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Justice-driven agrivoltaics: Facilitating agrivoltaics embedded in energy justice

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ABSTRACT

Agrivoltaics comprises solar energy generation and agricultural activities co-located to create multi-purpose agricultural solar energy systems. In 2021, the global agrivoltaics sector was valued at USD $3.6 billion and is projected to grow to USD $9.3 billion by 2031. Agrivoltaics projects have successfully attracted increasing investment and research demonstrating the technical, economic, and scientific rationale to advance agrivoltaics as a crucial technology to achieve net zero emissions goals. The legal framework enabling agrivoltaics development is at varying stages of maturity across different jurisdictions. This study provides the first socio-legal study of agrivoltaics development applying an energy justice framework. It comparatively analyses the mature agrivoltaics sectors, laws, and policies in Massachusetts (United States of America) and Japan in a functional comparative analysis with New South Wales (Australia) applying the three principal pillars of energy justice; recognition, procedural, and distributive justice. This study demonstrates how energy justice can generate a framework for regulatory reform. Such reform can facilitate the expansion of agrivoltaics and unlock the full potential of co-locating of solar energy and agriculture.

1. Introduction

The uptake of solar energy globally has advanced rapidly driven by increased economic feasibility, technical advancements, social acceptance, and enabling policy environments. The decrease in unit costs of solar photovoltaic (PV) technology by 62% since 2015 [1] has increased solar energy penetration in global energy systems. One megawatt (MW) of utility-scale solar PV requires a variable average of 2 hectares (ha) of land [2]. Consequently, "making smart land-use decisions" [3] is fundamental to the ongoing success of utility-scale solar PV. Agricultural land provides ideal utility-scale solar PV project siting conditions comprising high solar energy generation potential situated near electricity transmission infrastructure. Concerns over agricultural land conversion for solar PV projects and the need to address land conflicts affirm the need for global acceleration of agrivoltaics. Agrivoltaics act as a synergetic catalyst combining land uses and benefits for both solar energy generation and agricultural outputs.

Agrivoltaics utilise land for both solar energy generation and agricultural production through co-location. Co-location minimises land use competition and provides increased economic and potential ecological benefits to regenerate and promulgate sustainable agricultural land stewardship and activities. Agrivoltaics development is highly variable in its maturity for many countries and states. Despite this, agrivoltaics is forecasted to be a rapidly growing sector resulting in a USD $9.3 billion market globally by 2031. Coupling solar energy and agricultural activities has led to increasing agrivoltaics research to mitigate climate change and increase technological adoption.

Technological innovations in agrivoltaics as a dual land use offer a myriad of synergistic benefits [4] including, but not limited to, creating an additional income stream for agricultural landholders; avoiding land

Abbreviations: AIA, Agricultural Impact Assessment; ASTGU, Agricultural Solar Tariff Generation Units; FiT, feed-in-tariff; GW, gigawatts; kWh, kilowatt-hour; NSW, New South Wales; PV, Solar photovoltaics; SMART, Solar Massachusetts Renewable Target; USA, United States of America; USD, United States Dollar.

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conversion; decarbonisation of agricultural operations; reducing drought and flooding stress; and creating higher solar output by harnessing radiative cooling [5]. These advantages render agrivoltaics as an enabler to achieving several Sustainable Development Goals including Goal 7 Affordable and Clean Energy, Goal 13 Climate Action, and Goal 15 Life on Land [6]. However, a robust regulatory structure is the fundamental cornerstone to harness the uptake and benefits of agrivoltaics across agricultural communities and regions.

In New South Wales (NSW), Australia, the Electricity Infrastructure Investment Act 2020 (NSW) enshrines the target of creating 12 GW (GW) of new renewable energy generation and 2 GW of long-duration storage by 2030. It seeks to reduce investment risks and foster “local community support for investment in new generation, storage, network, and related infrastructure” (s 3). The objectives of mitigating commercial risks for new renewable energy generation while increasing community support and benefits can be activated by agrivoltaics regulation drawing on energy justice principles as explored within this study.

Agrivoltaics regulation embedded in energy justice paired with political support can address potentially polarising views of renewable energy on agricultural land while creating multi-sectoral economic opportunities and community acceptance. For example, rural community economic opportunities are a well-documented outcome of agrivoltaics policies and regulation. These economic opportunities range from additional agricultural service payments for landholders operating agrivoltaics farms to broader rural community ownership and agrivoltaics cooperatives [7]. Agrivoltaics projects may attract significantly increased development and operational costs compared to ground-mounted solar PV projects. The custom PV technology and various siting plans to accommodate and couple agricultural activities with solar PV infrastructure require significant planning and capital. For example, Mamun et al. conduct a review of agrivoltaics research including studies concluding a 30% increase in CAPEX costs for agrivoltaics systems [8]. Regulatory frameworks supporting agrivoltaics enabled by energy justice are instrumental to reduce costs by providing sectoral incentivisation while achieving renewable energy goals to rapidly develop utility-scale renewable energy and foster community benefits. This study hypothesises that agrivoltaics regulation facilitated by energy justice in a new justice-driven agrivoltaics framework will activate the full range of social, economic, environmental, and community benefits to realise the enhanced capabilities of agrivoltaics.

This study establishes the first application of energy justice to agrivoltaics in designing a framework for regulatory reform in NSW. NSW hosts increasing large-scale solar energy project developments in Australia. Agrivoltaics projects represent cross-sectoral opportunities to increase solar energy development, reduce carbon emissions, and achieve enhanced agricultural outputs and benefits. Specific agrivoltaics development assessment processes and frameworks embedded in energy justice hold the potential to activate decarbonisation, increase food security, safeguard agricultural land, and recognise agricultural landholder stewardship. For example, agrivoltaics can increase land efficiency by up to 70% by combining energy and crop output while creating social benefits through new jobs, community income, and tax revenue [9]. Finally, in recognising the importance of agricultural activities co-located with solar energy generation the interests of both renewable energy and agricultural sectors are acknowledged and maintained. The triumvirate of energy justice tenets is applied to the NSW agrivoltaics policy environment enhanced by a socio-legal functional comparative analysis with two mature agrivoltaics jurisdictions, Massachusetts (USA), and Japan. This study explores the opportunity to transform solar energy developments into agrivoltaics projects by offering a novel justice-driven agrivoltaics framework as a platform for regulatory reform.

This study is structured in six parts. Following the introduction, Section 2.0 provides a literature review, theoretical analysis of energy justice and outlines the comparative functional methodology. Section 3.0 conceptualises and probes agrivoltaics technical opportunities and barriers and proposes a justice-driven agrivoltaics framework applying energy justice principles to stimulate the full potential of agrivoltaics. Section 4.0 provides a brief sectoral analysis of agrivoltaics in NSW, Massachusetts, and Japan. Section 5.0 outlines the study results and discussion assessing three energy justice elements (distributive, procedural, and recognition justice) and performs a comparative functional analysis of agrivoltaics regulation in NSW, Massachusetts, and Japan. Finally, Section 6.0 concludes by outlining recommendations for reform and creates a roadmap for future agrivoltaics research.

2. Literature review and theory: mapping energy justice

Energy justice draws attention to the embeddedness, equitability, benefits, and costs of energy technologies [10]. Energy justice theory is underpinned by the examination of burdens, benefits, risks, costs, and the distribution of energy providing a guiding framework to create and recognise processes and functions governing diverse sectors and societal actors. Energy justice studies span underlying principles, social theory, technical analysis, and interaction with key stakeholders. For example, Heffron and De Fontenelle examine the relationship between the energy sector and society embedded within the “new social contract” to ensure citizens’ rights and well-being [11]. Sovacool et al. examine solar energy uptake through a “whole of systems lens” across the lifespan of technologies spanning demographic inequity (between groups); spatial inequity (across geographic scales); interspecies inequality (between humans and non-humans); and temporal inequality (across future generations) [12]. Existing energy justice research examines energy infrastructure [13], renewable energy projects, and hydrogen [14]. These studies primarily applying procedural and recognition justice to dissect common policy and legal challenges of energy transition processes within social groups [15].

Energy justice comprises both core principles and critical elements collectively influencing factors to achieve just energy development and systems. Seven broadly agreed international principles comprise energy justice; availability, affordability, due process, transparency and accountability, sustainability, intra and intergenerational equity, and responsibility [16]. The practical application of energy justice in laws and policies comprises five core elements: distributive, procedural, recognition, cosmopolitanism, and restorative justice [17]. Each element highlights different aspects of the energy justice concept, the distribution of benefits, consideration of rights, legal process, societal benefits, and enforcement of laws.

