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Original research article

The power of assumptions: A literature review on how algorithmic design influences energy justice in electrical distribution grids☆

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ABSTRACT

Recent energy justice scholarship has argued for the need to reflect more explicitly on the normative assumptions that underpin claims to justice in energy systems. While such reflections increasingly inform energy policy, less attention has been paid to how these assumptions shape the design of algorithmic systems central to energy system planning and operations. This paper explores how normative assumptions in the design of algorithmic systems used to request flexibility from electricity consumers and producers to manage grid congestion may influence distributive justice outcomes. By systematically reviewing the scientific literature presenting such systems, we define two categories of assumptions: (1) *scope assumptions*, which set the boundaries of the justice analysis by determining which burdens and benefits, scale, subjects, and timeframe are considered relevant; and (2) *design assumptions*, which specify how these considerations are translated into the structure of algorithmic systems, such as allocation principles, technical problem framing, data availability and evaluation metrics. We find that the particular assumptions adopted within each category determine the distributive outcomes of these algorithmic systems. Recognizing their normative character, we propose that scope assumptions should be informed by context-specific risks of injustice identified by policymakers, while engineers should reflect on and validate their design assumptions in relation to these risks.

1. Introduction

As justice becomes an increasingly recognized concern in the energy transition, energy justice scholarship has offered a conceptual lens through which scholars and practitioners examine who benefits, who bears burdens, and whose perspectives are considered in energy decision-making [1]. This lens has informed a range of analytical frameworks, typically encompassing distributive, procedural, recognition, restorative and cosmopolitan dimensions [2,3]. These frameworks have been widely applied in scientific studies that examine citizens' perspectives on developments in the energy system, such as wind farm siting and rooftop solar adoption [4,5].

However, despite their extensive application in empirical research, integrating these frameworks into policy development and implementation has proven challenging [6]. To make these frameworks more practical, several scholars have emphasized the importance of identifying and reflecting on the *normative assumptions* embedded in energy justice claims and governance processes [7,8]. By normative assumptions, we refer to those assumptions that express judgments about what ought to be considered just. Such assumptions are often institutionalized and presented as objective, even though they reflect particular normative viewpoints [9]. Clarifying these assumptions has the potential to reveal the normative viewpoints that different stakeholders may hold, assisting decision-makers in navigating competing claims [7].

At the same time, energy systems are increasingly shaped by algorithmic systems, for example to manage energy within buildings and coordinate energy markets [10–12]. The development of algorithms for such purposes involves simplifying complex problems into manageable sub-problems by omitting or generalizing contextual details, a process commonly referred to as *abstraction* [13]. Inherently, the process of abstraction requires making assumptions.

These assumptions include not only those with clear normative implications, such as which principle of justice to apply, but also more technical ones, such as which data proxies best represent the relevant households in a system. These technical choices may have *indirect* normative implications for the outcomes of an engineered and deployed algorithmic system. However, the normative implications

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of algorithmic development have not received much attention in the energy justice literature.

In this paper, we focus on algorithmic systems used for requesting flexibility from electricity consumers and producers to mitigate grid congestion, an application where questions about justice are arising due to the scarcity of grid capacity [14]. While public debate in countries with increasing grid congestion, such as the Netherlands and the United Kingdom, has mainly focused on the distributive consequences of connection queues, similar concerns are now emerging in day-to-day grid operations [15,16]. As electricity demand and renewable generation fluctuate throughout the day, grid operators rely on various algorithmic tools to detect and manage congestion [17,18]. Among these tools are systems that may limit the output of solar or wind installations or request consumers to reduce their electricity usage.

While design choices in such algorithmic systems are often treated as neutral and technical, they can influence who bears the costs of managing congestion [15]. In this paper, we ask: *what types of normative assumptions about distributive justice influence the design of algorithmic systems for managing congestion in electrical distribution grids?* By algorithmic systems, we refer to computational approaches used by a grid operator to request flexibility from consumers or producers to manage congestion in distribution grids, typically through curtailment or demand response. Such flexibility requests directly affect energy access for households and small businesses.

This paper extends our prior work by contributing to the growing body of research on normative assumptions in energy justice scholarship [19]. In that earlier study, we analyzed how the literature varied in its scoping of distributive justice problems, its selection of allocation principles, and its use of evaluation metrics. Here, we extend that contribution by identifying a broader set of assumption categories and critically assessing the assumptions applied in the literature.

The remainder of this paper is structured as follows. Section 2 provides the relevant background and scientific gaps that motivate our research. Section 3 describes the literature review methodology and analytical approach. Section 4 presents the categorization and critical analysis of the assumptions identified in the reviewed articles. Section 5 discusses the implications of these findings, including the risks of relying on simplified assumptions in algorithmic systems and the importance of justifying such assumptions. Finally, Section 6 argues that, while energy justice scholarship has largely focused on policymakers, it should also aim to make its concepts accessible to engineers who influence distributive justice outcomes through algorithmic design.

