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Article

Evaluating Sociotechnical Factors Influencing the Feasibility of Vineyard Photovoltaic Integration in Malta

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Abstract

This study investigates the feasibility of viticultural photovoltaics (Viti-PV) in Malta—a small European island state in the Mediterranean—through a mixed-methods approach, combining a standardised questionnaire (*n*= 13 viticulturists) with expert interviews involving stakeholders from viticulture, energy and policy. Results show that while Viti-PV offers tangible benefits such as shading, reduced irrigation needs and income diversification to this sunny, warm and relatively dry island, adoption is constrained by high investment costs, regulatory prohibitions and concerns over landscape impacts. For policy and practice, the findings highlight the necessity of tailored financing models, regulatory adaptation and participatory pilot projects to build evidence and stakeholder confidence. Viti-PV can contribute simultaneously to renewable energy targets and viticultural climate resilience, but its implementation depends on coordinated support across technical, economic and institutional dimensions.

Keywords: viticultural photovoltaics; Viti-PV; agrivoltaics; climate adaptation; socio-technical integration; landscape impact

1. Introduction

The transition towards renewable energy is one of the defining challenges for Europe in the coming decades, requiring innovative solutions that combine energy generation with sustainable land use. Photovoltaics (PV) has emerged as a cornerstone technology for decarbonisation, yet its large-scale deployment often intensifies competition for land resources, particularly in regions where agricultural production is already under pressure. Agrivoltaic concepts that enable dual land use therefore play a critical role in reconciling renewable energy deployment with food production and they are increasingly recognised within European energy and agricultural policy frameworks [1].

Viticulture represents a unique case for such integration. As one of the most climate-sensitive agricultural sectors, winegrowing is highly exposed to the consequences of global warming. Prolonged droughts, heat stress and changing precipitation patterns are expected to significantly reduce vineyard suitability across the Mediterranean region by the end of the century. Malta, a small island state in the central Mediterranean, illustrates these challenges in a particularly acute way: limited agricultural land, severe water scarcity and ambitious renewable energy targets converge to create strong incentives for dual land-use innovations [2].

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Viticultural photovoltaics (Viti-PV) offers a promising response. By integrating PV systems into vineyards, this approach not only supports national renewable energy goals but also provides potential co-benefits such as shading to reduce heat stress, lower water consumption and improved resilience of grapevines to climatic extremes. As such, Viti-PV exemplifies the kind of systemic solution needed to advance both the energy transition and agricultural adaptation to climate change [3].

Malta's agricultural sector provides a particularly relevant setting for studying agrivoltaic integration in small island states. With 10,449 farms recorded in 2020 by the Maltese National Statistics Office (90% cultivating less than two hectares and many consisting of highly fragmented parcels), agriculture in Malta faces structural constraints that closely mirror those of other Mediterranean and insular regions. Land fragmentation, often driven by inheritance and land sales, reduces both the economic viability and efficient use of agricultural areas, while declining farm numbers and shrinking cultivated land intensify the pressure to maintain productivity. These conditions, combined with severe water scarcity and limited arable land, make the exploration of dual land-use models such as Viti-PV especially relevant. Insights gained from Malta thus extend beyond the national context, offering valuable lessons for other small-scale agricultural economies seeking to reconcile renewable energy deployment with the preservation of traditional Mediterranean farming systems [4].

The aim of this paper is to assess the feasibility and potential of Viti-PV in Malta. Specifically, it seeks to (i) identify the socio-economic and regulatory conditions under which Viti-PV could be successfully implemented, drawing on existing technical literature rather than site-specific engineering analysis, (ii) capture the perspectives of viticulturists as key actors in adoption processes and (iii) provide an integrative framework that connects literature-based technical considerations with social acceptance and policy design. By employing a mixed-methods approach that combines quantitative surveys and qualitative interviews with relevant stakeholders, this research delivers the first exploratory analysis of Viti-PV in Malta.

In doing so, the study not only contributes to the growing body of agrivoltaics research but also addresses the intersection of renewable energy expansion, land-use optimisation and climate adaptation in a European island context. It aims to generate practice-oriented insights for policymakers, energy planners and agricultural stakeholders on how Viti-PV can become part of a broader strategy for sustainable energy and agricultural resilience.

To contextualise Viti-PV implementation in Malta, several Mediterranean case studies provide relevant insights. In Puglia, southeastern Italy, a 5400 m^2 vineyard was equipped with a Viti-PV system by Svolta Company (Bari, Italy), cultivating Primitivo grapes under PV modules and in an open control field. Panels cover 43% of the area horizontally. Similar to Malta, Puglia experiences arid conditions, extreme temperatures and variable rainfall. Shading effects on yield, fruit quality, microclimate, soil moisture and temperature were assessed, revealing a 277% yield increase and improved grape quality under Viti-PV, with minimal impact on air temperature and reduced wind speed.

However, the substantial reported yield increase reflects the particular baseline conditions of the pilot site and should therefore not be interpreted as a generally transferable outcome for all Viti-PV applications. The system generated 53 kWh/m^2 of ground area/year, reflecting the specific panel spacing and agrivoltaic configuration of the experimental site, and corresponding to a Land Equivalent Ratio (LER) of 3.54 which classifies the productivity of a dual land-use system [5].

In northern Italy, results are more moderate. In the Veneto region, a three-year study on Corvina grapes under a similar Viti-PV configuration reported slight yield reductions: 3.42–4.85 kg under Viti-PV versus 3.78–5.66 kg in control plots [6]. These findings highlight the influence of local climate and vine water stress, suggesting that Viti-PV benefits are maximised under arid or water-limited conditions.