Despite the application of energy justice principles to utility-scale PV projects [18], analysis of agrivoltaics combined with energy justice theory remains notably absent in existing research. As such, the novelty of this study is emphasised in focusing on comparative agrivoltaics policies and regulations across emerging and mature agrivoltaics jurisdictions revealing how energy justice principles can create more sustainable energy planning and project outcomes [19]. Heffron et al. conclude distributive, procedural, and recognition justice as the most relevant energy justice applications to solar energy technologies. These three energy justice tenets relate to the distribution of benefits, the legal process, and rights for different groups and form the basis of this socio-legal comparative study charting how regulation underpinned by energy justice can stimulate agrivoltaics and its benefits.

Distributive justice can be defined as the equitable benefit and burden allocation in energy development. The distribution of benefits in innovative energy technologies, such as agrivoltaics, has the potential to address potentially novel justice impacts and eradicate existing inequities. Agrivoltaics can recognise pre-existing “actors, processes, and policies” [20] to include locational aspects unique to agricultural land; reduce social costs by ensuring farmers benefit from existing and new agricultural activities alongside solar energy generation; and recognise key agricultural landholders and communities to craft agrivoltaics project co-design. Energy justice can be effectively harnessed as a normative and pragmatic decision-making tool [21].

Recent energy justice research specifically probes the need for procedural justice to ensure impartial and inclusive decision-making in new energy systems. Energy technologies, particularly novel technologies, are an opportunity for social sustainability as suggested by Fortier et al. [22]. Social sustainability frameworks employ social life cycle assessments that evaluate and measure social impacts and benefits through the energy system life cycle. Adopting social sustainability frameworks can lead to pathways for equitable deep decarbonisation. Spurlock et al. posit equitable deep decarbonisation can reformulate development to collaborate "maximizing the multiplicative benefits potential of mitigation measures" [23]. Equitable deep decarbonisation is relevant to co-design and creates co-benefits for landholders and communities hosting agrivoltaics including generating increased autonomy in the energy transition, improved employment opportunities, and wealth building.

Recognition justice evaluates the legitimacy and sustainability of energy technologies from a technological and territorial perspective [24]. Bouzarovski argues spatially-sensitive and energy-justice driven policies must develop tools to address "non-recognition" [25], first conceptualised by Fraser [26], where certain groups are not identified or ignored in energy-related decisions. Incorporating continued agricultural activities co-designed with agricultural landholders alongside solar PV generation removes risks of "non-recognition" of the agricultural sector ensuring sustainable structural dynamics and advancing recognition justice.

In sum, the three energy justice tenets of principal interest to agrivoltaics regulation and policy must address who is involved in and benefits from agrivoltaics design and operation (distributive justice), what legal processes and mechanisms should be considered to encourage agrivoltaics by energy justice (procedural justice), and how recognition of existing and future agricultural activities should occur (recognition justice) to create acceptability from a technological and territorial perspective [27].

2.1. *Methodology: functional comparative analysis*

Functional comparative analyses enable a critical juxtaposition of similar legal regimes to assess key similarities and differences in approaches to legal challenges [28]. Existing agrivoltaics studies often apply methodologies inclusive of scientific, economic, and engineering structural data evaluation [29]. This study probes the unexplored functional socio-legal aspects of agrivoltaics development. Key legal functions support the development of agrivoltaics. Firstly, site planning, technical requirements, economic analysis, and technical design must be completed. Secondly, impact and other assessments are conducted to inform authorisation. Finally, incentivisation of agrivoltaics development provides the basis for commercial growth.

The quantification and analysis of legal and policy settings to stimulate justice-driven agrivoltaics projects remains limited. This study aims to move beyond the technical and economic phases of agrivoltaics analysis to examine the three core functions of agrivoltaics development, authorisation, and incentivisation applying the principles of energy justice. Energy justice harnessing a functional comparative methodology illustrates the comparable approaches in different regulatory environments, namely Massachusetts and Japan, that can be applied to the evolving agrivoltaics sector in NSW. Functionalism creates evaluative legal criteria where legal problems are compared based on the same factual challenge [30].

Table 1 outlines the comparable agrivoltaics development, authorisation, and incentivisation functions in NSW, Massachusetts, and Japan. It also reviews the relevant regulation and policy analysed within this study as a precursor to creating principles for reform in NSW incorporating energy justice.

The three functions of agrivoltaics planning development, authorisation, and incentivisation in Table 1 will be comparatively analysed across three jurisdictions (NSW, Massachusetts, and Japan) by examining key policies and regulations throughout this study.

Table 1
Agrivoltaics regulation and policy in NSW, Massachusetts, and Japan.

Jurisdiction	Function	Policy/Regulation
NSW, Australia	Agrivoltaics Development, Authorisation, and Incentivisation	• Environmental Planning and Assessment Act 1979 (NSW) • Environmental Planning and Assessment Regulation 2021 (NSW) • Large-Scale Solar Energy Guideline 2022 (NSW) • Planning Secretary's Environmental Assessment Requirements Large-Scale Solar Energy
Massachusetts, USA	Agrivoltaics Development, Authorisation, and Incentivisation	• An Act Relative to Solar Energy (MA) Chapter 75 (2016) • Massachusetts Department of Energy Resources. 225 CMR 20.00: Solar Massachusetts Renewable Target (SMART) Program • Massachusetts 2022 Clean Energy Act
Japan	Agrivoltaics Planning Development, Authorisation, and Incentivisation	• 6th Basic Plan for Energy • Basic Plan for Food, Agriculture, and Rural Areas • Design and construction guidelines for farming solar power generation systems

Source: Compiled by authors.

This research is limited to a doctrinal socio-legal comparative analysis. Desktop socio-legal research is limited and may lead to erroneous or untested results without practical application. It does not address technical or economic aspects of agrivoltaics, and future research must test the underlying assumptions of the validity and rigor of energy justice to stimulate agrivoltaics. Although the results of this study are confined to legal and policy spheres without empirical evidence, the analysis is both timely and novel. Most research examining agrivoltaics over the past decade has focused on the technical, engineering, and economic basis of agrivoltaics. This study seeks to fill this evident analytical gap in agrivoltaics research and respond to the need for increased practical energy justice research [31]. Applying energy justice to agrivoltaics from a socio-legal perspective provides an important basis for legal reform to stimulate commercial development and ongoing incentivisation [32]. This research importantly directly addresses the emerging regulatory challenges of agrivoltaics including planning, development assessments, incentivisation, and community benefits.

3. Conceptualising agrivoltaics through energy justice

Agrivoltaics projects provide an alternative to mono-siting and singular solar energy development land uses by encouraging agricultural activities. Two key forms of large-scale agrivoltaics exist broadly. First, crop cultivation and horticultural agrivoltaics situating solar energy projects on cropping land, and second, grazing or ranching agrivoltaics situating solar energy projects combined with livestock activities. Agrivoltaics is a technological facilitator of the energy transition while minimising negative social and technical externalities at a minimum of three levels. First, enabling the coexistence of food and energy production to diminish potential land use conflicts; second, agricultural landholder income diversification and increased revenue stability; and third, producing the opportunity for profit-sharing models and co-benefits for agricultural communities.

Technical, decarbonisation, and economic benefits of agrivoltaics are well documented. For example, Cuppari et al. examine crop yield productivity for agrivoltaics creating an increase in annual net revenues of between 300 and 500% in Oregon and North Carolina, USA [33]. Dinesh et al. found economic value from farms deploying agrivoltaics systems compared with traditional agriculture increased by 30% in Kansas City, USA [34]. Agrivoltaics advantages extend to sociotechnical paradigms. Agricultural landholders managing agricultural activities and land uses within agrivoltaics projects create the need to consider the social benefits and burdens of agrivoltaics to ensure agrivoltaics co-location as a dual "spatial dimension to energy justice" [35]. Environmental, social, and governance goals increasingly require renewable energy projects to be reflexive of community needs and benefits. Such a transformative shift may encompass agrivoltaics as developments move beyond specific environment and planning conditions to consider broader co-benefits to de-risk investment and create "legal, social, and economic legitimacy" [36].

Regulating novel energy technologies to create conditions for successful sector scalability is crucial to cementing technical feasibility, cost-effectiveness, and market certainty. In response, agrivoltaics has prompted new and emerging policy and legal discourses. For example, Japan holds an established regulatory regime that recognises the importance of "solar sharing" and enforces several technical parameters including acknowledging "agricultural production must be continued under the PV panels and about 80% of the per-unit production must be maintained in comparison to the level before agrivoltaic installation" [37] for farmland that is not classified urban farmland or devastated farmland. Similarly, Massachusetts requires several conditions be satisfied for a solar energy development to attract an Agricultural Solar Tariff Generation Units (ASTGUs) defined as a solar energy project "located on Land in Agricultural Use or Important Agricultural Farmland that allows the continued use of the land for agriculture". The ASTGU programme created in 2018 represents the first specific agrivoltaics tariff scheme in the USA. ASTGUs incentivise the uptake of agrivoltaics by stipulating several guidelines including "(demonstrating) how each square foot of land will be used for agriculture production" [38].

