported
H2	IG $\rightarrow$ OS	0.285	6.638	<0.001	Supported
H3	DB $\rightarrow$ OS	0.321	7.842	<0.001	Supported
H4a	AW $\rightarrow$ OS	0.069	1.720	0.086	Not supported
H4b	AW $\times$ RF $\rightarrow$ OS	0.157	3.109	0.002	Supported

Source: Author's analysis of the study dataset (n = 330).

The structural results corroborate hypothesis H1, H2 and H3. The three main predictors, DB, IG, and RF, have the largest standardized path coefficients respectively of 0.321, 0.285 and 0.251. The direct awareness effect is positive though not statistically significant at the 5% level ($\beta = 0.069$, $p = 0.086$), thus, H4a is not supported. However, the strong AW $\times$ RF interaction ($\beta = 0.157$, $p = 0.002$) suggests a positive interaction between awareness and retrofit feasibility and overall support and therefore confirms H4b.

DISCUSSION

The findings indicate that the support for green-energy in UNESCO heritage tourism could be explained in an integrated manner because of the retrofit feasibility, institutional governance and demand-side behaviour, which are statistically significant and showed different coefficients in regression and structural analysis depending on the analytical specification. Retrofit feasibility shows that visits are related to perceived practicality, operational viability and conservation compatibility of interventions for green energy and efficiency; institutional governance underlines the need for coordination, credible implementation, monitoring, maintenance, and communication. Demand-side behaviour also points to the fact that sustainable mobility, responsible resource use, and sustainable visitor behaviour contribute to decarbonization and can complement an infrastructure-based transition. At the 5% level, awareness does not directly influence overall support ($\beta = 0.069$, $p = 0.086$), but the significant interaction term between retrofit feasibility and overall support ($\beta = 0.157$, $p = 0.002$) suggests that awareness can play a more significant role when visitors consider concrete and feasible retrofit options. Moreover, no significant differences in overall support between the four heritage contexts indicate that these central transition determinants can influence any category of heritage, and that their application can remain specific to the technical, operational and conservation needs of each site.

Theoretical and Practical Implications

The study contributes to sustainable heritage-tourism studies by introducing technical feasibility,

institutional governance and visitor demand in the GRD framework and making a socio-technical governance process rather than only an infrastructure decision as green-energy transition. The greater moderation effect also suggests that the salience of the visitors' awareness increases when visitors evaluate the feasibility of concrete green-energy measures. Realistically, the role of heritage authorities as regards retrofit assessments must be site specific and consider conservation compatibility, and the role of tourism and local-government authorities must be defined in terms of responsibilities for retrofit, monitoring, maintenance and communication. To promote responsible mobility and resource use, destination managers need to increase demand-side measures and targeted sustainability communication on all points of contact. The policy level, Tamil Nadu could come up with a coordinated heritage-energy policy that incorporates renewable-energy planning, heritage conservation, tourism management, public transport, local governance, and visitor engagement, while leaving room for implementation to be tailored to the needs of individual heritage sites.

Limitations and Future Research

There are some limitations in the study. The cross-sectional design precludes causal interpretation and only the visitor perspective is represented, missing out on the views of heritage bodies, local people, the tourism industry, transport companies and energy companies. There are also four UNESCO heritage contexts that restrict the ability to generalize to other destinations. Therefore, future studies should use a longitudinal and mixed-method design and involve a variety of stakeholders, as well as incorporate survey-based evidence, complemented by objective metrics like energy use, renewable generation, water usage, waste, transport emissions, and visitor numbers. The robustness and applicability of the GRD framework could be further tested through comparative studies across Indian states and other heritage places in the Global South and by advanced SEM approaches that involve multiple groups.

CONCLUSION

The transition towards green energy in tourism activities in the UNESCO protected area is not a matter of installing renewable technologies! The findings in Tamil Nadu have shown that there is a positive association between retrofit feasibility, institutional governance and the behaviour of visitors to a decarbonized and sustainable heritage-tourism transition. The structural results also suggest that the role of visitor awareness is more complex, as it does not have a direct effect that is statistically significant in the model, but the interaction with retrofit feasibility is significant. The key message is an integrated transition logic. Technically compatible interventions, credible institutional arrangements and demand management that serve the visitors' need to all work together in heritage-energy policy. Where awareness is linked to practical, visible and credible action, it becomes more meaningful. This lays the foundation for transitioning from disjointed sustainability projects to a more unified heritage-energy governance framework in Tamil Nadu that can ensure heritage conservation

and promote low-carbon tourism.

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