2. Background: energy justice in electrical distribution grids

This section provides the technical and conceptual background for the subsequent analysis. We begin by introducing the growing challenge of grid congestion and the role of algorithmic systems in mitigating it. We then discuss the foundations of energy justice and the existing literature on distributive justice in electrical distribution grids.

2.1. Grid congestion and algorithmic systems

Grid congestion is increasingly recognized as a barrier to the energy transition in many countries [20]. Technically, it refers to situations where the grid lacks sufficient capacity to transport electricity from one location to another. This issue is becoming more common as decentralized renewable generation and the electrification of heating and transport place growing demands on electrical power systems [21].

For example, in the Netherlands, one of the countries most affected by grid congestion, around 10,000 large users and 7,500 generation projects were waiting to connect to the electrical grid in early 2025. In the United Kingdom, over 1,100 renewable energy projects were in the queue at the end of 2024, with some facing delays of up to ten years [16]. In both countries, these developments have led to public debate about the justice implications of allocating new grid connections based on the ‘first come, first served’ principle [15,16].

While these debates tend to focus on how grid capacity is allocated during the connection process, similar justice concerns are now emerging in day-to-day operations [15]. Grid operators are developing algorithmic systems to detect where grid congestion might occur and automatically decide on actions to mitigate these congestion risks [22]. For example, they might temporarily limit the output from solar or wind installations or ask consumers to reduce their electricity use. By doing so, grid operators can make more efficient use of existing infrastructure, allowing more users to connect without grid expansion.

However, such interventions by the grid operator can raise justice concerns in different ways. For example, the same households may be repeatedly targeted due to prioritization rules or their physical location on the grid [10]. Besides, compensation schemes might disproportionately benefit households with high energy consumption and advanced technologies, such as rooftop solar or electric vehicles [23].

The magnitude and frequency of such interventions vary across contexts, shaped by the availability of grid capacity and the adoption levels of renewable energy, electric vehicles, and heat pumps. In some regions, requests to curtail generation or provide demand-side flexibility may remain occasional, while in others, they could become routine as the energy transition accelerates and grid reinforcement lags. When interventions become routine rather than occasional, the risk of systemic disadvantage for certain households or businesses increases. Against this backdrop, we now turn to the foundations of energy justice, which provide the conceptual lens for this paper.

2.2. Foundations of energy justice

Since its introduction in the early 2010s, the concept of energy justice has received growing attention as a way to address societal concerns that are often overlooked in the predominantly technical and economic perspectives of the energy field [24]. This expanding body of work emphasizes that the shift toward sustainable energy is not only a technical challenge but also a social one, with the potential to reduce or exacerbate existing inequalities [3]. Accordingly, energy justice research seeks to identify what is just or unjust in energy systems and to promote a fair and inclusive transition to sustainable energy [7].

Energy justice is commonly conceptualized through five key tenets [2,3]. Distributive justice concerns the equitable allocation of energy-related benefits and burdens across different groups. Procedural justice emphasizes the role of decision-making processes, including transparency and meaningful participation. Recognition justice focuses on acknowledging and respecting the diverse needs, identities, and capabilities of affected communities. Restorative justice seeks to repair harm and rebuild trust where injustices have occurred. Finally, cosmopolitan justice extends the scope of justice to global responsibilities, considering impacts beyond national borders.

Energy justice scholarship has aimed to inform policymaking in recent years [25], however its integration into policy processes appears to be difficult in practice [6,26]. Barriers to implementation include a lack of normative clarity in the tenet approach, insufficient alignment with existing policy instruments, and a policymaking culture that does not always support critical reflection on justice [6–8,27]. In response to these challenges, several scholars have argued for making normative assumptions about justice explicit in policymaking and stakeholder engagement [6–8].

To address this, Van Uffelen et al. [7] have proposed five categories of normative assumptions to help clarify how different stakeholders understand and frame claims of justice. These categories include principles of justice, scale, subjects, knowledge, and time. Building on this work, our paper examines how these normative assumptions appear in the algorithmic systems presented in the scientific literature.

Although the tenet approach to energy justice encompasses distributive, procedural, recognition, restorative, and cosmopolitan dimensions, our analysis focuses specifically on the normative assumptions associated with distributive justice. Examining the other dimensions would require analyzing the broader policy and governance arrangements surrounding algorithmic systems, such as transparency and accountability requirements, participation arrangements, and the ways in which different households' capabilities are recognized. These considerations fall outside the analytical focus of this study, which concentrates on the normative assumptions in system design.

We recognize that distributive justice alone does not capture the full scope of energy justice. However, clarifying assumptions about distributive justice in the design of algorithmic systems provides a starting point for subsequent work on the other dimensions. Explicit distributive assumptions can, for example, inform procedural justice by making algorithmic decision-making more transparent and contestable, which in turn may strengthen participation in flexibility programs. In this way, distributive justice offers a first step toward identifying the normative assumptions that shape the design of algorithmic systems.