Table 2 outlines the regulatory approaches and agrivoltaics definitions in Japan and Massachusetts.

The agrivoltaics definitions outlined in Table 2 demonstrate detailed guidance on agricultural land production and yields to receive agrivoltaics status and attract tariff incentivisation in both Massachusetts and Japan. NSW currently does not hold a tender, tariff, or any economic incentivisation system for agrivoltaics nor does it define what would constitute an agrivoltaics project. NSW recently amended its Large-Scale Solar Energy Guidelines in 2022 to recommend, rather than require, solar energy proponents consider co-locating solar energy with agricultural land. Co-location is defined as a mitigation strategy to continue "with existing agricultural practices and investigate the feasibility of agrivoltaics where it would result in a meaningful benefit". This delineation falls short of overtly defining agrivoltaics [39]. Technical agrivoltaics guidelines also remain notably absent in NSW despite the recently revised Large Scale Solar Energy Guidelines.

Without a harmonized definition for agrivoltaics systems, there is a real possibility of *ad hoc* policy and legal approaches creating barriers to industry entry across various jurisdictions and planning controls. As emphasised by Vollprecht et al., "a homogenized definition of agrivoltaics … would promote the inclusion of agrivoltaics in the legal framework and thus would be beneficial in the distribution of this technology and the collaboration with neighbouring countries" [40]. States must develop regulatory frameworks to mitigate and manage risks while accommodating evolving technologies, such as agrivoltaics, crucial to reaching net zero by 2050 goals. Regulatory responses by states should be reflective of technological advancements, energy policy priorities, and societal responses to risk.

Agrivoltaics could trigger regulatory enhancement in NSW by incorporating energy justice principles into project development, authorisation, and incentivisation. To move beyond traditional technocratic regulation, key regulatory principles must be applied to agrivoltaics against the backdrop of energy justice. The conditions, rules, and goals of agrivoltaics are required to create an ongoing level of

Table 2
Agrivoltaics regulation compared in Massachusetts and Japan.

Jurisdiction	Regulation/ Guideline	Definition	Guideline
Massachusetts	225 CMR 20.00: Solar Massachusetts Renewable Target (SMART) Program Guideline Regarding the Definition of Agricultural Solar Tariff Generation Units	S 20.02: "A Solar Tariff Generation Unit located on Land in Agricultural Use or Important Agricultural Farmland that allows the continued use of the land for agriculture".	"a. demonstrate how the proposed dual-use design will provide equal or greater total agricultural yields than if both the agricultural crop and solar array were grown and installed separately, utilising the same amount of total land area for the comparison; b. demonstrate how each square foot of land will be used for agriculture production, and c. demonstrate how the design will be able to accommodate a variety of potential agricultural products throughout the SMART tariff term".
Japan	Act on Promoting Generation of Electricity from Renewable Energy Sources Harmonized with Sound Development of Agriculture, Forestry, and Fisheries Act No. 81 of 2013 Notification No. 2887 of the Director-General of the Rural Development Bureau, Ministry of Agriculture, Forestry and Fisheries	Guideline 14.3 "Farming-type solar power generation systems give priority to agricultural work, so maintenance should be carried out in such a way that inspections are carried out when the impact on farmland is minimal, and the tools used for inspection, such as stepladders and scaffolding, do not affect the farmland. It is desirable to discuss inspection plans and methods with farmers in advance."	(i) "agricultural production must be continued under the PV panels (about 80% of the per-unit production must be maintained in comparison to the level prior to agrivoltaic installation); (ii) the height and spacing of the support poles must not obstruct the operation of agricultural machinery; (iii) the area of the support columns should be kept to a bare minimum; (iv) the agrivoltaic installation should not have an impact on the surrounding farmland; (v) the Agricultural Committee shall be informed of the annual harvest and crop type; (vi) renewal reviews are required every three years".

Source: Compiled by authors.

understanding and support [41]. Fig. 1 provides preliminary guiding principles to create a socio-legal framework embedding energy justice in NSW and creating a justice-driven agrivoltaics sector.

Fig. 1 does not outline a comprehensive and exhaustive survey of all principles to create agrivoltaics regulation embedded in energy justice. Rather, it presents the initial core principles and reflects initial recommendations to explore possible regulatory frameworks and functions and enable the benefits of agrivoltaics in more detailed future studies. The need for regulatory certainty, embodied in energy justice principles, is essential to supporting the development and incentivisation of the agrivoltaics industry in NSW. Section 4.0 examines and compares the different development stages of the agrivoltaics sector in NSW, Massachusetts, and Japan.

4. Agrivoltaics adoption in NSW, Massachusetts, and Japan

In NSW, significant policy efforts have been made to establish a pathway for the agricultural sector during a period of growth, change, and competing demands for land use [42]. Critiques of planning regulation for large-scale solar PV projects identify environmental, social, and economic co-benefits of co-locating solar energy and agricultural land. Guerin recommends the adoption of agrivoltaics to "reduce land deficits for food and fibre production" [43]. Similarly, the updated NSW Large-Scale Solar Energy Guidelines [44] and the Agricultural Commissioner Issues Paper [45] identify the benefits and potential for solar and agriculture co-location. The majority of agrivoltaics projects are sited on grazing properties in NSW with the opportunity for horticultural agrivoltaics at a commercial scale largely unexplored.

The spectrum of agrivoltaics installations or MW installation targets within the three comparative jurisdictions analysed in this study are outlined in Table 3. In 2020, NSW had a total of 10 agrivoltaics installations equipped with grazing capability [46]. In comparison, Japan holds a cumulative total of 3,474 agrivoltaics installations. While Massachusetts does not record its agrivoltaics projects overtly, it holds jurisdictional targets for agrivoltaics and extended its solar energy target to 3200 MW in 2022 with an overarching goal of 80 MW AC agrivoltaics capacity and 12 registered SMART projects with agricultural adders [47].

Massachusetts holds an established agrivoltaics sector stimulated by the SMART program and ASTGUs guidelines. ASTGUs directly incentivise the deployment of agrivoltaics systems through fiscal incentivisation [51]. The incentive operates as a feed-in tariff (FiT) to benefit utility companies harnessing agrivoltaics solar energy generation. The legal mechanics of ASTGU were formed under 225 CMR 20.00 [52] and function as a "declining block incentive program". This programme creates incentive rates for system owners to decline proportionately as more capacity blocks are allocated between utility companies (measured in MW output) are filled [53].

Table 3
Number of agrivoltaics Installations/MW targets for 2020 in NSW, Massachusetts, and Japan.

Jurisdiction	Agrivoltaics Installations/Agrivoltaics Installation MW Targets
NSW	10 installations [48]
Japan	3474 installations [49]
Massachusetts	80 MW AC; 12 SMART projects with agricultural adder [50]

Source: Compiled by authors.

The ongoing trajectory of the ASTGUs program in Massachusetts is clear with an overarching goal of reaching 80 MW AC capacity. Further legislative developments such as the Massachusetts Clean Energy Act [54], which in addition to incorporating a net zero emissions goal by 2050, prioritises the development of agrivoltaics projects in the state's energy and climate policy. Specifically, the Clean Energy Act provides clarity that an agrivoltaics project is treated as an agricultural use and therefore the land remains as agricultural land for property tax purposes. The Clean Energy Act provides the additional impetus for a new commission to identify obstacles to agrivoltaics projects and formulate strategies to address these challenges in Massachusetts.

In Japan, interest in agrivoltaics stems from a means of generating revenue in rural areas and decreasing abandoned farmlands [55]. To reach carbon neutrality by 2050 [56], the Japanese government has defined its policy to support the expansion of agrivoltaics as a source of solar energy generation. In this context, the Basic Plan for Food, Agriculture, and Rural Areas, Japan's agricultural policy guideline established in March 2020, states that "the introduction of renewable energies such as agrivoltaics will be promoted to improve rural incomes and promote circular economy within communities" [57]. The 6th Basic Plan for Energy, adopted under Prime Minister Kishida, provides the basis for actions designed to achieve 2050 carbon neutrality [58], and also declares that "the government will boost the installation of renewable energy and agrivoltaics in agriculture" [59].

