

Review

The Environmental Impacts of Sprawl: Emergent Themes from the Past Decade of Planning Research

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Abstract: This article reviews studies published in English language planning journals since 2001 that focus on the environmental impacts of sprawl. We organise our analysis of the reviewed literature around: (1) the conceptualisation or measurement of sprawl; (2) a comparison of research methods employed and findings with respect to four categories of environmental impacts—air, energy, land, and water; and (3) an exploration of emergent and cross-cutting themes. We hypothesise that the trend towards breaking down silos observable in other areas of planning scholarship is also reflected in the recent sprawl literature and structure our review to test this proposition. International in scope, our work demonstrates how focusing on outcomes can facilitate balanced comparisons across geographic contexts with varying rates of urbanisation and affluence. We find that the sprawl research published in planning journals over the past decade frequently engages with broader themes of resilience and justice, increasingly considers multiple environmental outcomes, and suggests a convergence in the way sprawl is studied that transcends national boundaries as well as the developing-developed country dichotomy.

Keywords: sprawl; environmental impact; resilience; justice; urban planning

1. Introduction

Urban sprawl remains the dominant pattern of development in the United States [1] and is an increasingly common phenomenon around the globe [2,3]. At its core, urban sprawl is a complex and multifaceted phenomenon with no universally accepted definition [4–6] and these characteristics have had a profound impact on the way that sprawl research has been conducted. The lack of a standard definition has contributed to the longevity and contentiousness of debate, while the breadth of the issue has made it difficult to study in a comprehensive manner. Much of the early literature focused on the economic and environmental impacts of sprawl [7–9] with four related questions dominating much of the sprawl research conducted during the 1990s:

- (1) how to best define and measure sprawl,
- (2) what are the fundamental causes of sprawl,
- (3) what are the costs and benefits of sprawl, and
- (4) which policies are most effective for combating sprawl.

This conventional sprawl debate [10] centred on the fundamental question of whether sprawling development is harmful or largely benign [11,12] and while some degree of disaggregation and bounding is necessary, the conceptual ambiguity, broad scope, and sometimes conflicting empirical evidence offered by sprawl researchers may have hindered opportunities to fully connect with other scholarly discourses and emerging issues [6].

In a frequently cited review of this literature published about a decade ago, Johnson [5] provided an overview of the most salient environmental impacts of sprawl, but much has changed in the intervening years. Deepening inequality and climate change impacts are two specific issues that have gained increasing attention from both policymakers and the public, and the way that development takes place in and around urban areas figures prominently in these debates, challenging researchers to look beyond disciplinary and political boundaries in seeking knowledge regarding the causes and consequences of different development patterns. At the same time, while emerging issues like these are global, traditional conceptualisations of sprawl are not. In the Western context the term typically evokes images of low density, automobile dependent, and largely monotonous residential development along the periphery of an urban area. However, this characterisation is less useful in many developing countries where urbanisation has different drivers and appears in a different guise, posing yet another challenge for the generalizability of research findings.

This article extends the foundation laid by Johnson [5] by summarising more recent empirical studies of the environmental impacts of sprawl and identifying trends in how that research is conducted. We organise our analysis of the reviewed literature around: (1) the conceptualisation or measurement of sprawl; (2) a comparison of research methods employed and findings with respect to four categories of environmental impacts—air, energy, land, and water; and (3) an exploration of emergent and cross-cutting themes. In each of these sections, we provide a summary table that serves as a general roadmap to the literature and aids the reader in understanding key points from the analysis. Ewing [11] uses the negative consequences of urban sprawl as the central criterion for identifying it, and we adopt a similar approach here. We expect to find that the trend towards breaking down silos observable in other areas of planning scholarship is also reflected in the recent sprawl literature and

structure our review to test this proposition. International in scope, our work demonstrates how focusing on outcomes can facilitate balanced comparisons across geographic contexts with varying rates of urbanisation and affluence. While environmental outcomes are only one of the dimensions of urban sprawl, we contend that if considered in a holistic way it can offer a framework for bridging the idiosyncrasies of growth across national contexts and alleviate the need to articulate a definition of sprawl that works everywhere.