Southern Spain offers additional insights on Viti-PV integration with vineyard structures. At the Technical University of Cartagena, Viti-PV systems were combined with trellis-based vineyards, optimising row spacing and panel height to limit excessive shading. Configurations with a row-to-panel height ratio ≥1.5 m allowed near-full sunlight exposure, achieving LER values of 1.27–1.50 [7]. While primarily addressing land-use efficiency, these designs do not specifically target crop protection. Complementary social research in Alicante found that two-thirds of respondents support limited Viti-PV deployment if it preserves the cultural and landscape heritage of PDO wine regions [8].

A recent study by Arias-Navarro et al. (2026) assessing social perception among wine tourists visiting pilot Viti-PV systems in south-eastern Spanish vineyards found that acceptance was strongly influenced by visual impact and perceived agricultural benefit [9]. The semi-arid Murcia region of south-eastern Spain, influenced by the Mediterranean climate, has—like Malta—a strong wine culture, consolidated traditions and significant wine tourism. These findings closely mirror stakeholder responses observed in the present study, suggesting that landscape sensitivity and dual-use legitimacy represent consistent social feasibility factors across Mediterranean viticultural contexts. Notable divergence exists: whereas Spanish wine tourists showed broadly positive landscape perceptions, 83% of Maltese winegrowers rated landscape change negatively.

Social acceptance has been identified as a critical determinant of agrivoltaic diffusion. Torma and Aschemann-Witzel (2023) conducted 27 semi-structured interviews and found that stakeholder perceptions of agrivoltaic systems are shaped by a complex interplay of economic incentives, regulatory frameworks and landscape concerns, with farmers and local communities expressing both enthusiasm for dual land-use benefits and scepticism regarding long-term land productivity and fair revenue distribution [10]. These findings are directly relevant to the Maltese context, where similar tensions between economic opportunity, regulatory uncertainty and landscape sensitivity were identified in the present study and a holistic perspective is necessary for decision making.

In Almeria, southern Spain, the German Aerospace Centre (DLR) investigated Viti-PV effects on vine growth, soil conditions and climate adaptation. In collaboration with the Cortijo el Cura vineyard, Merlot vines are cultivated under PV panels covering 40% of a 120 m^2 area using bush training methods. The study aims to inform climate-resilient agriculture and decentralised renewable energy systems [11].

Finally, Martínez-Hernández et al. [12] recently systematically synthesised 249 peer-reviewed studies on agrivoltaic systems published between 2010 and 2025, following the PRISMA 2020 guidelines. The review simultaneously examined three dimensions: technical efficiency, environmental sustainability and institutional governance. Results demonstrated superior land-use performance, with LER values ranging between 1.2 and 1.8, and water-use efficiency improvements of 15–30% in water-stressed regions. Additionally, design-dependent correlations between panel configuration and crop suitability were identified [12]. Critically for the present study, the review highlights that large-scale deployment remains constrained by institutional barriers—including the absence of dedicated regulatory frameworks and fragmented agricultural and energy policies—constraints that are directly reflected in the Maltese context examined here.

2. Materials and Methods

2.1. Research Design

This study employed a parallel mixed-methods design to investigate the feasibility of Viti-PV in Malta. Quantitative data was collected through a standardised questionnaire, while qualitative data was gathered using semi-structured and unstructured expert interviews. Both methods were implemented concurrently, and the findings were triangulated to generate a comprehensive understanding of the technical, social and regulatory conditions relevant to the introduction of Viti-PV. The advantages of such a design lie in the complementarity of data sources, where the limitations of each method can be mitigated by the strengths of the other [13].

However, this study focuses on the socio-technical and perceptual dimensions of Viti-PV feasibility and does not address detailed engineering aspects.

Given the absence of prior studies on Viti-PV in Malta, the design emphasised qualitative depth while supporting it with quantitative breadth to capture demographic structures, challenges in viticulture and perceptions toward Viti-PV. This approach follows the rationale of Creswell (2009) [14], who highlights the value of combining inductive and deductive methods in exploratory research.

The concept of feasibility is operationalised as a multidimensional construct comprising technical, economic, regulatory and social dimensions (Table 1). This framework provides the analytical basis for both data collection and interpretation.

Table 1. Matrix of the dimensions of feasibility comparing survey and interview themes.

Feasibility Dimension	Survey Items (Quantitative)	Interview Themes (Qualitative)	Integration in Analysis
Technical	Perceived benefits (e.g., shading, water reduction)	Agronomic impacts, system design, climate adaptation	Compared perceived vs. expert-based technical expectations
Economic	Willingness to adopt under funding scenarios	Investment costs, profitability, financing models	Identified gaps between interest and financial barriers
Regulatory	(Indirectly captured via perceived barriers)	Legal restrictions, land-use policies	Highlighted regulatory constraints as key limiting factor
Social	Acceptance, perceived risks, landscape concerns	Attitudes, cultural values, stakeholder concerns	Cross-validated acceptance patterns

Technical feasibility refers to the physical and agronomic compatibility of Viti-PV systems with local vineyard conditions. This includes aspects such as shading effects, irrigation needs, system design and climate adaptation potential. Given the exploratory scope of this study, technical feasibility is primarily assessed through stakeholder perceptions and existing literature rather than site-specific modelling.

Economic feasibility refers to the financial viability of Viti-PV systems, including investment costs, potential revenue streams and the availability of financial support mechanisms.

Regulatory feasibility captures the compatibility of Viti-PV with existing legal, planning and land-use frameworks in Malta, including potential restrictions or approval barriers.

Social feasibility refers to stakeholder acceptance, perceived risks (e.g., landscape impacts) and the willingness of viticulturists to adopt Viti-PV systems.