The key support measure for agrivoltaics uptake in Japan is the adoption of a FiT. Established in 2012, the FiT obliged power utilities to

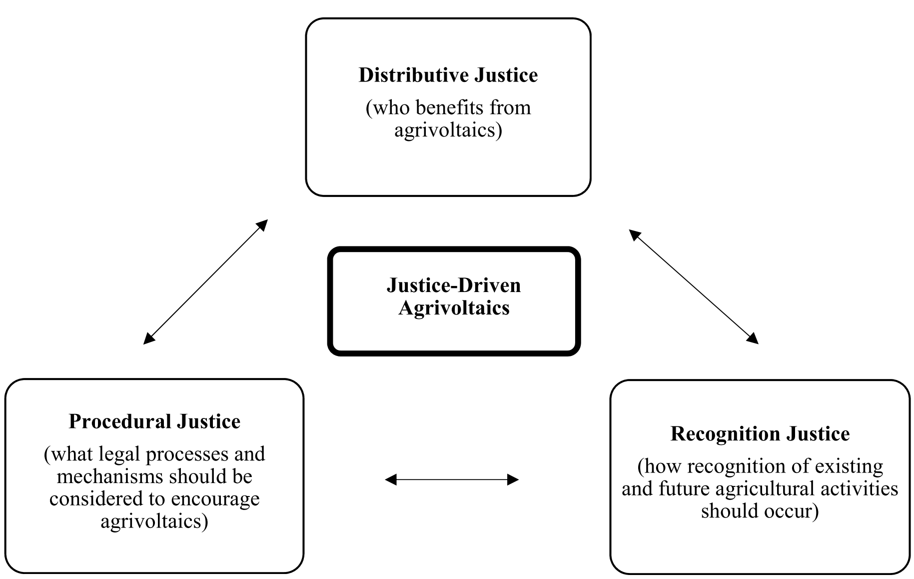

Fig. 1. Justice-driven agrivoltaics framework.
Source: Compiled by authors

buy electricity generated from renewable energy sources at a predetermined price for a set length of time [60]. Although the FiT has now been reduced, and energy supplied by small-scale commercial solar power generation (from 10 kW to 50 kW) is not purchased in principle, the full FiT is still applied to agrivoltaics between 10 kW and 50 kW to encourage uptake [61]. As a result of these initiatives, Japan had 3474 agrivoltaics facilities permitted (as of March 2021), covering 872.7 ha and are co-located with a variety of crops, including rice, wheat, tea, soy, blueberries, and kiwi [62]. 779 new agrivoltaics facilities were installed in FY2020 alone [63].

5. Results and discussion: applying energy justice and comparing agrivoltaics regulation and functions

The differing rates of agrivoltaics adoption and proliferation in NSW, Massachusetts, and Japan are reflective of regulatory environments. As demonstrated throughout this study, agrivoltaics increasingly requires definitions, clear functions, and robust planning regulation to incentivise agrivoltaics. Social assessment and acceptance of agrivoltaics are also crucial as renewable energy developments may be challenged by communities [64]. More mature renewable energy technologies such as solar and wind energy demonstrate how community acceptance across the energy life cycle can be created by harnessing energy justice to address legal and stakeholder concerns [65]. Sections 5.1–5.3 of this study analyses and compares the three tenets of energy justice applied to agrivoltaics development, authorisation, and incentivisation functions outlined in Table 1 applied to NSW, Massachusetts, and Japan to reveal opportunities for reform.

5.1. Distributive justice

Distributive justice frames the allocation of energy "goods and ills" [66] across society in both temporal and spatial elements probing when and how financial benefits and burdens of energy are distributed. Distributive justice applied to agrivoltaics may consist of community benefit sharing, diversification of community ownership, and equitable distribution of compensation. Distributive justice is inherently socio-spatial. To mitigate any potential burdens of agrivoltaics developments for rural communities' distributive justice is essential. For example, inadequate co-design, lack of co-benefits, and inadequate consultation may lead to project opposition by rural communities [67]. It is crucial to satisfy distributive justice principles by mapping any potential risks, impacts, and benefits ensuring the functions of agrivoltaics planning development, project design, assessment, and incentives extend beyond the host agricultural landholder.

Benefit sharing may create distributive justice by harnessing the function of incentivisation. Benefit sharing is highlighted by the NSW Large-Scale Solar Energy Guideline as assigning "(in) building community support by ensuring that the project delivers positive, tangible, and long term social and economic outcomes for the local community" [68]. Benefit sharing exists using Voluntary Planning Agreements [69] and Community Enhancement Funds, all of which are voluntary for agrivoltaics developers. In addition, at least three different levels of benefits co-designed with communities should be afforded to agrivoltaics communities to embed distributive benefits: (1) compensation for neighbouring agricultural properties; (2) local benefits for the hosting town; (3) regional benefits for the broader agricultural region hosting the projects [70].

Massachusetts is a useful case study for the successful implementation of local agrivoltaics policy and distributive justice. As described by Pascaris [71], the combination of federal and state energy financing mechanisms coupled with favourable state and local land use policies provide "the quintessential framework for agrivoltaics to prevail" [72]. The agrivoltaics policy framework in Massachusetts confirms this proposition, as it positions adaptive local settings within the federal policy architecture for solar development. A key insight reached by the social-political study undertaken by Pascaris et al. [73] is the need for local policymakers to be responsive to the critical social dimension of agrivoltaics developments. The study found that in the absence of supportive local policy, participants of the study expected agrivoltaics development to encounter challenges [74]. Conversely, where a development preserves local agricultural interests, there "may be an opportunity for agrivoltaics projects to become the prevailing norm of solar development in communities with conflicting land use interests" [75].

The state level control over land use creates differing regulations affecting agrivoltaics while providing opportunities for tailored policy responses to community needs [76]. Tailored policy responses are evident in Massachusetts which is currently the only state in the USA that has a dedicated and mature policy program designed specifically for agrivoltaics incentivisation under the SMART Program. The SMART Program commenced in November 2018 replacing the previous Solar Renewable Energy Certificate program to provide a long-term sustainable solar incentive program that promotes cost-effective solar development [77].

The Japanese government has encouraged the expansion of agrivoltaics installations by harnessing a generic FiT mechanism to incentivise agrivoltaics development. The Japanese FiT is a scheme in which the government guarantees the purchasing price of renewable energy generated electricity, rather than a specific payment dedicated to agrivoltaics, as is the case in Massachusetts. This charge is fixed regardless of the electric power supplier or electricity rate. The cost is calculated by multiplying the volume of electricity (kWh) used throughout the month by the levy rate per kWh. The Japanese FiT is a mechanism in which all consumers who use electricity share a portion of the cost of acquiring renewable energy. As a result, these expenses are shared by a broad range of entities. Between 2012 – and 2019, the Japanese Renewable Energy Levy increased. Initially equating to 0.22 yen per kWh, it increased to roughly 3 yen per kWh in 2019.

In both Massachusetts and Japan, distributive justice has focused on ensuring economic feasibility for agrivoltaics through FiT incentivisation. Massachusetts has created a specific agrivoltaics tariff and developed an accompanying Shading Analysis Tool providing agricultural landholders and developers with the ability to propose an agricultural production plan consistent with the broader shading profile. However, ensuring the burdens and benefits of agrivoltaics beyond tariffs to guarantee the distribution of benefits to agricultural landholders and communities is not well developed in either jurisdiction. In NSW, no specific definition, incentivisation, or specific FiT exists for agrivoltaics, thereby creating a clear opportunity for distributive justice and incentivisation functions for future agrivoltaics projects.

5.2. Procedural justice

Procedural justice embeds justice and fairness across all three functions in agrivoltaics legal development, assessment, and incentivisation. Procedural justice requires community participation and representation, transparency, and objectivity in decision making [78]. Previous studies examine the importance of procedural justice in developing renewable energy technologies such as solar and wind [79]. Like other large-scale renewable energy projects, agrivoltaics design must incorporate community interests to achieve procedural justice. This includes harnessing deep agricultural knowledge and expertise within communities to design projects and anticipate agricultural system change throughout the project lifespan [80]. For example, solar energy projects that are increasingly being co-designed in Australia with Aboriginal and Torres Strait Islander communities [81] and wind energy cooperatives owned by community members embody principles of procedural justice.

In NSW, the planning regulatory framework requires agrivoltaics projects to conduct a range of functional development assessments and authorisations [82]. Agrivoltaics as a dual land use also requires mapping and mitigating potential social impacts and designing agrivoltaics to ensure the mitigation of social impacts. By preserving agricultural land and requiring "respectful, inclusive and meaningful engagement" [83] with communities, opportunities are provided for procedural justice embodied within participatory decision making and co-design. Collaborative decision making can identify and predict social impacts and encourage mitigation and monitoring using citizen panels, deliberative forums, community reference groups, and other forms of consultation within the Social Impact Assessment Guidelines [84].

In addition to planning assessments within the Environmental Planning and Assessment Act 1979 (NSW), solar energy proponents in NSW must also complete an Agricultural Impact Assessment (AIAs) where projects are located on or adjacent to 'important agricultural land' or 'moderate capacity land' following soil assessment to verify the quality of the agricultural land. Highly productive agricultural land (Class 1–3 Biophysical Strategic Agricultural Land) will require a "consideration of co-location to support the continued productivity of the land" forming part of a detailed AIA. AIAs also offer the opportunity for community consultation alongside Environmental Impact Assessments and Social Impact Assessments with input from community members and agricultural landholders to co-design transparently. For example, agricultural landholders could provide specific guidance for the co-design [85] of developing agrivoltaics projects. While this practice is not mandated in agrivoltaics projects in NSW currently, Moore and Hackett propose using 'place-making' processes to provide a frame for substantiating the siting of agrivoltaics [86].