The rest of this article is organized as follows. In the next section, we describe our approach to selecting the reviewed studies. Section 3 discusses and summarises how the reviewed studies fit into established ways of conceptualising sprawl as well as new measures employed by some recent studies. Section 4 presents an analysis of the literature organized by four primary categories of environmental impacts as well as research findings on what factors continue to cause sprawl or what approaches are more effective at controlling it. In section five we explore the direct and implied connections between the reviewed studies and the emergent themes, then present our conclusions and an agenda for future research in section six.

2. Scope and Methodology

We reviewed articles published in English language planning journals since 2001, relying primarily on ISI's Web of Science[®] database and the following list of journals:

- Cities
- Environment & Planning A, B, C, and D
- European Urban & Regional Studies
- Habitat International
- Housing Policy Debate
- Intl. Journal of Environmental Sciences
- Intl. Journal of Urban & Regional Research
- Journal of Environment & Development
- Journal of Env. Planning & Management
- Journal of Planning Education & Research
- Journal of the American Planning Assoc.
- Land Use Policy
- Landscape & Urban Planning
- Third World Quarterly
- Town Planning Review
- Urban Studies

The above list includes what are in our view a mix of “core planning journals” [13] as well as journals affiliated with the urban planning discipline relevant to our interest in empirical sprawl research and covering a variety of geographic contexts. In addition to the anchor term “planning”, the following keywords were used to identify articles for inclusion in the analysis:

- Automobile dependence
- Decentralisation
- Land development
- Leapfrog development
- Low density development
- Segregated land uses
- Sprawl
- Suburbanisation
- Unmanaged growth
- Urban expansion

In addition to serving as a resource for researchers, our work aids practitioners who wish to engage the literature in their own domain and consider their interdependence with related domains. It should however be noted that our evaluation is non-exhaustive and aims to uncover patterns in how the characteristics, causes, and costs of sprawl are understood in the recent planning literature.

3. Conceptualising Sprawl

Galster *et al.* [4] offer eight objective dimensions for measuring sprawl and outline six general approaches to conceptualising urban sprawl commonly used within the literature. While the dimensions such as density, centrality, *etc.* are helpful for measurement research, the six general approaches present a more useful framework for organising the existing literature. In fact, we found that four of these approaches were represented among the 52 journal articles we analysed. Table 1 summarises how each of the articles fits within this modified typology with most studies exhibiting more than one of these in the way it conceptualises urban sprawl. The most common approach is what Galster *et al.* [4] describe as sprawl understood as the cause of a negative externality. Many studies focus on one or more specific consequences as a basis for distinguishing sprawl and the justification for a policy response. For example, automobile dependence [14,15] and the loss of farmland [16,17] are used in precisely this way and given our focus on the environmental impacts of sprawl, it is not surprising that the notion of sprawl as the cause of negative externalities is a common theme.

A significantly smaller number of articles understand urban sprawl as a consequence or symptom of some larger phenomenon. Many studies cite sprawling development as a direct result of population growth [18–21]. This view is disputed by other researchers who argue that “sprawl is not an inevitable consequence of economic growth, but rather a result of specific government policies” that allow and in some cases promote unsustainable development ([22], p. 287) with “hidden government subsidies” ([23], p. 731) as a key contributor, particularly in developed country contexts. Among the studies analysed, sprawl is most commonly conceptualised as a consequence of uncoordinated, inadequate, or nonexistent planning [17,24,25] or alternatively as the result of “increasingly affluent householders and commercial investors exercising their locational choices in a free market, aided by the availability of good quality transport infrastructure and relatively cheap private transport” [26].