2.3. Distributive justice in electrical distribution grids

Without proper contextualization, the distributive effects of algorithmic decision-making remain abstract and difficult to assess. Therefore, we situate our study within the broader justice concerns that arise in electrical distribution grids. These concerns are not new: an increasing body of literature examines who bears the burdens and who enjoys the benefits of reliable electricity [24]. Previous work has highlighted disparities affecting rural and urban communities, low-income households, and minority populations. Such disparities may manifest in outage risks [28,29], the siting of grid infrastructure [30], and the relationship between energy costs and household income [31,32].

Efforts to reduce grid congestion by relying on curtailment and demand-side flexibility introduce new questions about justice. For example: Who is called upon to provide flexibility, how often, and under what conditions? Who can access compensation for these requests, and who bears the costs of enabling technologies? Households may differ in their ability to respond to flexibility requests, a capacity described in the literature as *flexibility capital* [33]. Material resources (smart appliances, home energy systems), cognitive resources (digital literacy, trust), temporal constraints (work or caregiving schedules), and social factors all shape whether households can provide flexibility to the grid operator [34]. These differences mean that algorithmic coordination of flexibility can amplify existing disparities if not carefully considered.

In the power systems engineering literature, the distributive consequences of curtailment and demand response algorithms are typically addressed under the label of *fairness*. A recurring theme in this strand of literature is the lack of consensus on what constitutes the "fairest" approach to requesting flexibility [18]. As such, they have proposed various principles to distribute the burdens and benefits of flexibility requests. For example, some scholars advocate for equal power reductions across all parties connected to a substation [35], while others propose proportional reductions based on generation capacity [36].

Existing reviews of localized energy systems and electricity markets have mapped such principles and indicators across the literature [12,37,38]. However, they have not examined other assumptions, such as which subjects are considered what spatial scale is used, and how objectives are formulated. Our paper addresses this gap by identifying and examining the normative assumptions that influence distributive outcomes of algorithmic systems used for managing grid congestion.

2.4. Summary and research gap

While policymakers increasingly recognize the importance of justice in the energy transition, they often face challenges in translating these concerns into concrete instruments. At the same time, engineers are already making decisions that shape how justice is considered in the design of algorithmic systems. Our paper does not claim to resolve the operationalization challenges of energy justice, but it offers a bottom-up perspective on the kinds of assumptions that might have distributive consequences. By making these assumptions visible, we aim to provide guidance to policymakers and engineers on identifying and mitigating foreseeable injustices introduced by algorithmic systems used for flexibility-based mitigation of grid congestion.

Table 1
Search terms used for the literature review.

Databases	Search terms in the title/abstract/keywords
Scopus IEEE Xplore	('fairness' OR 'non-discrimination' OR 'justice') AND ('congestion' OR 'demand response' OR 'curtailment' OR 'voltage control') AND ('distribution') AND ('power' OR 'electrical' OR 'grid')

3. Methodology

To surface the assumptions that influence distributive justice outcomes in our analysis, we conducted a review of the scientific literature that proposes new algorithmic systems for requesting flexibility from connected parties to mitigate the risks of grid congestion. The methodology involved three main steps. We started by selecting relevant literature through a comprehensive database search. Next, we applied an abductive analysis approach, identifying assumptions in the literature, comparing them with the existing assumption categories by Van Uffelen et al. [7] and refining the framework based on the identified gaps and differences. Finally, we conducted a structured literature analysis of each assumption category, critically assessing the assumptions found in the literature. These steps are described in more detail in the following subsections.

3.1. Literature selection

We searched the IEEE Xplore and Scopus databases using the search terms in Table 1. The search, conducted on May 1, 2024, covered the years 2009 to 2024 and included only English articles. The first papers appeared to be from 2014, confirming 2009 as a suitable starting point.

We initially found 261 articles, with 108 from Scopus and 153 from IEEE Xplore. After removing duplicates, we had 197 unique articles. The first author then reviewed the abstracts based on two criteria: the discussion of distributive justice in algorithmic systems and the focus on managing grid congestion in electrical distribution systems. This initial review, based on abstracts, narrowed the selection to 82 articles. After a thorough review of the full articles and application of the same criteria, 52 articles were selected for the analysis. This selection process is illustrated in Fig. 1. An overview of the final set of articles is provided in Appendix A.

The authors of the reviewed articles are generally affiliated with institutions in North America, Australia, New Zealand, and Western Europe, with limited representation from Asia and Latin America, and none from Africa. This regional bias suggests that current research on distributive justice in algorithmic systems for flexibility-based congestion management largely reflects perspectives from contexts with advanced digital infrastructure and liberalized electricity markets. Consequently, the normative assumptions identified may not fully represent viewpoints from regions with different governance models or limited digital infrastructure.