An emerging model of vertical policy alignment for agrivoltaics exists in the USA with legal frameworks underpinning the development of solar technologies at both a federal and state level. To optimise the deployment of solar energy at a federal level, several sectoral incentive schemes are underwritten by both federal legislation and programs enabled through the American Department of Energy and Office of Energy Efficiency & Renewable Energy. At a state level, some states are innovating a framework that empowers the co-benefits of agriculture and small-scale solar installations [87].

In Massachusetts, the development of transparent land use, siting, and project guidelines mandate conditions for agrivoltaics to receive ASTGUs including the existing use and development and site characteristics. For example, pursuant to 225 CMR 20.05 (5) (e), three categories of land use planning exist, including Category 1 Agricultural, informing legal conditions to constitute an ASTGU project. Providing transparency and clear guidelines for both solar energy developers and rural communities is key to achieving procedural justice. In contrast to NSW, Massachusetts does not have robust and applicable environmental and planning assessments applicable to agrivoltaics. Rather, research-led community guidance has provided procedural justice. The University of Massachusetts funded by the Massachusetts Department of Agriculture Resources has provided community focused specific agrivoltaics guidelines including legal and financial considerations, location considerations, and specific resources for specific agricultural sectors, including cranberry growers [88].

In Japan, when converting farmland to non-arable use, the authorisation function is performed by the local government's Agricultural Committee. Unauthorised conversion of agricultural land is a breach of the Cropland Act [89], punishable by up to three years imprisonment or by a fine of up to three million yen for individuals and 100 million yen for companies. Initially, a temporary conversion of agricultural land for agrivoltaics required several conditions to be met. Conditions included 80% of the per-unit production being maintained on agricultural land in comparison to the level before agrivoltaics installation and the Agricultural Committee was informed of the annual harvest and crop type.

Between 2018 and 2021, the Japanese government relaxed agrivoltaics reporting requirements. First, in 2018, condition (vi) requiring renewal reviews every three years was eased. Since 2021, agrivoltaics developed on urban farmland or devastated farmland, or by certified farmers, require a renewal evaluation every ten years. Furthermore, in 2021, criterion (i) was relaxed so that yield maintenance is not necessary while utilising devastated farmland for agrivoltaics. Despite this, procedural justice elements are evident in the need for solar energy to be subservient to agriculture in Japan's most recent agrivoltaics guidelines. Guideline 5.3 requires the survey of farmland utilisation and crops guided by interviews with farmers. Farmer co-design in agrivoltaics is expressly referenced as crucial to "understanding of crop varieties and past average yields and quality on the target farmland" [90].

Overall, in NSW, Massachusetts, and Japan, legal processes to obtain agrivoltaics development and planning approval require adherence to guidelines. In addition, NSW includes a detailed agricultural land impact assessment regime while Japan requires engagement and co-design with farmers. Massachusetts does not have a specific impact assessment regime for agrivoltaics, rather guidance for community and agricultural sectors to engage exists.

5.3. Recognition justice

Recognition justice requires the acknowledgment of the rights of different groups in society, specifically host agricultural communities and farmers, in the case of agrivoltaics. Recognition justice primarily forms part of the authorisation and approvals function in agrivoltaics regulation and corresponds with agrivoltaics development and incentivisation functions. Agrivoltaics research to date has cited the need to ensure social acceptance is stimulated through "policy measures, public participation models, and social institutions" [91]. Recognition justice also aligns with policy measures to empower farmers to actively participate in agrivoltaics projects enhancing incentivisation functions.

In the context of the energy transition, an energy justice approach seeks to assess whether energy systems, regulations, and policies entrench social inequity [92]. Recognition justice involves meaningful engagement with farmers to improve community incentives and outcomes leading to more likely planning authorisation, Recognition justice diverts from a 'top-down' policy approach that places onerous requirements on farmers and may deepen the divide between communities and government or developers. In the case of agrivoltaics, there is a shift from the traditional locus of energy justice applied to fossil fuels to energy justice during the transition to a lower emissions economy [93]. Empirical studies examining agrivoltaics within a socio-legal context remain limited [94]. As such, a significant role for exists policymakers at both a state and federal level to determine appropriate engagement with various stakeholders and in particular, host communities.

In NSW, despite enacting the Right to Farm Act 2019 (NSW), there is a lack of specific regulatory conditions forming the authorisation of agrivoltaics and transparency over agrivoltaics leases. Rather, the Large-Scale Solar Energy Guideline provides four generic principles for solar energy developers to: "(1) consider the agricultural capability of the land during the site selection process; (2) avoid siting solar energy projects on important agricultural land as far as possible; (3) Agricultural assessment should be proportionate to the quality of the land and the likely impacts of a project; and (4) Mitigation strategies should be adopted to ensure that any significant impacts on agricultural land are minimised" [95].

The ASTGU scheme in Massachusetts was analysed by Pascaris who argues the Massachusetts model also provides insight into the appropriate level of prescription for system parameters and thereby the appropriate level of engagement with communities [96]. Moore et al. in contrast, view agrivoltaics as consisting of a "new set of sociotechnical practices and systems requiring deep cross-sector cooperation and community engagement to succeed" [97]. For example, to be an eligible system operator for ASTGUs, the system parameters required include a raised racking system that elevates the solar array to allow for agricultural machinery and labour (minimum height of the lowest panel to be 8 feet above ground) [98]. Other system requirements include "maximum direct sunlight requirements for the land underneath the panels by adhering to panel spacing and shading parameters" [99]. These requirements may cause additional capital costs for custom solar arrays, or in the case of panel spacing, may reduce the capacity of the array and nullify the benefit received by the accumulation of ASTGUs [100]. Despite clear guidance for solar energy proponents under the ASTGU system, broader agricultural community engagement principles beyond the University of Massachusetts and Massachusetts Department of Agriculture Resources remain absent. This finding has led to the creation of the new Agrivoltaics Commission in the recent Clean Energy Act amendment to engage with stakeholders in developing Massachusetts's updated agrivoltaics regulatory framework.

Japan's Cropland Act [101] recognises "the important role played by the ownership of agricultural land by cultivators" (Article 1) and stipulates that "Persons who have ownership of or the right of lease of cropland, or any other right to use and derive profit from cropland must ensure that cropland is used in an agriculturally-appropriate and efficient manner" (Article 2-2). Despite this protective stance, agrivoltaics projects are increasingly managed by corporate entities, rather than agricultural landholders. In 60% of agrivoltaics sites, a distinct individual or entity other than the farmer who owns the field installs and manages the agrivoltaics project [102]. Consequently, some agrivoltaics projects may be implemented without recognition justice for agricultural landholders.

The lack of recognition justice in requiring agricultural landholders to manage agrivoltaics projects in Japan has led to two key challenges. First, PV panels on farms are often sited too low for farm machinery to operate safely, the distance between the poles is too narrow for farming equipment, and PV panels are positioned too closely to provide sunlight required for crop development underneath them [103]. Second, as recognised by the Ministry of Agriculture, Forestry and Fisheries, only less labour-intensive crops are often planted (and crops are changed in 56% of agrivoltaics cases), appropriate cultivation is not carried out, farmland quality deteriorates, or farming ceases to exist entirely [104]. The challenge is to strike the correct balance and harmonise both agricultural and energy producing objectives by balancing farmer's private property rights versus agriculture as a public good, as identified by Moore et al. [105].

It is critical to coordinate agrivoltaics development within agricultural communities. Collaboration between developers and farmers, including the implementation of an appropriate regulatory framework to outline agricultural landholder rights and lease terms, could better assure recognition justice. For example, energy communities – enekomi [106] – evident in Japan may represent collaborative vehicles to generate benefits between agricultural landholders and solar energy developers including negotiating agrivoltaics leases, compensation rates, and Right to Farm protections.

As analysed throughout Section 5.0 of this study, agrivoltaics development, authorisation and incentivisation functions underpinned by regulation and policy have the potential to address and achieve all three energy justice principles. The underlying assumptions of the research could be improved by future empirical analysis applying the justice-driven agrivoltaics framework outlined to proposed agrivoltaics projects. Enabling enhanced agrivoltaics benefits may also support the achievement of Sustainable Development Goals, particularly Goal 7 Affordable and Clean Energy through increasing solar PV development, Goal 13 Climate Action due to decarbonisation potential of agrivoltaics, and Goal 15 Life on Land ensuring an equitable and sustainable relationship between agricultural landholders and agrivoltaics developers.