The second most common approach to defining sprawl is to focus on its physical characteristics as a particular pattern of development. While there is some variation in the specific criteria used, most of the articles analysed rely on a combination of descriptors like low-density, discontinuous, scattered, leap-frog, uncontrolled, and single land use. Some studies emphasise the quantification of sprawl and measure several of these physical characteristics. An example can be seen in Sarvestani *et al.* [27] where the ratio of developed land area to population is coupled with entropy measures to distinguish urban sprawl, with the former capturing the density aspect of the sprawl and the latter measuring the degree of scattering or discontinuity. In this way, the familiar density and continuity dimensions of sprawl [4] can be easily operationalised. In other cases sprawl is defined in less specific terms and understood as occurring when the rate of urban expansion exceeds the rate of population growth [22,28] or simply as low density residential development [29–32]. However, even multi-dimensional definitions of urban sprawl that primarily focus on physical characteristics have limitations. For example, many of the studies from developing country contexts focus on low-density residential development as the primary characteristics of sprawl, while rapid and haphazard urbanisation that may be actually be higher in density is the most common concern. According to Pucher *et al.* ([14], p. 381) Indian “cities are increasingly being surrounded by unplanned, haphazard suburban sprawl” and although such development is typically higher in density than most U.S. suburbs, its impacts are still problematic.

Table 1. Approaches to defining urban sprawl (after Galster *et al.* [4]).

Context	Article	Cause of Externalities	Consequence or Outcome	Land Development Pattern	Process
Developing	Barredo and Demicheli [33]			X	X
	Fazal [18]	X			X
	Kamini <i>et al.</i> [19]	X	X		
	Küçükmehtemoğlu and Geymen [34]		X	X	X
	Liu <i>et al.</i> [35]	X			
	Pucher <i>et al.</i> [14]	X			
	Roy [21]			X	
	Sarvestani <i>et al.</i> [27]			X	
	Sietchiping <i>et al.</i> [15]	X			
	Wang <i>et al.</i> [36]	X			X
	Xi <i>et al.</i> [37]	X		X	X
	Xu [38]	X			X
	Zhao and Lu [39]	X		X	
	Zhao <i>et al.</i> [40]	X		X	
	Zhou <i>et al.</i> [41]	X		X	X
	Developed	Abelairas-Etxebarria and Astorkiza [25]	X	X	
Barbour and Deakin [42]		X	X		
Bart [22]		X		X	
Berke <i>et al.</i> [43]		X		X	
Brody <i>et al.</i> [32]		X		X	
Conway [44]				X	X
Davis <i>et al.</i> [45]		X			
De Ridder <i>et al.</i> [46]		X	X	X	
Domene and Saurí [47]				X	
Dumas <i>et al.</i> [20]		X			
Frenkel [28]		X			X

Table 1. Cont.

Context	Article	Cause of Externalities	Consequence or Outcome	Land Development Pattern	Process
	Garcia and Riera [29]	X			
	Hamin and Gurrán [30]	X		X	
	Haase and Nuisl [48]	X			X
	Holden and Norland [49]			X	
	House-Peters and Chang [50]	X		X	
	Huang <i>et al.</i> [51]	X		X	X
	La Greca <i>et al.</i> [24]	X	X	X	X
	Lee and French [52]	X			
	Maruani and Amit-Cohen [53]	X		X	
	McEldowney <i>et al.</i> [26]	X	X		
	Nuisl <i>et al.</i> [54]	X		X	
	Paül and Tonts [17]			X	X
	Pauleit <i>et al.</i> [55]	X		X	
	Poelmans <i>et al.</i> [56]	X		X	
	Power [23]	X	X		
	Rayne and Bradbury [57]	X			
	Robinson <i>et al.</i> [3]	X		X	X
	Song [58]	X			
	Stone Jr. <i>et al.</i> [59]	X		X	
	Stone Jr. <i>et al.</i> [60]	X		X	X
	Tang <i>et al.</i> [61]	X			X
	Tiwari <i>et al.</i> [62]	X		X	
	Vallianatos <i>et al.</i> [16]	X			
	Vimal <i>et al.</i> [63]	X			
	Zasada <i>et al.</i> [31]	X			
Both	Lehmann [64]	X		X	

Source: Compiled by the authors.

The final and third most common approach to defining sprawl among the studies analysed emphasises its dynamic aspects, explicitly understanding sprawl as a process. These articles typically adopt a longitudinal approach when describing or analysing urban sprawl [18,33,37,48]. The land conversion aspect of sprawl is often a central concern, which in part explains the increasing popularity of remote sensing and scenario analysis as research methods. When understood as a process, sprawl transitions from noun to verb presupposing a “before and after” contrast and accentuating the need for monitoring (change detection) and indicators (metrics) to document and analyse the phenomenon. While the physical characteristics of sprawl may vary from place to place, the notion that sprawl is fundamentally about change and involves a remaking of the landscape is universal.