2.2. Fieldwork

Data collection was conducted during a field stay in Malta between May and July 2025. The field phase included site visits to vineyards, informal conversations with viticulturists and direct observations of local cultivation practices. These exploratory insights informed the refinement of the questionnaire and interview guidelines.

2.3. Questionnaire Survey

The questionnaire was constructed in Google Forms (Google LLC, Mountain View, CA, USA), following the methodological recommendations of Reinders et al. (2022) [13], who stated the following: "a questionnaire is a scientific instrument that stimulates individuals to respond to a collection of questions or stimuli with the goal of systematically recording facts". The design was adapted from previous studies on Viti-PV in Central Europe [15,16], with modifications to fit the Maltese context.

The questionnaire consisted of 16 questions divided into three sections (see the Supplementary Materials):

1. General background information (e.g., vineyard size, location, cultivated grape varieties, years of experience).
2. Climate-related challenges (e.g., perceived changes in climatic stress, severity of impacts, coping strategies).
3. Perceptions of Viti-PV (e.g., awareness of the technology, perceived benefits and risks, willingness to adopt under different support schemes).

To capture attitudes, several items employed 5-point Likert scales, a widely used instrument in social sciences for measuring degrees of agreement [17]. Questions were available in English and Maltese to ensure accessibility and higher response rates. Participation was anonymous and informed consent was obtained at the beginning of the survey.

A pilot test of the questionnaire was conducted with a small group ($n = 5$) outside the target sample to verify clarity and usability. The survey was accessible online between 15 May and 5 July 2025 (51 days).

2.4. Expert Interviews

The qualitative component consisted of 16 expert interviews, with five interviews following a fully semi-structured design and 11 following an unstructured design of which 9 interviews were conducted alongside questionnaire distribution to capture immediate perceptions of the viticulturists.

The semi-structured interviews were guided by a thematically organised set of open-ended questions (7–11 per interview).

Four interviews were recorded and transcribed verbatim and 12 were documented through detailed written notes. While verbatim transcription was not possible for all interviews, detailed contemporaneous notes were taken to minimise data loss. It is acknowledged that this approach may introduce interpretive bias, as nuance and precise wording may not have been fully preserved in note-based documentation.

The interviews followed the standard structure outlined by Reinders et al. (2022) [13], consisting of entry, warm-up, main and closing phases. A neutral stance was maintained by the interviewer to avoid bias and allow authentic responses.

2.5. Participant Selection

For the questionnaire survey, the sampling targeted both large and small-scale wineries listed by the Maltese Directorate of Agriculture's Wines of Distinction registry, complemented by additional wineries identified via online research. A total of 17 viticulturists from 13 wineries were contacted directly via phone, email and in-person visits. Eleven wineries replied with a result of 13 survey responses. Recruitment was further supported by snowball sampling, information sheets with QR codes distributed in agricultural cooperatives and bars and assistance from institutions such as the Farmers' Cooperative, the Farmers' Bar and the viticulture producer organisation Viti-Malta.

For the qualitative interviews, participants were selected purposefully to cover a broad range of perspectives relevant to Viti-PV implementation, including viticulturists, representatives from the energy sector, policymakers, PV engineers and academic experts. Participants were approached individually, with informed consent obtained for recording and data use.

2.6. Ethical Considerations

All participants were informed about the purpose of the study, data handling procedures and their right to withdraw participation at any time. The questionnaire was conducted anonymously, and interview transcripts were pseudonymised before analysis.

2.7. Data Analysis

Quantitative data from the questionnaire were exported from Google Forms into Microsoft Excel (Version 365, Microsoft Corporation, Redmond, WA, USA) and analysed using descriptive statistical methods. These included absolute frequencies (n) and relative frequencies (%) for all categorical variables. For Likert-scale items, response distributions were reported and, where appropriate, mean values and standard deviations were calculated to summarise central tendency and variability. Cross-tabulations were used to explore relationships between selected variables (e.g., vineyard size and willingness to adopt Viti-PV).

Given the small sample size ($n = 13$), all quantitative results are interpreted as exploratory and not statistically representative. This approach aims to identify key patterns, perceptions and barriers rather than to generalise findings.

Viticulturists with structural relevance for potential Viti-PV implementation were targeted, belonging to particularly larger and more accessible wineries. The analytical validity of the results is supported by the mixed-methods design, combining the survey with expert interviews ($n = 16$).

Qualitative data were analysed using qualitative content analysis as developed by Mayring (2000) [18] and further detailed by Gläser-Zikuda et al. (2022) [19]. This method applies systematic summarisation, explanation and structuring of textual material to identify core categories and themes. Initial open codes were derived inductively from the data, then grouped into thematic categories through iterative comparison across all interview documents. The analysis prioritised meaning condensation and categorisation, with coding criteria refined across multiple cycles to ensure consistency and clarity. Figure 1 illustrates the resulting thematic categories. For example, statements regarding permit uncertainty were coded as regulatory barriers under the category "Political & Regulatory Framework", while references to visual impact were coded as visual concerns under "Social Aspects".

Triangulation was applied in the interpretation phase by systematically comparing quantitative response patterns with qualitative interview themes, enabling convergent and divergent perspectives to be identified. For instance, survey findings on financing barriers were corroborated through interview responses addressing regulatory uncertainty and structural constraints.

As the analysis was conducted by a single researcher, formal intercoder reliability testing was not applied. Analytical consistency was ensured through multiple coding cycles and systematic category revision. Recurring themes across interviews indicate a sufficient level of thematic saturation, strengthening the robustness of the identified categories.