6. Conclusion

The global agrivoltaics sector is anticipated to grow from USD $3.6 billion in 2021 to USD $9.3 billion by 2031 representing an annual compound growth rate of 10.1% per annum [107]. Agrivoltaics hold significant and expansive potential. Yet, without well-defined and transparent legal frameworks the sector might falter unless the industry can demonstrate fair and equitable distribution of benefits to all stakeholders, including agricultural landholders. This is increasingly critical in NSW with the target of creating 12 GW of renewable energy across five renewable energy zones located in rural and regional areas. These circumstances correspond to developments in community acceptance increasingly recognised as a key element of commercial viability in new and proposed renewable energy projects and signals a convergence between commercial, technical, and community needs and benefits. This new approach to the planning and operation of renewable energy projects is urgent and fundamental if the agrivoltaics sector is to grow and flourish as an important technology in the race to achieve the Sustainable Development Goals and net zero emissions reduction targets.

To meet the ambitions of agrivoltaics development, an enabling framework embodying energy justice is critical. This study analyses NSW, Massachusetts, and Japan and their respective agrivoltaics socio-legal frameworks. The resulting comparative functional analysis demonstrates the varying approaches to conceptualising and encouraging the co-location of solar energy and agricultural activities. Overall, NSW lacks detailed policies specifically applicable to agrivoltaics. NSW largely relies upon project proponents developing solar and agriculture co-location proposals. Without clear standardised agrivoltaics planning conditions, potential project delays and an increase in overall costs may become increasingly evident. In contrast, in Massachusetts, agrivoltaics has had a rapid and successful trajectory underpinned by its mature regulatory framework and specific agrivoltaics tariff tender system. This is backed by research and guidelines based on energy justice principles, which support the inclusion of stakeholder interests.108 Japan holds one of the oldest agrivoltaics sectors and applicable regulatory framework. Japan's established agrivoltaics sector has been created in response to concerns over food security, abandoned farmland, and declining agricultural output. Preservation of arable land is at the heart of the Japanese regulation which safeguards aspects of energy justice for both solar energy and agricultural sectors.

This study demonstrates that agrivoltaics activated by a justice-driven agrivoltaics framework could stimulate energy justice leading to the uptake and benefits of agrivoltaics. The triumvirate of tenets; distributive, procedural, and recognition justice applied in this study reveals a new framework in Fig. 1 for policymakers to consider in amending three key functions of development, authorisation, and incentivisation regulating agrivoltaics. The hypothesis of this study agrivoltaics regulation facilitated by energy justice in a new justice-driven framework to stimulate the enhanced capabilities of agrivoltaics has been tested and proven.

The justice-driven agrivoltaics framework designed in this study is a conduit to realising the full potential for agrivoltaics. This framework is designed as a cycle in which regulation must incorporate the following principles: who benefits from agrivoltaics; what legal processes and mechanisms should be considered; and how recognition of existing and future agricultural activities should occur. This framework contributes a pragmatic roadmap for future agrivoltaics regulatory reform and policymaking. The three functions of agrivoltaics development, authorisation, and incentivisation examined in this study demonstrate synergies with energy justice principles resulting in the first examination of agrivoltaics in energy justice research. This analysis is a fertile basis for new research to probe the practical application of the energy justice principles to legal processes delivering justice-driven energy transition with agrivoltaics as its enabler.

CRediT author statement

Madeline Taylor: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualisation, Project administration Jordie Pettit: Conceptualization, Writing – original draft, Writing – review & editing. Takashi Sekiyama: Writing – original draft Writing – review & editing Maciej M. Sokołowski Original draft preparation Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Dr Madeline Taylor reports a relationship with REAlliance that includes: board membership. The authors declare the following personal relationships which may be considered as potential competing interests: Dr Madeline Taylor lead author of this paper is a guest editor of the Special Issue in this study appears in. Dr Taylor was blinded during the review process and the paper was handled by another editor.

Data availability

Data will be made available on request.

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References

[1] Intergovernmental panel on climate change AR6 working group III report. 2022. p. 965.
[2] Intergovernmental panel on climate change AR6 working group III report. 2022. , 968.
[3] Ibid, 968.
[4] Barron-Gafford GA, Pavao-Zuckerman MA, Minor RL, et al. Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. Nat Sustain 2019;2:848–55. https://doi.org/10.1038/s41893-019-0364-5.
[5] Lytle W, Meyer T, Nagendra, Tanikella G, Burnham L, Engel J, et al. Conceptual design and rationale for a new agrivoltaics concept: pasture-raised rabbits and solar farming. J Clean Prod 2021;282:1–11. https://doi.org/10.1016/j.jclepro.2020.124476.
[6] Waltson L, et al. Opportunities for agrivoltaic systems to achieve synergistic food-energy-environmental needs and address sustainability goals. Front Sustain Food Syst 2022;6. https://doi.org/10.3389/fsufs.2022.932018.
[7] Barron-Gafford GA, Pavao-Zuckerman MA, Minor RL, et al. Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. Nat Sustain 2019;2:848–55. https://doi.org/10.1038/s41893-019-0364-5.
[8] Mamun M, Dargush P, Wadley D, Zulkarnain N, Aziz A. A review of research on agrivoltaics systems. Renew Sustain Energy Rev 2013;161:1–16. https://doi.org/10.1016/j.rser.2022.112351.
[9] Mamun M, Dargush P, Wadley D, Zulkarnain N, Aziz A. A review of research on agrivoltaics systems. Renew Sustain Energy Rev 2013; 161:1-16.
[10] Sovacool B, Hess D, Cantoni R. Energy transitions from the cradle to the grave: a meta-theoretical framework integrating responsible innovation, social practices, and energy justice. Energy Res Social Sci 2021;75. https://doi.org/10.1016/j.erss.2021.102027. 102027.
[11] Heffron R, De Fontenelle L. Implementing energy justice through a new social contract. J Energy Nat Resour Law 2023;41:141. https://doi.org/10.1080/02646811.2023.2186626.
[12] Sovacool B, Barnacle M, Smith A, Brisbois M. Towards improved solar energy justice: exploring the complex inequities of household adoption of photovoltaic panels. Energy Pol 2022;164:112868. https://doi.org/10.1016/j.enpol.2022.112868.
[13] Jones C. Building more just energy infrastructure: lessons from the past. Sci Cult 2013;11:157–63. https://doi.org/10.1080/09505431.2013.786991.
[14] Dillman KJ, Heinonen J. A 'just' hydrogen economy: a normative energy justice assessment of the hydrogen economy. Renew Sustain Energy Rev 2022;167: 112648. https://doi.org/10.1016/j.rser.2022.112648.
[15] Saxe J, Boman J, Bondi M, Norton U, Righetti T, Rony A, Sajjadi B. Just or bust? Energy justice and the impacts of siting solar pyrolysis biochar production facilities. Energy Resources and Social Science 2019;48:101269. https://doi.org/10.1016/j.erss.2019.101259.
[16] Heffron R. Applying energy justice into the energy transition. Renew Sustain Energy Rev 2022;156:111936. https://doi.org/10.1016/j.rser.2021.111936.
[17] Sokolowski M, Taylor M. Just energy business needed! How to achieve a just energy transition by engaging energy companies in reaching climate neutrality: (re)conceptualising energy law for energy corporations. J Energy Nat Resour Law 2023;41:157–74. https://doi.org/10.1080/02646811.2023.2190691.
[18] Heeter J, Reames T. Incorporating energy justice into utility-scale photovoltaic deployment: a policy framework. Renewable Energy Focus 2022;42:1–7. https://doi.org/10.1016/j.ref.2022.04.003.
[19] Taylor M. Planning the energy transition: a comparative examination of large-scale solar energy siting on agricultural land in Australia. Utrecht Law Rev 2023; 18:70–86. https://doi.org/10.36633/ulr.814.
[20] Hearn A, Sohre A, Burger P. Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. Energy Res Social Sci 2021;78(1 – 10):2. https://doi.org/10.1016/j.erss.2021.102127.
[21] Jenkins K, Stephens J, Reames T, Hernández D. Towards impactful energy justice research: transforming the power of academic engagement. Energy Res Social Sci 2020;67:1–6. https://doi.org/10.1016/j.erss.2020.101510.
[22] Fortier M, Teron L, Reames T, Munardy D, Sullivan B. Introduction to evaluating energy justice across the life cycle: a social life cycle assessment approach. Appl Energy 2019;236:211–9. https://doi.org/10.1016/j.apenergy.2018.11.022.
[23] Spurlock A, Elmallah S, Reames T. Equitable deep decarbonization: a framework to facilitate energy justice-based multidisciplinary modeling. Energy Res Social Sci 2022;92:1–6. https://doi.org/10.1016/j.erss.2022.102808.
[24] Bouzarovski S, Simcock N. Spatializing energy justice. Energy Pol 2017;107: 640–8. https://doi.org/10.1016/j.enpol.2017.03.064.
[25] Bouzarovski S and Simcock N. Spatializing energy justice. Energy Pol 2017; 107: 640-648.
[26] Fraser N. From redistribution to recognition? Dilemmas of justice in a "post-socialist" Age. N Left Rev 1995;212:68–93.
[27] McCauley DA, Heffron RJ, Stephan H, Jenkins K. Advancing energy justice: the triumvirate of tenets. International Energy Law Review 2013;32:107–10. http://hdl.handle.net/1765/125727.
[28] Michaels R. The functional method of comparative law in Reimann M and Zimmermann R (eds), The oxford handbook of comparative law. Oxford University Press. 2012, 339.
[29] Michaels R. The functional method of comparative law in Reimann M and Zimmermann R (edsThe oxford handbook of comparative law. Oxford University Press. 2012, 339.
[30] Zweigert K, Kötz H. An introduction to comparative law. third ed. Clarendon Press; 1998.
[31] Heffron R. Energy law in crisis: an energy justice revolution needed. J World Energy Law Bus 2022;15:167–72. https://doi.org/10.1093/jwelb/jwac012.
[32] Heffron R. Energy law for the next generation, towards 2030 to 2050. J Energy Nat Resour Law 2023;41(41):131–9. https://doi.org/10.1080/02646811.2023.2190688. 2023.
[33] Cuppari R, Higgins C, Characklis G. Agrivoltaics and weather risk: a diversification strategy for landowners. Appl Energy 2021;291(1):1. https://doi.org/10.1016/j.apenergy.2021.116809.
[34] Dinesha H, Pearce J. The potential of agrivoltaic systems. Renew Sustain Energy Rev 2016;54:299–308. https://doi.org/10.1016/j.rser.2015.10.024.
[35] Upham P, Sovacool B, Ghosh B. Just transitions for industrial decarbonisation: a framework for innovation, participation, and justice. Renew Sustain Energy Rev 2022;167(4):112699. https://doi.org/10.1016/j.rser.2022.112699.
[36] Vanclay F. Principles to gain a social licence to operate for green initiatives and biodiversity projects. Curr Opin Environ Sustain 2017;29:48–56.
[37] Japan (Notification No. 2887 of the director-general of the rural development bureau, [Ministry of Agriculture, Forestry and Fisheries)].
[38] Massachusetts USA. Guideline regarding the definition of agricultural solar tariff generation units). 2022.
[39] New South Wales Government. Large-scale solar energy guideline. 2022. https://shared-drupal-s3fs.s3.ap-southeast-2.amazonaws.com/master-test/fapub_pdf/Lisa+Drupal+Documents/16007_DPIE+Large+Scale+Solar+Energy+Guidelines_22-8-22.pdf. [Accessed 2 September 2022].
[40] Vollprecht J, Trommsdorff M, Hermann C. Legal framework of agrivoltaics in Germany. AIP Conf Proc 2021;2361(1). https://doi.org/10.1063/5.0055133. Melville: American Institute of Physics.
[41] Briggs C, et al. Building a 'Fair and Fast' energy transition? Renewable energy employment, skill shortages and social licence in regional areas. Renewable and Sustainable Energy Transition 2022;2:100039. https://doi.org/10.1016/j.rset.2022.100039.
[42] Taylor M. Planning the energy transition: a comparative examination of large-scale solar energy siting on agricultural land in Australia. Utrecht Law Rev 2023; 18:70–86. https://doi.org/10.36633/ulr.814.
[43] Guerin T. Evaluating expected and comparing with observed risks on a large-scale solar photovoltaic construction project: a case for reducing the regulatory burden. Renew Sustain Energy Rev 2017;74:333–48. https://doi.org/10.1016/j.rser.2017.02.040.
[44] New South Wales Department of Planning and Environment. Large-scale solar energy guideline. 2022. https://shared-drupal-s3fs.s3.ap-southeast-2.amazonaws.com/master-test/fapub_pdf/Lisa+Drupal+Documents/16007_DPIE+Large+Scale+Solar+Energy+Guidelines_22-8-22.pdf. [Accessed 7 September 2022].
[45] New South Wales Government. Issues Paper: Renewable Energy & Agriculture in NSW. 2022. https://www.nsw.gov.au/sites/default/files/2022-04/INT22%20