The preceding discussion demonstrates significant variation in the way sprawl is conceptualised in the recent literature. Further, the scale at which the analysis is conducted and the methodologies employed also vary significantly across the studies considered, confounding efforts to summarise what has been learned from sprawl research. We address these divergences by limiting our analysis to environmental outcomes and while this is but one of the familiar sustainable development pillars [65,66], it helps to bridge the idiosyncrasies of scale, methodology, and national context.

4. The Environmental Impacts of Urban Sprawl

Building on the foundation laid by Johnson [5], we identify four primary categories of environmental impacts attributed to urban sprawl in the articles considered—air, energy, land, and water. For each of these categories, below we detail issues commonly addressed and identify representative studies from the literature organised by scale and research methods. Table 2 further synthesises our findings.

4.1. Air

Many of the studies in this category focus on the relationship between transportation and air pollution. Vehicles have long been established as key contributors to air quality issues in urban areas [67], but notable advances have been made over the past decade in specifically linking urban sprawl to diminished air quality. Stone Jr. *et al.* [59] couple vehicle activity forecasting with a mobile source emissions model to explore the relationship between sprawling development and four pollutants—carbon monoxide, nitrogen oxides, fine particulate matter, and volatile organic compounds—in eleven metropolitan areas of the Midwestern United States. Their findings suggest that compact development can significantly reduce pollutant emissions at the regional scale, but only over the long-term and when complemented with growth controls, disincentives for vehicle use, and technological emissions controls. This is an important study because it dispels the notion that focusing solely on indicators like vehicle miles travelled (VMT) alone is enough to successfully address the air quality issues faced by many metropolitan areas. It also highlights the importance of understanding behavioural aspects of the sprawl–air quality connection in order to identify effective policy levers. A study of the effect of urban sprawl on air quality in Germany’s Ruhr region [46] also offers significant insights. The authors conclude that while urban sprawl has a relatively minor impact on the overall exposure of residents in an area like the Ruhr to air pollution, those living in more suburban areas are far less impacted than those living in denser, central city locations. Sprawl thus becomes not only a

cause of externalities, but in some instances an environmental justice issue where those with the means to move out of the city experience lower health hazards exposures. Transport-related air pollution is also a major concern in the larger cities such as Beijing and Delhi where sprawl contributes to the problem by increasing average travel times and traffic congestion [14].

After decades of denial, misinformation, and debate, global climate change has emerged as one of the most significant challenges for urban planning [68]. The 2001 report released by the Intergovernmental Panel on Climate Change (IPCC) is viewed in retrospect as a watershed moment—by synthesising vast amounts of data and previous research it provided a clear and compelling articulation of the connection between human-induced greenhouse gas (GHG) emissions and climate change [69]. Carbon dioxide (CO₂) is “the most important anthropogenic greenhouse gas” [70] due to its high radiative forcing and relative longevity in the atmosphere and is therefore, of central concern in efforts to mitigate climate change and its expected impacts. The consumption of fossil fuels is the largest contributor to CO₂ emissions followed by land use change [70] and these are the primary connections between urban sprawl and climate change observable in the planning literature.

Several articles use the urban heat island effect as a critical link between land use, transport, air quality, and climate change impacts. Song [58] examines the urban heat island effect in Bundang, South Korea, which is one of several new towns in the greater Seoul region. Analysing a time series of satellite imagery of the larger region and modelling surface temperatures with regression techniques, the study concludes that the town is indeed experiencing a heat island effect that elevates average surface temperatures, thereby exacerbating air pollution. These findings are mirrored by a study conducted in the Atlanta region [52] that discusses the implications of sprawling development for air quality (ground ozone) and energy consumption (demand for interior cooling) within the broader context of the urban heat island effect. A third study by Stone Jr. *et al.* [60] suggests a different but equally important connection in the form of a positive correlation between sprawl and extreme heat events between 1956 and 2005 for 83 metropolitan areas in the United States. As demonstrated by these three examples, sprawl research continues to engage with air quality in new ways by integrating ideas from policy debates as well as broader discussions like environmental justice and climate change.