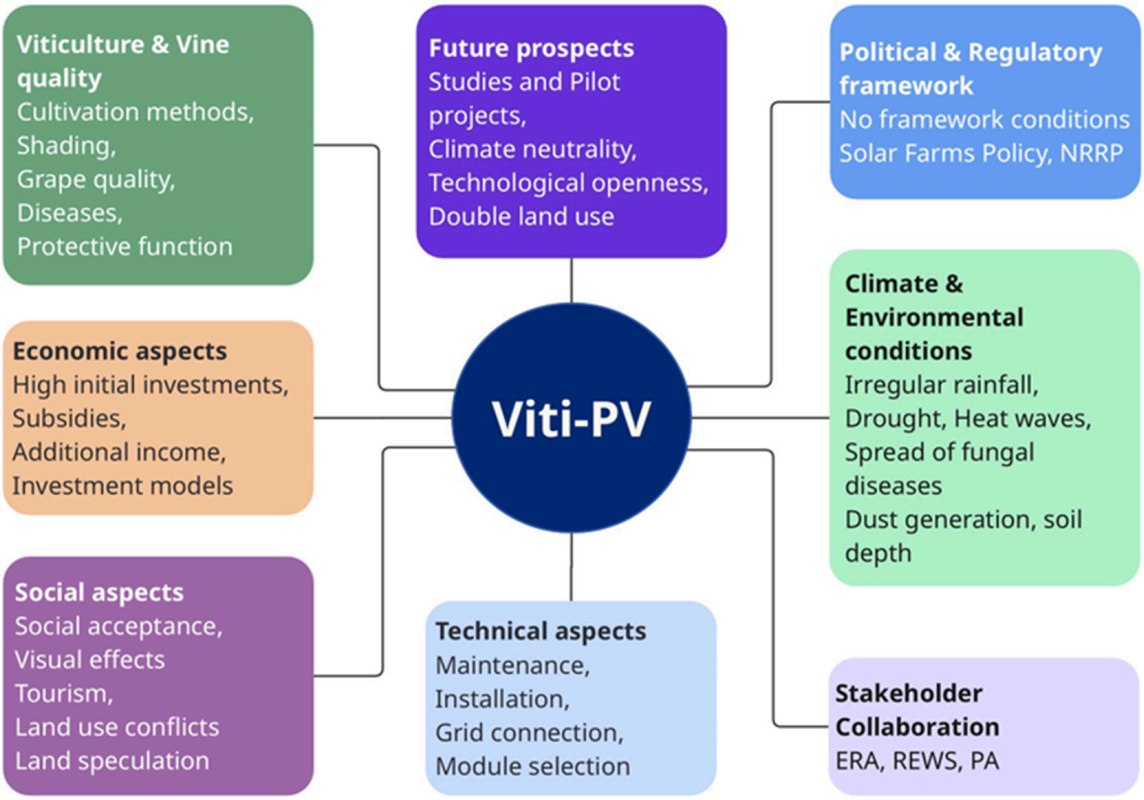

Figure 1. Interrelationships between topics related to the Viti-PV based on the interviews conducted (n = 16); ERA: Environment & Resources Authority, REWS: Regulator for Energy and Water Services, PA: Planning Authority, NRRP: National Recovery and Resilience Plan.

Accordingly, the findings are considered analytically valid and contextually meaningful, providing insight into key stakeholder perspectives despite the limited sample size.

3. Results

3.1. Survey Results

A total of 13 viticulturist responded to the survey, providing both quantitative and qualitative data. Table 2 summarises the contacted wineries, responding viticulturists, adapted cultivation methods, the location and size of the vineyards, the years of experience and number of cultivated varieties.

Table 2. Contacted wineries, responding viticulturists and their size, adapted cultivation methods, years of experience, location and cultivated varieties.

Viticulturist	Winery No.	Size (ha)	Adapted Cultivation Methods	Location of Winery	Cultivated Varieties
V1	1	26–50 ha	Use of shading, use of machinery	Northern Region	3
V2	2	11–25	Use of irrigation	Western Region	6
V3	3	<5	Use of irrigation, diversification of varieties	Western Region	3
V4	4	<5	Use of irrigation	Eastern Region	3

Table 2. *Cont.*

Viticulturist	Winery No.	Size (ha)	Adapted Cultivation Methods	Location of Winery	Cultivated Varieties
V5	5	<5	Use of irrigation, diversification of varieties	Gozo Region	5
V6	6	<5	Use of irrigation	Western Region	5
V7	7	11–25	Use of irrigation, use of machinery, restrict evaporation, sprayed vines with Caolino	Eastern, Gozo, Northern, Southern, Western Region	14
V8	7	11–25	Use of irrigation, diversification of varieties, use of machinery	Gozo, Northern, Southern Region	5
V9	7	26–50 ha	Use of irrigation, use of sunscreen for crops, diversification of varieties	Eastern, Gozo, Northern, Southern, Western Region	10
V10	8	11–25 ha	Use of irrigation	Gozo Region	6
V11	9	<5	Use of irrigation, use of machinery, fungicide application when symptoms appear	Western Region	1
V12	10	<5	Use of irrigation, shading, machinery	Southern Region	4
V13	11	>50	Use of irrigation, diversification of varieties, machinery, herbicide, restrict evaporation	Gozo, Northern, Southern, Western Region	24

While the sample size is small (n = 13), the responding viticulturists represent the largest winegrowers in Malta, collectively accounting for the majority of commercial viticultural activity on the island. Findings should nonetheless be interpreted as exploratory rather than statistically representative of the sector as a whole.

Note: Three respondents belong to the same winery but reported different vineyard size categories, likely reflecting their individual areas of responsibility within the operation. All 13 responses were retained in the analysis as they represent independent perceptions and professional roles.