49292%20%20Attachment%20A%20%20Ag%20Commissioner%20Issues%20Paper%202022.pdf, [accessed 10 August 2022].
[46] Clean Energy Council. Australian guide to agrisolar for large-scale solar. 2021. https://assets.cleanenergycouncil.org.au/documents/resources/reports/agrisolar-guide/Australian-guide-to-agrisolar-for-large-scale-solar.pdf. [Accessed 10 August 2022].
[47] Commonwealth of Massachusetts. Solar Massachusetts renewable target (SMART) program. 2023. https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program. [Accessed 12 August 2022].
[48] Clean Energy Council. Australian guide to agrisolar for large-scale solar. 2021. https://assets.cleanenergycouncil.org.au/documents/resources/reports/agrisolar-guide/Australian-guide-to-agrisolar-for-large-scale-solar.pdf.
[49] Ministry of Agriculture. Forestry and Fisheries. Farming-type solar power generation [営農型太陽光発電について, einō-gata taiyōhikarihatsuden nit suite. 2022. https://www.maff.go.jp/j/shokusan/renewable/energy/attach/pdf/einou-1.pdf. [Accessed 3 September 2022].
[50] MassLand. Agrivoltaics. 2023. https://massland.org/sites/default/files/files/agrivoltaics_mltc_2023_complete_final.pdf. [Accessed 1 September 2023].
[51] Massachusetts Department of Energy Resources. 225 CMR 20.00: Solar Massachusetts renewable target (smart) program..
[52] Massachusetts Department of Energy Resources. 225 CMR 20.00: Solar Massachusetts renewable target (smart) program..
[53] Massachusetts Department of Energy Resources. Solar Massachusetts renewable target program summary. 2021. https://www.mass.gov/doc/smart-launch-and-program-overview/download?_ga=2.264790863.1181886720.1541775161-483334923.1493903549. [Accessed 15 August 2022].
[54] H. 5060, *An act driving clean Energy and offshore wind* (the "clean energy act") chapter 179 of the acts of 2022 (United States)..
[55] Cassotta S, Sokołowski MM. Regulatory models of community energy (CE) in a multi-regulatory approach: juxtaposing the global, the EU, the Japanese and Swedish cases. Eur Environ Law Rev 2022;31(3):189. https://doi.org/10.54648/eelr2022013.
[56] Sokołowski MM. Energy transition of the electricity sectors in the European Union and Japan: regulatory models and legislative solutions. Cham: Palgrave Macmillan; 2022.
[57] Basic plan for food, agriculture, and rural areas[食料・農業・農村基本計画, shokuryō nōgyō nōson kihon keikaku]. Ministry of Agriculture, Forestry and Fisheries; 2020.
[58] Sokołowski MM, Kurokawa S. Energy justice in Japan's energy transition: pillars of just 2050 carbon neutrality. J World Energy Law Bus 2022;15:183. https://doi.org/10.1093/jwelb/jwac011.
[59] Ministry of Economy, Trade and industry. 6th Strategic Energy Plan [第6次エネルギー基本計画, dai 6-ji enerugī kihon keikaku]; 2021.
[60] Ministry of Economy. Trade and industry. Feed-In tariff scheme in Japan. 2012. https://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/summary201207.pdf. [Accessed 3 September 2022].
[61] Ministry of Economy. Trade and industry. Feed-In tariff scheme in Japan 2012;3. . [Accessed September 2022].
[62] Ministry of Agriculture. Forestry and Fisheries. Farming-type solar power generation. 2022 [営農型太陽光発電について, einō-gata taiyōhikarihatsuden ni tsuite], https://www.maff.go.jp/j/shokusan/renewable/energy/attach/pdf/einou-1.pdf. [Accessed 3 September 2022].
[63] Ministry of Agriculture, Forestry and Fisheries. Farming-type solar power generation. 2022. [営農型太陽光発電について, einō-gata taiyōhikarihatsuden ni tsuite], 3 September 2022].
[64] Caballero M, Gunda T, McDonald Y. Energy justice & coastal communities: the case for meaningful marine renewable energy development. Renew Sustain Energy Rev 2023:1–12.
[65] Roddis P, Roelich J, Tran K, Carver S, Dallimer M, Ziv G. What shapes community acceptance of large-scale solar farms? A case study of the UK's first 'nationally significant' solar farm. Sol Energy 2020;209:235. https://doi.org/10.1016/j.solener.2020.08.065.
[66] Dillman KJ, Heinonen J. A 'just' hydrogen economy: a normative energy justice assessment of the hydrogen economy. Renew Sustain Energy Rev 2022;167:1. https://doi.org/10.1016/j.rser.2022.112648.
[67] Brunswick S, Marzillier D. The new solar farms: growing a fertile policy environment for agrivoltaics, 24 the Minnesota journal of law. Sci Technol 2023:123–80.
[68] New South Wales Department of Planning and Environment. Large-Scale Solar Energy Guideline, https://shared-drupal-s3fs.s3.ap-southeast-2.amazonaws.com/master-test/fapub_pdf/Lisa+Drupal+Documents/16007_DPIE+Large+Scale+Solar+Energy+Guidelines_22-8-22.pdf, August 2022 [accessed 7 September 2022].
[69] Voluntary Planning Agreements include monetary contributions to 'public purposes', but are not limited to, any of the following pursuant to Subdivision 2 of the Environmental Planning and Assessment Act 1979 (NSW): (2) A public purpose includes (without limitation) any of the following— (a) the provision of (or the recoupment of the cost of providing) public amenities or public services; (b) The provision of (or the recoupment of the cost of providing) affordable housing; (c) The provision of (or the recoupment of the cost of providing) transport or other infrastructure relating to land; (d) The funding of recurrent expenditure relating to the provision of public amenities or public services, affordable housing or transport or other infrastructure; (e) The monitoring of the planning impacts of development; (f) The conservation or enhancement of the natural environment.
[70] RE-Alliance. Submission to DPE on revised large-scale solar energy guidelines, https://www.re-alliance.org.au/largesolar_guidelines_sub, 1 March 2022 [accessed 15 August 2022] 10.
[71] Pascaris A. Examining existing policy to inform a comprehensive legal framework for agrivoltaics in the U.S. Eng Pol 2021;159:112620. https://doi.org/10.1016/j.enpol.2021.112620.
[72] Ibid, 8.
[73] Pascaris A, et al. Integrating solar energy with agriculture: industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. Energy Res Social Sci 2021;75:102023. https://doi.org/10.1016/j.erss.2021.102023.
[74] Pascaris A, et al. Integrating solar energy with agriculture: industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. Energy Res Social Sci 2021;75:102023.
[75] Ibid, 7.
[76] Klass AB. Climate change and the convergence of environmental and energy law. Fordham Environ Law Rev 2013;24(2):180–204. http://www.jstor.org/stable/26195843.
[77] Commonwealth of Massachusetts. Solar Massachusetts renewable target, https://www.mass.gov/solar-massachusetts-renewable-target-smart [accessed 15 August 2022].
[78] McCauley D, Ramasar V, Heffron R, Sovacool B, Mebratu D, Mundaca L. Energy justice in the transition to low carbon energy systems: exploring key themes in interdisciplinary research. Appl Energy 2019;233:916–21. https://doi.org/10.1016/j.apenergy.2018.10.005.
[79] Elmallah S, Rand J. "After the leases are signed, it's a done deal": exploring procedural injustices for utility-scale wind energy planning in the United States. Energy Res Social Sci 2022;89:102549. https://doi.org/10.1016/j.erss.2022.102549.
[80] Moore S, Graff H, Ouellet C, Leslie S, Olweean D. Can we have clean energy and grow our crops too? Solar siting on agricultural land in the United States. Energy Res Social Sci 2022;91(1):3. https://doi.org/10.1016/j.erss.2022.102731.
[81] See First Nations Clean Energy Network for a list of community-driven renewable energy projects by and for First Nations peoples in Australia. First Nations Clean Energy Network, https://www.firstnationscleanenergy.org.au/community. [Accessed 13 August 2022].
[82] For example, New South Wales, Social Impact Assessments are required for all State Significant Developments, which include large-scale solar energy developments with a capital investment value of more than $30 million, or a capital investment value of more than $10 million and is in an environmentally sensitive area of state significance under Part 4 of the Environmental Planning and Assessment Act 1979 (NSW).
[83] Department of Planning and Environment. Social impact assessment guideline. 2021. p. 30–1. . [Accessed 17 August 2022].
[84] Department of Planning and Environment. Social impact assessment guideline, < 2021 [17 August 2022] 30-31.
[85] Prehoda E, Winkler R, Schelly C. Putting research to action: integrating collaborative governance and community-engaged research for community solar. Soc Sci 2019;8:1. https://doi.org/10.3390/socsci8010011.
[86] Moore S, Hackett E. The construction of technology and place: concentrating solar power conflicts in the United States. Energy Res Social Sci 2016;11:67–78. https://doi.org/10.1016/j.erss.2015.08.003.
[87] Pascaris A. Examining existing policy to inform a comprehensive legal framework for agrivoltaics in the. U.S. Eng Pol 2021;159:112620. https://doi.org/10.1016/j.enpol.2021.112620.
[88] Centre for Agriculture, Food, The Environment. Solar PV and agriculture information. 2022. https://ag.umass.edu/clean-energy/research-initiatives/solar-pv-agriculture. [Accessed 20 June 2023].
[89] Cropland Act [農地法, nōchi-hō] 1952;249(15).
[90] New Energy and Industrial Technology Development Organization. Design and construction guidelines for farming solar power generation systems. 2021. Guideline 5.3.
[91] Pascaris A, et al. Integrating solar energy with agriculture: industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. Energy Res Social Sci 2021;75(1):3. https://doi.org/10.1016/j.erss.2021.102023.
[92] Dillman KJ, Heinonen J. A 'just' hydrogen economy: a normative energy justice assessment of the hydrogen economy. Renew Sustain Energy Rev 2022;167:112648. https://doi.org/10.1016/j.rser.2022.112648.
[93] Jenkins K, McCauley D, Heffron R, Stephan H, Rehner R. Energy justice: a conceptual review. Energy Res Social Sci 2016;11:174–82. https://doi.org/10.1016/j.erss.2015.10.004.
[94] Pascaris A, et al. Integrating solar energy with agriculture: industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. Energy Res Social Sci 2021;75(1):10. https://doi.org/10.1016/j.erss.2021.102023.
[95] New South Wales Department of Planning and Environment. Large-Scale Solar Energy Guideline https://shared-drupal-s3fs.s3.ap-southeast-2.amazonaws.com/master-test/fapub_pdf/Lisa+Drupal+Documents/16007_DPIE+Large+Scale+Solar+Energy+Guidelines_22-8-22.pdf, August 2022 [accessed 25 August 2022] 26.
[96] New South Wales. Department of Planning and Environment. Large-scale solar. energy guideline 2022.
[97] Moore S, Graff H, Ouellet C, Leslie S, Olweean D. Can we have clean energy and grow our crops too? Solar siting on agricultural land in the United States. Energy Res Social Sci 2022;91(1):3. https://doi.org/10.1016/j.erss.2022.102731.
[98] Moore S, Graff H, Ouellet C, Leslie S, Olweean D. Can we have clean energy and grow our crops too? Solar siting on agricultural land in the United States. Energy Res Social Sci 2022;91(1):3.