4.2. Energy

The role of land use, and density in particular, in affecting energy use outcomes remains a controversial issue within the urban planning literature. Several studies [71–73] have contributed evidence supporting Newman and Kenworthy’s [74] findings that more compact urban form is also more energy efficient, from a transportation perspective. Within the buildings sector, the connection between urban sprawl and climate change hinges on energy losses through transmission lines (*i.e.*, longer distances spanned), larger heated areas on average, and increased surface temperatures by virtue of the heat island effect in areas with more sprawl [75]. Development that is contiguous with existing urban areas, more compact in terms of both average structure size and overall net density, and vegetated is associated with lower rates of residential energy consumption [75] and “the most densely populated cities utilise less energy for private passenger transport and generally have lower greenhouse gas emissions per capita” ([76], p. 193). More recently, however, Echenique *et al.* [77] conducted a scenario-type simulation study of several metro areas in the UK and found the effect of compacting

urban form on energy use to be “very modest” (p. 136), highlighting the vitality of debate surrounding these issues. It should be noted that this study has been extraordinarily controversial, eliciting serious and sustained challenges from urban planning researchers [78].

Some of the studies we reviewed consider the impact of sprawl on energy consumption for both transport and buildings. For example, Holden and Norland [49] conduct a household survey of eight regions of Oslo, Norway and model residential energy use for heating and travel. The authors find a significant positive relationship between energy consumption in larger and older residences, as well as evidence of dampening effect on energy consumption associated with more densely developed areas. Based on these results, the authors argue for more compact urban form as a means of improving energy efficiency and moving toward more sustainable patterns of development.

Others use climate change to frame and direct the research linking sprawl to energy consumption and in the developing country context, China is particularly well-represented [14,39,40,64]. Using data from household travel surveys Pucher *et al.* [14] contrast transportation policies and their implications of greenhouse gas emissions in China and India as two of the most populous and developing countries. Sprawling areas in China are generally characterised by higher densities than typical North American suburbs and the planning of these areas is closely coordinated with the provision of basic public infrastructure. Development is less tightly managed in India with “decongestion” of city centres as a key goal informing development policy. Given these background conditions, the study reveals a higher non-motorised trip share in China than in India, greater public transport shares in cities with rapid population growth, and a significant increases in private motorised vehicle travel in both countries with attendant increases in GHG emissions. Further, the urban poor are disproportionately affected by the social and environmental impacts of the transport system’s weaknesses because they are forced to live on the urban periphery where public transportation options are limited and rising motor vehicle use triggers greater traffic dangers, noise, and air pollution.

4.3. Land

The loss of farmland, open space, forest, and habitat are the most common issues addressed by articles focusing on the impacts on sprawl from a land use perspective. The question of how to use scarce land resources more efficiently is echoed in Frenkel’s [28] study of growth management policies in Israel. Using a combination of scenario planning and quantitative models, this article [28] demonstrates that focused growth management policies can be more effective than current policies in preserving open space and farmlands. Maruani and Amit-Cohen [53] focus specifically on Tel Aviv and also argue that large amount of public land ownership in Israel (93%) is ideally suited for strong environmental protection policies through land management regulations. Sprawl has also been linked to habitat loss [3,20,51], but primarily within the developed country context.

Table 2. Major categories of environmental impacts.