3.2. Framework development through abductive analysis

We began our literature review with an established framework to examine the normative assumptions underlying the claims of justice made by Van Uffelen et al. [7]. This framework identifies five categories of assumptions: principles (rules for determining what is just or unjust), scale (the geographical level at which justice is considered), subjects

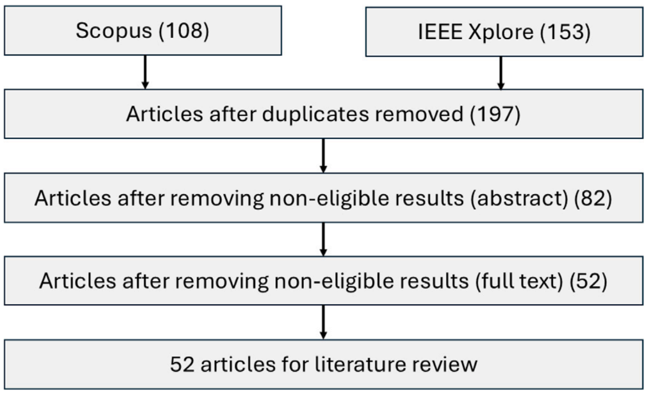

Fig. 1. Article selection process.

(the relevant stakeholders for justice claims), time (the relevant timeframe, such as past, present, or future), and knowledge (the beliefs or knowledge that stakeholders have about what is true).

Building on this framework, we applied abductive analysis, a method that combines existing theories with new insights to adapt and refine a theoretical framework [39]. We started by exploring the assumptions present in the literature, specifically looking for those that varied between articles. Then, we compared these assumptions with those in the conceptual framework. We found that assumptions about scale, time, subjects, and principles were all present in the literature. However, the knowledge category was not applicable in the context of the literature we reviewed, as algorithmic systems do not possess beliefs about knowledge. Based on this, we categorized assumptions that were not included in the conceptual framework, adding new categories.

During the analysis, we observed that these categories cluster into two overarching types: scope assumptions and design assumptions. Scope assumptions describe the conditions under which distributive injustices may arise or worsen with the introduction of algorithmic systems. Design assumptions describe the modeling choices that might address or worsen the risks of injustice embedded in the scope assumptions. This distinction structures the presentation of our findings.

3.3. Critical assessment of assumptions in the literature

After finalizing the framework, the first author re-analyzed all articles using the stabilized framework. This analysis focused on identifying assumptions that influence distributive outcomes either explicitly articulated in the text or implicitly inscribed in a mathematical model representation. We did not analyze the underlying source code of the simulation models and relied on the reporting provided by the authors for our analysis. In practice, normative assumptions were frequently found in simulation setups and reported model configurations.

For each assumption category, we selected examples that illustrate both the form the assumption takes in the literature and its distributive consequences. We specifically focused on cases that make these distributive consequences visible, combining representative cases that recur across multiple articles with edge cases. To support a critical assessment of the field, we included examples that operationalize the same category in different ways, showing how these assumptions influence distributive outcomes.

4. Findings: normative assumptions influence distributive justice

Our analysis reveals two overarching types of normative assumptions that reflect different forms of abstraction. Scope assumptions involve acts of *boundary abstraction*: they set the conceptual boundaries of justice analysis by determining what is included and excluded and at what level of granularity. Design assumptions involve acts of *technical abstraction*: they determine how justice considerations are represented within those boundaries through engineering decisions. Together, these abstractions influence how distributive justice is inscribed into the logic of algorithmic systems.

Fig. 2 provides an overview of the types of assumptions found in the literature. A comprehensive analysis of each individual paper is available in Appendix A. The following subsections provide a more detailed discussion of each assumption category.

4.1. Scope assumptions determine the conceptual boundaries of justice analysis

Scope assumptions define the conditions under which distributive injustices may arise or worsen with the introduction of algorithmic systems. They set the boundaries for what is within and out of scope, by determining which burdens and benefits (do not) matter, who is (not) considered, at what geographic scale, and over what time horizon. The following subsections summarize the main patterns observed in the reviewed literature for all scope assumptions.

4.1.1. Burdens and benefits: lacking recognition of interdependencies

The reviewed literature often does not explicitly recognize the normative implications of selecting a burden or benefit that should be distributed. To clarify these implications, our analysis distinguishes six types of burdens and benefits that appear in the literature. Energy reduction refers to the amount of energy that is reduced for each customer, while energy provision denotes the amount of energy that is provided to each customer. Energy reduction time captures the duration for which a customer's energy is reduced. Rewards for energy reduction are financial incentives that compensate for the reduction in energy. Costs of energy reduction represent the economic implications of reducing energy, such as missed income from curtailment. Finally, delays in energy provision assume that the requested energy is supplied later to a customer (e.g., in the case of charging electric vehicles), with the burden being the time a customer has to wait until receiving its requested amount of energy.