3.2. General Background

The participating viticulturists manage vineyards spread across Malta and Gozo, often with non-contiguous plots (Table 2). The distribution of vineyards is spread along the southwestern, northern and Gozo regions. Most respondents (46.2%) cultivate less than 5 ha, while only two manage larger holdings of 26–50 ha (Figure 2). Vineyard experience ranges from 5 to 30 years, with over 40% having more than two decades of practice. A wide variety of 26 grape varieties is cultivated, dominated by Syrah, Merlot, Chardonnay and Cabernet Franc (Figure 3).

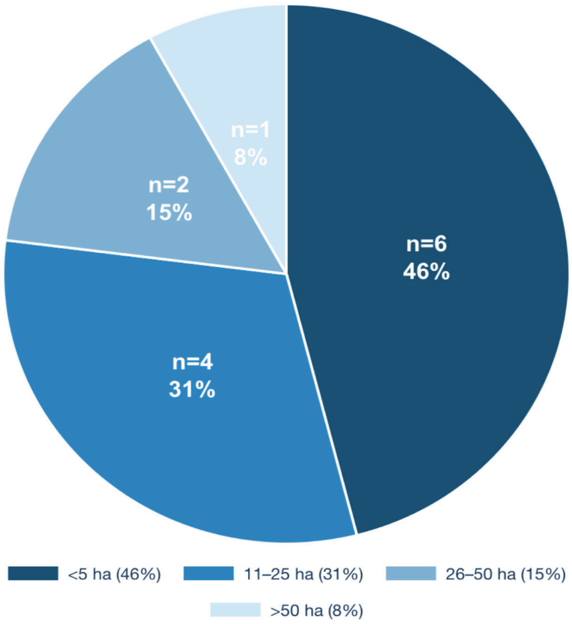

Figure 2. Cultivated vineyard size of the viticulturists interviewed (n = 13) [absolute number and percentage].

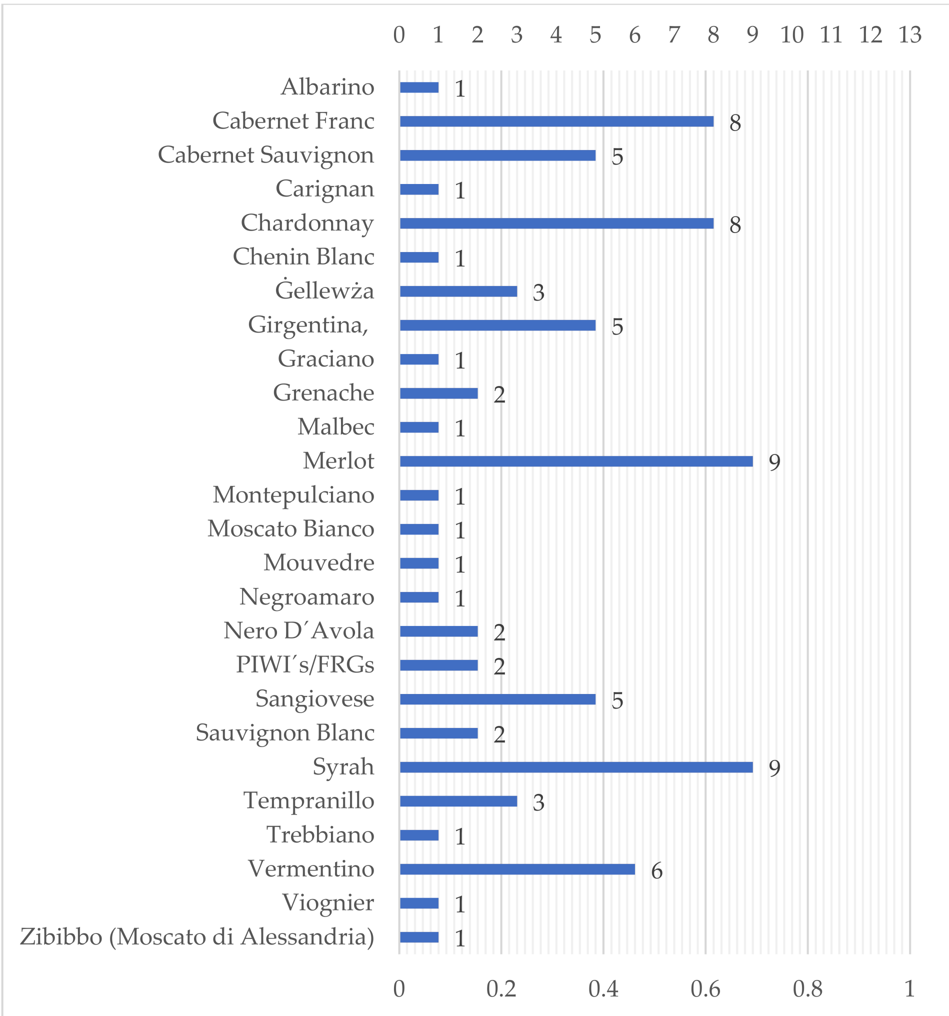

Figure 3. Cultivated grape varieties among surveyed viticulturists (n = 13) [absolute number and percentage] (PIWIs/FRGs describes Fungal Resistant Grapes).

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3.3. Climate-Related Challenges

All viticulturists reported experiencing climate-related problems. Drought and irregular rainfall were identified as the most critical issues, with 10 of 13 respondents rating drought impacts as high or very high (Table 3). Additional open responses highlighted concerns about salinity from irrigation, pest damage and labour shortages (Table 4).

Table 3. Perceived severity of climate-related challenges among viticulturists interviewed (n = 13); Note: 13 participants; some questions were skipped, so response counts vary; colour gradient represents magnitude (light = low, dark = high).