[99] Ibid.
[100] Ibid.
[101] Cropland Act [農地法, nōchi-hō]. 249 Jul 15, 1952.
[102] Ministry of Agriculture, Forestry and Fisheries. Current Status and Challenges of Farming-Type Solar Power Generation [本検討会の概要及び営農型太陽光発電の現状と課題について, hon kentōkai no gaiyō oyobi einō-gata taiyōhikarihatsuden no genjō to kadai ni tsuite]. 2021. https://www.maff.go.jp/j/study/einougata_taiyoukou.html/attach/pdf/einou_kaigi-5.pdf. [Accessed 3 September 2022].
[103] Ministry of Agriculture, Forestry and Fisheries. Current Status and Challenges of Farming-Type Solar Power Generation [本検討会の概要及び営農型太陽光発電の現状と課題について, hon kentōkai no gaiyō oyobi einō-gata taiyōhikarihatsuden no genjō to kadai ni tsuite], 2021 [3 September 2022].
[104] Ibid.
[105] Moore S, Graff H, Ouellet C, Leslie S, Olweean D. Can we have clean energy and grow our crops too? Solar siting on agricultural land in the United States. Energy Res Social Sci 2022;91(1):3. https://doi.org/10.1016/j.erss.2022.102731.
[106] Sokołowski MM. Models of energy communities in Japan (enekomi): regulatory solutions from the European Union (rescoms and citencoms). Eur Environ Law Rev 2021;30(4):149–59.
[107] Allied Market Research. Agrivoltaics market by system design 2021 – 2031. 2023.
[108] Taylor M, Taylor S. Applying energy justice principles: a case study of solar energy in Vanuatu. J World Energy Law Bus 2022;10:1–19. https://doi.org/10.1093/jwelb/jwac003.