The choice among these options can significantly affect distributive outcomes. For example, distributing the burden of energy reduction or the benefit of energy provision equally may lead to different results. Consider two households: Household A, which typically consumes 50 kWh of energy, and Household B, which typically consumes 100 kWh. If the burden is the reduction of energy consumption by 20 kWh in total and this is shared equally, each household would need to reduce 10 kWh. Household A would then consume 40 kWh, while Household B would consume 90 kWh. Conversely, if the benefit is to provide energy and the same equal distribution is applied, both households would receive 65 kWh. This illustrates how equal distribution can produce very different outcomes depending on whether it is applied to energy reduction or energy provision.

While the example above shows that distributing energy reduction and energy provision equally can yield different outcomes, an additional complication is that the justice implications of the amount of energy reduced also depend on the compensation offered. This interdependence means that the identified burdens and benefits are co-determined rather than separable, yet the literature typically focuses on one type and ignores alternatives in how the package of burdens and benefits could be allocated. A more comprehensive approach would therefore analyze allocation jointly across multiple burdens and benefits, rather than treating each in isolation.

4.1.2. Scale: opportunities for evaluation beyond neighborhood level

In terms of scale, the reviewed articles generally focus on geographical scales smaller than an urban district. Most literature considers distributive outcomes at the secondary substation level, which serves neighborhoods or city blocks. Some studies extend to medium-voltage areas, covering multiple neighborhoods or a district. We identified only

SCOPE ASSUMPTIONS		
	Burdens and benefits	Energy reduction amount Energy provision amount Energy reduction time Energy reduction rewards Energy reduction costs Energy provision delay
	Scale	Primary substation Medium-voltage feeder Secondary substation
	Subjects	Photovoltaic systems Distributed energy resources Electric vehicles Demand response
	Time	Single time-point Historical time-points Future time-points

DESIGN ASSUMPTIONS		
	Allocation principles	Proportional Uniform Min-max Global Fixed limits
	Technical problem	Over/under voltage Line overloading Transformer overloading
	Data availability	Predicted data Real-time data
	Evaluation metrics	Jain's index Proportional Jain's index Gini coefficient Mean-based Variation-based Ratio-based

Fig. 2. Overview of scope and design assumptions with distributive justice implications.

three articles that examined the distribution of burdens and benefits at the primary substation level, which spans areas equivalent to a small town or a large urban district. This emphasis on secondary substation analyses reveals differences within neighborhoods, while analyses at the primary substation scale are needed to identify broader spatial disparities that remain hidden at local scales.

This local focus partly reflects how distribution grids are operated: the scope of analysis is defined within the boundaries of a single distribution system. Consequently, optimization at scales larger than a single distribution system (i.e., above the primary substation level) generally lies outside the responsibility of an individual grid operator. Although cross-operator optimization is uncommon in grid operations, cross-area or cross-operator evaluation of distributive outcomes can reveal patterns and disparities that are not visible at local scales. We find that such larger scale evaluations are largely absent in the reviewed literature.

4.1.3. Subjects: limitations of defining subjects by technical assets

The reviewed literature primarily focuses on technical assets as the subjects of distributive justice. On the consumption side, the emphasis is on demand response programs, which involve consumers adjusting their electricity usage based on grid operators' requests. Most of the focus has been on electric vehicle charging, but general demand response is also considered without specifying any particular technology. On the supply side, the main focus is on photovoltaic systems (solar panels) and distributed energy resources (e.g., solar panels, wind turbines, or small natural gas-fueled generators). Notably, only two articles integrate both supply and consumption perspectives [40,41].

However, it is debatable whether only the type of technical appliance should be considered when distinguishing between subjects. Some households have multiple appliances, such as photovoltaic systems and electric vehicles, and they may adjust their electric vehicle charging based on solar energy production. Moreover, the reviewed papers generally examine distributive justice within groups defined by the same technology, for example, among households with rooftop solar, rather than between households with and without such technologies. Focusing on just one type of technology or considering these technologies separately might overlook their combined effects.

These observations highlight a limitation in defining subjects solely by technical assets. While technology-based categorization might be convenient for modeling, it risks oversimplifying the heterogeneity of stakeholders in such systems. Distributive justice concerns might also intersect with socio-economic status, geographic location, or degrees of vulnerability or marginalization, which are not captured by technical attributes alone. Studying such alternative differences between subjects could offer insights into distributive outcomes beyond the field's current focus on technical appliances.

4.1.4. Time: simplified representations of temporal dynamics

The selected articles present various ways of addressing distributive justice outcomes in terms of time, primarily focusing on distributing a burden or benefit at a single point in time. While this approach simplifies the analysis, it may not capture the full picture, as it ignores temporal dynamics. Of the reviewed papers, 11 articles considered the allocation of burdens and benefits over time, incorporating historical events such as past energy provision [42] or past rewards [43]. Two articles also considered future expectations in decision-making, such as the expected charging time for electric vehicles [44].

The relationship between a grid operator and its connected parties is typically long-term, making it unrealistic to treat each decision as independent over time. Sequential decisions can accumulate burdens and benefits, shaping distributive outcomes in ways that single time-point analyses fail to capture. However, modeling distributive outcomes as the cumulative result of sequential decisions raises new questions: how should algorithmic systems account for extended periods of inactivity or irregular participation? For example, if non-usage during a holiday leads to "credits", how should these be balanced against future obligations? Addressing such questions requires moving beyond simplified temporal representations toward approaches that reflect the cumulative and dynamic nature of managing grid congestion over time.