	Very Low n (%)	Low n (%)	Medium n (%)	High n (%)	Very High n (%)	Σ
Pests and diseases	1 (7.7%)	2 (15.4%)	5 (38.5%)	2 (15.4%)	3 (23.1%)	n = 13
Earlier budding and changed harvest times	0 (0.0%)	4 (30.8%)	3 (23.1%)	5 (38.5%)	1 (7.7%)	n = 13
Changed grape quality	2 (15.4%)	6 (46.2%)	3 (23.1%)	1 (7.7%)	1 (7.7)	n = 13
Reduced acidity	1 (7.7%)	3 (23.1%)	8 (61.5%)	1 (7.7%)	0 (0.0%)	n = 13
Damage caused by heavy rain	7 (58.3%)	2 (16.7%)	1 (8.3%)	2 (16.7%)	0 (0.0%)	n = 12
Sunburn on grapes	0 (0.0%)	1 (8.3%)	9 (75.0%)	1 (8.3%)	1 (8.3%)	n = 12
Damage due to dry spells	0 (0.0%)	1 (8.3%)	1 (8.3%)	8 (66.7%)	2 (16.7%)	n = 12

Table 4. Additional climate problems reported by viticulturists (n = 13). Note: 13 participants; some questions were skipped, so response counts vary.

Abbreviation Viticulturist	Additional Climate Problems
V3	"Sparrows have become a challenge as they eat and damage grapes."
V4	"Less precipitation means more irrigation, even in the winter months and this increases the salt content in the soil."
V5	"Shortened lifespan of the vines"
V6	"Out-of-season rainfall could cause us problems. However, as Malta is quite dry, we can react to them, provided they are not too heavy or occur shortly before harvest time."
V7	"Labour: It is difficult to find people who want to do this kind of work."
V9	"The main problems are water shortages, mould growth due to dampness and labour shortages. Those employed in the sector no longer wish to work."
V10	"Periods of rain in spring in hot weather lead to botrytis."
V13	"The quality of the irrigation water (saline groundwater) is poor due to higher extraction volumes and lower rainfall. This also affects the salinity of the soil."

Challenges were reported across all growth stages, but were particularly pronounced during flowering, fruit set and véraison (Table 5).

Table 5. Problems across vine growth stages among winemakers interviewed (n = 13). Note: colour gradient represents magnitude (light = low, dark = high).

	Very Low n **(%)**	**Low** n **(%)**	**Medium** n **(%)**	**High** n **(%)**	**Very High** n **(%)**	**Σ**
Pruning	4 (30.8%)	2 (15.4%)	7 (53.8%)	0 (0.0%)	0 (0.0%)	n = 13
Budburst	4 (30.8%)	2 (15.4%)	6 (46.2%)	1 (7.7%)	0 (0.0%)	n = 13
Blossom	2 (15.4%)	3 (23.1%)	5 (38.5%)	3 (23.1%)	0 (0.0%)	n = 13
Fruit set	1 (7.7%)	4 (30.8%)	5 (38.5%)	2 (15.4%)	1 (7.7%)	n = 13
Véraison (colour change)	1 (7.7%)	3 (23.1%)	5 (38.5%)	4 (30.8%)	0 (0.0%)	n = 13
Harvest	1 (7.7%)	4 (30.8%)	6 (46.2%)	1 (7.7%)	1 (7.7%)	n = 13
Winter dor-mancy	2 (15.4%)	3 (23.1%)	2 (15.4%)	5 (38.5%)	1 (7.7%)	n = 13

Irrigation was the predominant measure to mitigate climate-related damage (twelve respondents), followed by mechanisation (six respondents) and varietal diversity (five respondents). Shading (two respondents), evaporation-limiting measures, herbicide use and sun protection (each one respondent) were reported less frequently.

3.4. Awareness and Perceptions of Viti-PV

Nearly 70% (9 out of 13) of respondents were unfamiliar with the Viti-PV concept. For those aware of it, the main sources of information were colleagues and online platforms (four responses each), while trade journals (three responses) and conferences or trade fairs (one response) were of lesser importance. Perceptions of Viti-PV potential were mixed across 13 responses: while six respondents rated it low or very low, four considered it moderate and three high to very high.

Detailed evaluations of Viti-PV characteristics showed a positive outlook on climate protection, reduced water demand and additional income through electricity sales, but significant concerns regarding high initial costs, landscape impacts and long-term effects on soil and plants (Table 6). Open comments further stressed financial constraints, bureaucratic hurdles and demographic challenges in the sector (Table 7).

Table 6. Evaluation of Viti-PV impacts and attributes among viticulturists interviewed (n = 13). Note: 13 participants; some questions were skipped, so response counts vary; colour gradient represents magnitude (light = low, dark = high).

		Very Negative n **(%)**	**Rather Negative** n **(%)**	**Neutral** n **(%)**	**Rather Positive** n **(%)**	**Very Positive** n **(%)**	**Σ**
1	Protection from extreme weather conditions	0 (0.0%)	0 (0.0%)	4 (30.8%)	7 (53.8%)	2 (15.4%)	n = 13
2	Reduced ground and air temperatures	0 (0.0%)	1 (7.7%)	4 (30.8%)	6 (46.2%)	2 (15.4%)	n = 13