4.2. Design assumptions determine how justice is inscribed into algorithmic systems

Design assumptions refer to engineering decisions that affect how distributive justice is represented and addressed within the boundaries set by scope assumptions. These include the selection of allocation principles, the formulation of the engineering problem to mitigate grid congestion, the availability and granularity of data used to represent subjects, and evaluation metrics to monitor the distribution of burdens and benefits. These assumption categories are elaborated on in the following subsections.

4.2.1. Allocation principles: lacking justification of assumptions

We found that the literature generally acknowledges the plurality of allocation principles that can be applied in algorithmic systems used for requesting flexibility to mitigate grid congestion. We identified five main types of principles: proportional, uniform, min–max, global, and fixed limits. Notably, about a third of the articles examine multiple allocation principles in a single study, acknowledging that no single principle is universally applicable.

A proportional principle allocates burdens or benefits based on certain properties of subjects, like their energy demand or generator capacity. This principle has been applied in the largest number of articles (38). Although "proportional fairness" is often referred to as a single concept, many factors determine this proportionality. We identified 18 such factors in the selected articles, like real-time energy production [36,45,46], number of past requests to reduce energy usage or production [47–49], or reliability in execution of requests [50]. As a result, the distribution of burdens and benefits can vary significantly based on the specific factors used for a proportional allocation.

The literature also frequently adopts a uniform allocation principle, which has been applied in 14 articles. A uniform principle strives for equal allocation of burdens and benefits among subjects. A min–max allocation principle, used in only three articles, aims to minimize the maximum burden or benefit among subjects, such as minimizing the maximum reduction in energy [18] or maximizing the minimum provision of energy [51]. Many articles also applied a global allocation principle, which aims to achieve a utilitarian objective, such as minimizing total energy reduction [41] or financial compensation [52] for all subjects.

Finally, some articles used an allocation principle based on fixed limits, which sets constraints on the distribution of burdens or benefits among subjects. We identified nine examples of such limits in the reviewed articles, grouped into two types: outcome-based and process-based constraints. Outcome-based constraints directly restrict results, such as limiting differences in energy reduction or delays between subjects [53,54], setting eligibility for participation [55], or capping the number, duration, and interval of requests [56]. Process-based constraints embed justice concerns into the procedure rather than outcomes, such as through sequential allocation based on a predefined priority, with each subject receiving or losing up to their claim before passing the remainder to the next [57].

In summary, the literature recognizes the variety of assumptions that can be made about allocation principles, often favoring proportional and uniform principles. The choice among these principles has clear distributive consequences, which most of the reviewed articles acknowledged. However, they rarely justify why specific principles or proportional factors are chosen, making it unclear whether these choices align with the scope of injustice they aim to address.

4.2.2. Technical problem: combined effects of grid constraints remain underexplored

Across the selected articles, grid congestion is defined through different grid limits. Many articles focus on curtailment to maintain voltage limits, particularly in scenarios with high solar generation. Some studies also address equipment overloading, such as transformers and lines, which can overheat with excessive power. Only six articles address these three types of constraints (over/under voltage, line overloading, and transformer overloading) simultaneously.

There seems to be a lack of comprehensive approaches that address multiple constraints together. This matters because actions to mitigate one limit can affect the same subjects as when managing another. For example, a model that allocates curtailment to manage voltage limits may primarily affect households on certain feeders. A separate model designed to prevent transformer overloads may again target the same households if it does not consider the curtailment already applied for voltage limits. When algorithmic systems for different constraints are developed or evaluated in isolation, their combined distributive effects remain invisible.

4.2.3. Data availability: limited attention to uncertainty and accessibility

Assumptions about the data available for designing algorithmic systems can also influence how justice is considered. Most articles focus on real-time control for managing grid congestion, while only six examine control based on predicted data. In practice, curtailment or demand response for managing congestion often relies on forecasts to avoid interference with electricity market closures. The choice between real-time and forecast-based control might have implications for distributive outcomes. As such, when the allocation is assessed based on predicted data, the actual distribution of burdens and benefits should be evaluated afterward.

Another key aspect is the type of data available for justice assessments by grid operators. The selected literature generally focuses on energy-related data for these assessments, such as electricity consumption or generation. However, if grid operators aim to consider differences among subjects on other aspects, such as socioeconomic factors or protected attributes, obtaining this data can be challenging due to privacy laws or practical constraints. These challenges can complicate the implementation of interventions that aim to mitigate the risks of injustice in this domain.

4.2.4. Evaluation metrics: lacking justification of assumptions

Metrics are quantitative tools used to evaluate how burdens or benefits are distributed. These metrics are typically applied after the optimization process to assess whether the resulting allocations align with engineers' expectations. While often grounded in allocation principles, such as uniform or proportional allocation, these metrics represent a more specific operationalization of those principles and are used to check whether the objectives and constraints are met.