Table 6. *Cont.*

		Very Negative *n* (%)	Rather Negative *n* (%)	Neutral *n* (%)	Rather Positive *n* (%)	Very Positive *n* (%)	Σ
3	Complex installation and operation of the systems	3 (23.1%)	6 (46.2%)	2 (15.4%)	1 (7.7%)	1 (7.7%)	*n* = 13
4	Adaptation of cultivation methods required	1 (7.7%)	4 (30.8%)	6 (46.2%)	2 (15.4%)	0 (0.0%)	*n* = 13
5	Changes in the growth of the vines	0 (0.0%)	3 (25.0%)	4 (33.3%)	4 (33.3%)	1 (8.3%)	*n* = 12
6	Reduced water requirement due to lower evaporation	1 (9.1%)	0 (0.0%)	1 (9.1%)	7 (63.6%)	2 (18.2%)	*n* = 11
7	Changes in the landscape	5 (41.7%)	5 (41.7%)	1 (8.3%)	0 (0.0%)	1 (8.3%)	*n* = 12
8	High initial investments	9 (69.2%)	1 (7.7%)	1 (7.7%)	1 (7.7%)	1 (7.7%)	*n* = 13
9	Additional source of income through electricity feed-in	0 (0.0%)	2 (16.7%)	2 (16.7%)	2 (16.7%)	6 (50.0%)	*n* = 12
10	Improved grape quality	1 (8.3%)	3 (25.0%)	3 (25.0%)	3 (25.0%)	2 (16.7%)	*n* = 12
11	Ongoing costs	2 (16.7%)	6 (50.0%)	3 (25.0%)	1 (8.3%)	0 (0.0%)	*n* = 12
12	Uncertainty about long-term effects on soil and plants	0 (0.0%)	8 (61.5%)	2 (15.4%)	2 (15.4%)	1 (7.7%)	*n* = 13
13	Changes in biodiversity due to altered microhabitats	1 (8.3%)	6 (50.0%)	4 (33.3%)	1 (8.3%)	0 (0.0%)	*n* = 12
14	Adaptation to existing infrastructure required	4 (33.3%)	4 (33.3%)	3 (25.0%)	1 (8.3%)	0 (0.0%)	*n* = 12
15	Increased risk of erosion	0 (0.0%)	2 (16.7%)	9 (75.0%)	1 (8.3%)	0 (0.0%)	*n* = 12
16	Reduced CO_2 footprint and contribution to sustainability	1 (8.3%)	0 (0.0%)	1 (8.3%)	5 (41.7%)	5 (41.7%)	*n* = 12
17	Need for technical expertise and training	2 (16.7%)	5 (41.7%)	4 (33.3%)	1 (8.3%)	0 (0.0%)	*n* = 12
18	Concerns about network integration and network infrastructure	2 (16.7%)	6 (50.0%)	3 (25.0%)	1 (8.3%)	0 (0.0%)	*n* = 12

Table 6. *Cont.*

		Very Negative n (%)	Rather Negative n (%)	Neutral n (%)	Rather Positive n (%)	Very Positive n (%)	Σ
19	Cost savings through self-generated electricity	0 (0.0%)	2 (16.7%)	2 (16.7%)	5 (41.7%)	3 (25.0%)	n = 12
20	Potential use of rainwater for irrigation	0 (0.0%)	4 (33.3%)	4 (33.3%)	2 (16.7%)	2 (16.7%)	n = 12
21	Harvesting at more comfortable temperatures	1 (8.3%)	0 (0.0%)	2 (16.7%)	3 (25.0%)	6 (50.0%)	n = 12
22	Uncertainties regarding the legal framework	5 (38.5%)	1 (7.7%)	3 (23.1%)	2 (15.4%)	2 (15.4%)	n = 13

Table 7. Additional factors shaping Viti-PV perceptions among viticulturists interviewed.

Abbreviation Viticulturist	Additional Factors
V3	"The value of land per square metre can be significantly increased compared to the sale of recreational or arable land by combining income from viticulture and electricity generation. This dual source of income provides farmers with a strong financial incentive to keep and manage their land rather than selling it for recreational purposes, as it ensures a solid and sustainable return on investment."
V5	"Government bureaucracy"
V6	"We need high levels of government investment for this."
V7	"Malta is small. Farmland is limited. Young farmers do not want to cultivate the land. Photovoltaics would be an excuse . . . to pretend to cultivate land, but in reality, it would be abandoned in favour of electricity generation."
V9	"Without sufficient funding, many farmers will not invest in something like this. In Malta and Gozo we don't have huge plots of land. We carry boxes with our hands as the fields are too small to use machinery. . . We don't even have electricity running through the fields. It's a great idea for farmers starting out with new technologies and financially supporting young farmers. Most of the winegrowers are now old and don't want to replant their vines."
V12	"Getting approval would be very difficult in Malta."

Financial support strongly influenced adoption. Under favourable financing models, 54% of respondents were positive, 15% were neutral and 31% expressed low or no willingness to adopt Viti-PV. Among support measures, viticulturists rated financial assistance (twelve respondents) and research/pilot projects (ten respondents) as most critical, followed by technical advice (seven respondents) and training/workshops (six respondents), while simplified approval procedures were least important (one respondents).

3.5. Interview Results

Sixteen expert interviews (five guidance-based and eleven unstructured) complemented the survey data. These interviews are separate from the questionnaire with additional experts from different sectors. Participants included viticulturists (nine participants), representatives of planning authorities (one participant), the agriculture directorate (one participant), energy providers (one participant), solar companies (two participants) and academia (two participants).

Content analysis revealed eight overarching categories: viticulture and vine quality, technical aspects, political and regulatory frameworks, climate and environmental conditions, economic considerations, social acceptance, stakeholder collaboration and future prospects (Figure 1).

- Viticulture and **grape quality:** Interviewees noted Viti-PV's potential benefits for white grape varieties, protection against sunburn and reduced water stress, but also expressed concerns about increased management complexity.
- **Technical aspects:** Issues such as module orientation, maintenance, dust accumulation and grid integration were emphasised.
- **Regulatory context:** Current policies do not permit Viti-PV in vineyards, highlighting the need for adapted frameworks.
- **Economic considerations:** High upfront costs and grid connection expenses were identified as major barriers, though leasing and investor-financed models could provide alternatives.
- **Social acceptance:** Visual impacts and fears of land speculation were considered sensitive issues.
- **Stakeholder collaboration:** Successful adoption requires coordinated efforts among farmers, government bodies, utilities and the tourism sector.
- **Future perspectives:** Pilot projects were widely seen as essential to test feasibility and inform both policy and practice.
- **Climate and Environmental conditions:** Irregular rainfall, drought and heat waves threaten vine cultivation. Dust generation and soil depth need to be considered for the installation and maintenance of the system.