The most common metric in the reviewed literature for the evaluation of distributive outcomes is Jain's index, which originates from research on computer networks. Jain's index ranges from $\frac{1}{|N|}$ (least equal) to 1 (most equal) and has been applied in seven articles. An additional five studies modified the index to reflect their interpretations of a proportional allocation. In addition, some articles used the Gini coefficient for evaluation, which originated in economics. Similar to the Jain's index, this metric also promotes uniform allocation, typically ranging from 0 (most equal) to 1 (least equal).

In addition to these more established metrics in the field, some authors also constructed their own metrics. Some of these metrics are based on mean values, such as the average burden or benefit between different subjects (e.g., large and small parties) [18] or average proportional distributions [58]. To measure variation, the standard deviation or the coefficient of variation (the standard deviation divided by the mean) were used. Furthermore, some articles compared the ratios of burdens to benefits, such as congestion management costs relative to rewards [59] or the timing of requests in preferred slots [60].

While the use of these metrics is a positive step toward evaluating algorithmic systems, many articles claim that their systems are *fair* without providing any justification for their chosen metrics, and some do not use any metrics at all. This might be problematic because metrics, often presented as objective indicators, are actually based on assumptions that influence outcomes. For example, Carvalho et al. [61] argue that "The proportional fairness algorithm reaches a maximum Gini of 0.45, comparable to inequality in the U.S., and thus may be judged socially acceptable". This reasoning rests on two contestable assumptions: first, that the Gini coefficient is an appropriate metric for evaluating distributive justice in this context; and second, that aligning with inequality levels in the United States is a just standard. Such assumptions illustrate the importance of assessing the relevance of selected metrics and providing explicit justification for their use.

5. Discussion

Our analysis shows that the design of algorithmic systems relies on a wide range of normative assumptions about distributive justice. By categorizing and critically assessing these assumptions, we revealed how specific design decisions in the scientific literature shape distributive outcomes. We next discuss the implications of these findings for engineers and policymakers and outline the limitations of our study.

5.1. Reflecting on simplifying assumptions to avoid misabstraction

The results show that many algorithmic systems rely on simplified representations of both grid conditions and the risks of injustice. These simplifications, for example, focus on a single type of physical constraint that may cause grid congestion, a single time point, or a narrow set of technical subjects, such as photovoltaic systems or electric vehicles. While abstraction, as a form of simplification, is a necessary component of algorithmic design, it also introduces risks.

In particular, simplification can lead to misabstraction, a situation where critical contextual factors are excluded during the design process, resulting in algorithmic interventions that fail or become problematic when introduced into the site of use [13]. To prevent misabstraction, it is important to make assumptions explicit and to reflect on their normative implications and relevance in the context of use. Our typology supports engineers in identifying where simplifications occur and how they shape the scope of justice analysis. This does not mean that abstraction is a problem in itself, but rather that it should be approached reflexively, recognizing that every modeling choice carries normative weight.

5.2. Anchoring scope assumptions in energy policy

The results further show that what we categorized as *scope assumptions* are often made without reference to upstream policy goals or known empirical disparities. For example, few studies consider differences in solar ownership and flexibility capital, despite their prominence in the energy justice literature [33,62]. Instead, assumptions seem to be based on modeling convenience, which may lead to a misalignment of algorithmic systems with the real-world justice concerns these are meant to address. To improve relevance and legitimacy, scope assumptions should be justified within the specific policy context in which the algorithmic system will be deployed.

Justice concerns are not universal; they vary across regions, grid configurations, regulatory environments, and social contexts. These differences should inform which risks of injustice are considered relevant and which groups are seen as potentially vulnerable. Importantly, this kind of contextual justification is not something that engineers can or should be expected to do alone. They may lack access to the necessary data and stakeholder input, or have a limited institutional mandate to define the risks of injustice in a particular context. Instead, there is a clear role for policymakers and regulators to clarify which risks of injustice are foreseen or known and to provide guidance on how these should be reflected in algorithmic system design. Such guidance can, for example, be grounded in democratic or rule-of-law principles, like protection against arbitrariness [63].

5.3. Validating design assumptions for justification

The results also show that what we categorize as *design assumptions* are often selected without clear justification. In particular, we did not find any links between the types of injustice that engineers aimed to address (when explicitly stated) and the specific principles, metrics, or data they chose to implement. In engineering practice, validation refers to testing whether design assumptions hold under real-world conditions. We argue that validating whether these design assumptions align with the defined scope is necessary to determine whether they effectively mitigate the risks of injustice identified. This requires asking whether the chosen allocation principles, metrics, data sources, and technical problem framing are appropriate, given the identified risks of injustice in a particular context.