4. Discussion

The study demonstrates that Viti-PV systems in Maltese vineyards present both technical opportunities and social challenges, reflecting a broader interplay between enabling factors and barriers across feasibility dimensions.

From a technical perspective, findings from comparable Mediterranean agrivoltaic studies suggest that Viti-PV installations have the potential to mitigate climate-related stresses, particularly heat and water scarcity, through shading effects that may reduce evapotranspiration—however, this has not been directly measured in the Maltese context. The exceptional yield increase reported under Viti-PV in Puglia [5] likely reflects the severity of baseline water stress in that context. While Maltese conditions are similarly arid and all of the surveyed winegrowers reported climate-related problems, local factors such as water availability and soil salinity may moderate comparable yield benefits. The dual function of combining energy generation with agronomic benefits suggests that Viti-PV can enhance vineyard resilience.

However, several technical barriers remain insufficiently explored. Factors such as grid integration constraints specific to Malta's island network, structural wind load requirements, potential corrosion risks associated with the maritime environment and the need for an adjustment of vineyard management practices represent critical areas for future investigation before large-scale deployment can be considered. Technological feasibility alone is therefore insufficient. Successful deployment requires adaptation to site-specific agronomic contexts.

It should be noted that this study focuses on socio-technical and perceptual dimensions of Viti-PV feasibility and does not address detailed engineering aspects.

From a social perspective, stakeholder perceptions play a decisive role in the adoption of Viti-PV. While the Spanish study by Arias-Navarro et al. [8,9] found broadly positive landscape perceptions among wine tourists, Maltese winegrowers expressed markedly stronger concerns. This divergence likely reflects both the different respondent groups—tourists versus producers—and Malta's particular sensitivity regarding its limited green landscape. Potential impacts on landscape aesthetics represent a major barrier. A potential enabling factor lies in the growing awareness of climate impacts and openness to adaptive solutions. This highlights the importance of context-specific acceptance and stakeholder group differences.

The analysis also highlights important economic and regulatory dimensions, where barriers currently outweigh enabling conditions. Enabling factors include emerging funding opportunities, such as support through the REPowerEU component of Malta's NRRP, and the potential adaptation of existing greenhouse PV regulatory frameworks. At the same time, major barriers persist, including high upfront investment and maintenance costs, the absence of clear policies and regulatory uncertainty. These constraints are further reinforced by structural characteristics of the sector, such as small-scale vineyard operations, land fragmentation and an aging workforce, which limit both willingness and capacity to invest in long-term innovations.

Across all dimensions, pilot projects emerge as a critical enabling factor, providing an opportunity to evaluate technical performance, economic viability and social acceptance under real conditions. Such projects could help reduce uncertainty, build stakeholder confidence and inform regulatory development.

Taken together, these findings suggest that socio-technical alignment—rather than technical readiness alone—represents the critical determinant of Viti-PV adoption in the Maltese context.

5. Conclusions

This study explored the technical and social factors influencing the adoption of Viti-PV systems in Maltese vineyards using a mixed-methods approach. The findings reveal a combination of barriers and opportunities that shape the feasibility and acceptance of this emerging technology.

Key barriers include regulatory constraints that currently prevent Viti-PV deployment in vineyards, high initial investment costs and concerns over visual impacts on the landscape. Conversely, Viti-PV offers tangible benefits for climate adaptation, including shading, microclimate modification and reduced irrigation needs, while enabling synergies between renewable energy generation and viticulture. Despite limited familiarity with Viti-PV, the majority of stakeholders expressed willingness to consider adoption if appropriate financing models are available.

A critical next step is the establishment of pilot projects, which would allow assessment of technical performance, economic viability and social acceptance under real-world conditions. Pilot initiatives could also guide regulatory adjustments, refine financing approaches and signal political support.

Overall, Viti-PV's potential is best realised through an integrated, site-specific and participatory approach, in which technical feasibility, social acceptance and policy alignment are addressed jointly. While the findings of this exploratory study are indicative rather than fully generalisable, they underscore that the primary challenge lies not in identifying technical solutions, but in navigating the societal, institutional and economic dimensions that determine adoption. Future research with larger samples and broader stakeholder engagement will be essential to refine these insights and inform scalable implementation strategies for Viti-PV in Maltese viticulture.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en19092213/s1, Questionnaire in S1: English; Questionnaire in S2: Maltese; Table S1: Codes and Categories.

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Institutional Review Board Statement: All procedures involving human participants, including the questionnaire survey and the expert interviews, were reviewed and approved by the Ethics Committee of Konstanz University of Applied Sciences (HTWG Konstanz). All participants were informed about the purpose of the study, data handling procedures, and their right to withdraw participation at any time. Informed consent was obtained from all participants prior to data collection. All methods were carried out in accordance with relevant guidelines and regulations, including the General Data Protection Regulation (GDPR). The study was conducted in full adherence to the principles of the Declaration of Helsinki.

Informed Consent Statement: All participants gave informed consent to participate in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author, the data are not publicly available to maintain privacy.

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Abbreviations

The following abbreviations are used in this manuscript:

LER	Land Equivalent Ratio
NRRP	National Recovery and Resilience Plan
PV	Photovoltaic
PDO	Protected Designation of Origin
QR	Quick response
Viti-PV	Viticultural photovoltaics

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