The responsibility for formulating and validating design assumptions lies primarily with engineers. Policymakers often lack visibility into the technical design space and may not possess the expertise to assess whether specific algorithmic choices support justice-related goals. This shows the need for coordination between both stakeholder groups, with iterative monitoring and reflexive adjustment. If assumptions prove invalid, or if new concerns emerge during implementation, this should trigger a feedback loop between engineers and policymakers to revisit and revise their assumptions.

5.4. Encouraging transparency about assumptions for contestability

During our analysis, we found that most assumptions were embedded in mathematical models or simulation setups; however, they were rarely discussed or reflected upon in the accompanying articles. This makes them difficult to identify and contest, especially for stakeholders without technical expertise. Even for those who are able to extract these assumptions, the absence of explicit reflection on their limitations and contextual relevance makes it difficult to assess whether they are appropriate for the setting in which the system will be deployed.

We argue that engineers have a responsibility not only to document these assumptions but also to reflect on them explicitly. This includes clarifying the contexts in which assumptions may hold and where they may fail. Transparency, in this sense, supports contestability by enabling stakeholders to understand and question the foundations of algorithmic decisions and to bring in alternative views that may otherwise be overlooked.

Nevertheless, previous studies have highlighted that transparency alone is not sufficient to support contestability. For example, Alfrink et al. [64] have shown that without meaningful avenues for control, transparency can feel irrelevant or burdensome to affected communities. Various scholars have emphasized the need for practical tools that enable scrutiny of algorithmic decisions for contestability [65]. One promising direction is the development of tools for collective contestability, allowing groups to compare decisions and connect with others who share similar experiences [66].

5.5. Limitations and future work

Although this paper focused on the distributive aspects of justice, we recognize that the ability to contest assumptions depends on the inclusiveness of decision-making processes and the recognition of diverse stakeholder perspectives. While our framework aims to support reflection and transparency within expert settings, it does not directly address how these assumptions can be communicated to or engaged with by affected communities. Future work could explore how assumptions can be made accessible beyond experts and how design processes could support participation from those most impacted.

Our analysis also has methodological limitations. First, assumptions that were not explicitly stated had to be interpreted by the researchers. Second, we do not claim to have identified all assumptions, as our analysis focused on those that varied across the literature. Third, our findings are based on published research rather than empirical observations of design processes, which means they reflect theoretical and reported practices rather than the dynamics of real-world implementation. Future work could validate these assumptions through studies that engage directly with practitioners and operational algorithmic systems.

Future research could explore how the proposed distinction between scope and design assumptions applies to other algorithmic applications in the energy system, such as market design or grid planning. It could also study how these categories can support more reflexive practices in real-world settings. For instance, these categories could help engineers and policymakers articulate and align their assumptions during the design process of algorithmic systems. These potential applications, however, require further investigation.

6. Conclusion

This paper aimed to clarify how normative assumptions that influence distributive justice outcomes are reflected in the algorithmic systems used for mitigating grid congestion in electrical distribution grids. To explore these assumptions, we conducted a literature review focused on algorithmic systems that are used to request flexibility from electricity consumers or producers. We built our framework on the theoretical foundations offered by Van Uffelen et al. [7], adapting and extending it to capture assumptions specific to algorithmic design.

Our analysis revealed two main categories of assumptions: *scope assumptions*, which concern who and what are considered relevant in justice assessments (e.g., subjects, scale, burdens, and benefits), and *design assumptions*, which relate to how distributive justice is implemented (e.g., allocation principles, technical problem framing, data availability, and evaluation metrics). While scope assumptions have been discussed in previous energy justice literature, design assumptions have received less attention.

A critical assessment of the algorithmic systems presented in the scientific literature showed that many of these systems rely on simplified representations of the risks of injustice related to managing grid congestion. Although such abstractions might be necessary to make complex problems computationally manageable, they can lead to *misabstraction*, where critical contextual factors are excluded. This risk highlights the need for engineers to make the normative assumptions guiding algorithmic system design explicit and to reflect on their relevance for the context in which these systems will operate.

Based on these insights, we proposed that scope assumptions should be anchored in energy policy and made explicit by policymakers, as engineers are not always equipped to determine which risks of injustice are most relevant in a given context. The assumption categories we identified can support policymakers by translating policy goals into engineering practice. Engineers, in turn, should reflect on and validate their design assumptions in relation to the identified risks of injustice, clarifying the contexts in which their design choices may or may not hold. For them, the introduced assumption categories provide a structured device to explicate, justify, and reflect on the normative assumptions underlying the algorithmic systems they develop.

We encourage future work in the energy justice field not only to continue making its concepts more accessible to policymakers, but also to consider how to support the engineers who shape energy justice outcomes through the design of algorithmic systems that mediate decision-making in our increasingly digital energy system.

CRediT authorship contribution statement

Eva de Winkel: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Zofia Lukszo:** Writing – review & editing, Validation, Supervision. **Mark Neerincx:** Validation, Supervision. **Roel Dobbe:** Writing – review & editing, Validation, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.erss.2026.104605.

Data availability

The data is shared in Appendix A.

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