Category	Issue(s)	Scale	Approach and Methods	Study Examples
Air	Air quality	Regional	Integrated modelling: land use and transport, meteorology, & atmospheric dispersion <i>etc.</i>	Stone Jr. <i>et al.</i> [59]; De Ridder <i>et al.</i> [46]
	Air quality	Regional	GIS; regression analysis	Lee and French [52]
	Urban heat islands, surface temperature; extreme heat events	Regional	Remote sensing; GIS; statistical correlation analysis	Song [58]; Stone Jr. <i>et al.</i> [60]
Energy	GHG emissions	National	Comparative analysis of transport indicators	Pucher <i>et al.</i> [14]; Sietchiping <i>et al.</i> [15]
	GHG emissions	City; regional	Survey; regression analysis	Holden and Norland [49]; Zhao and Lu [39]
	GHG emissions	Regional	Case study	Hamin and Gurrán [30]; La Greca <i>et al.</i> [24]; Lehmann [64]
Land	Loss of farmland, green space	City	Remote sensing for LULC change detection	Fazal [18]; Sarvestani <i>et al.</i> [27]
	Loss of farmland; open space	City; regional; national	Scenario analysis with PSS	Roy [21]; Frenkel [28]
	Loss of farmland	Regional	Scenario analysis with cellular automata simulation	Xi <i>et al.</i> [37]
	Loss of green space and habitat	Regional	Remote sensing for LULC change detection	Robinson <i>et al.</i> [3]; Dumas <i>et al.</i> [20]; Huang <i>et al.</i> [51]
	Loss of green space and habitat	Regional	Regression analysis	Vimal <i>et al.</i> [63]
	Loss of farmland	Regional	Mixed methods; regression analysis; interviews	Xu [38]
	Loss of green space	Regional	Mixed methods; interviews; contingent valuation analysis	Garcia and Riera [29]
	Loss of farmland	Regional	Spatial hedonic regression analysis	Abelairas-Etxebarria and Astorkiza [25]
	Loss of farmland	Regional	Content analysis of plans	Maruani and Amit-Cohen [53]
Loss of farmland	Regional	Case study; GIS	Vallianatos <i>et al.</i> [16]; Paül and Tonts [17]	

Table 2. Cont.

Category	Issue(s)	Scale	Approach and Methods	Study Examples
Water	Flooding	City	Remote sensing for LULC change detection; scenario planning with PSS	Kamini <i>et al.</i> [19]; Roy [21]
	Flooding	Regional	Regression analysis	Brody <i>et al.</i> [32]
	Water supply (encroachment)	Regional	Remote sensing for LULC change detection	Küçükmehtemoğlu and Geymen [34]
	Water supply (consumption)	Regional	Mixed methods; telephone interviews; regression analysis	Domene and Saurí [47]
	Watershed protection	Regional	Regression analysis; ecosystem economic valuation; remote sensing and ecological services measurement; GIS	Berke <i>et al.</i> [43]; Davis <i>et al.</i> [45]; Zhou <i>et al.</i> [41]; Wang <i>et al.</i> [36]
	Stormwater runoff (non-point source pollution)	Regional	Remote sensing for LULC change detection; scenario analysis; hydrologic model	Tang <i>et al.</i> [61]
	Water balance	City	Mixed methods; water balance model; interviews	Haase and Nuisl [48]
	Water balance	Regional	Integrated model coupling land use change and hydrology	Poelmans <i>et al.</i> [56]; Rayne and Bradbury [57]

We were able to identify fewer articles from developing country contexts that focus on land resources. Two articles [37,38] consider outward growth from cities in China as a threat to farmland along the fringe, while Fazal [18] documents similar patterns of prime farmland loss around Saharanpur City in northern India. Sarvestani *et al.* [27] use remotely sensed imagery and GIS to quantify and map the spatial dispersion of Shiraz, Iran from 1976 to 2005. Overall, the literature addressing land resource impacts from both developed and developing countries are comparable in their methodologies with remote sensing and GIS tending to play a prominent role [3,17,18,20,27,37,51,55,63].

4.4. Water

Sprawling development is characterised by an increase in impervious surfaces, which have extensive and well-documented effects on hydrology including an increase in the volume, rate, and pollutant content of storm water leaving a site [79]. Several of the studies we analysed are more general and consider watershed health [43] or the urban water balance [48,56], while others focus specifically on stormwater runoff [45,55,61], potable water supply [34,57], flooding [32], or household consumption patterns [50].

Rayne and Bradbury [57] examine the effects of residential subdivision development on groundwater resources in south-eastern Wisconsin where suburban developments often rely on domestic wells. The study concluded that development lot size, spread of subdivisions and soil type, all play significant roles in groundwater recharge. For example, when larger lots (commonly, 1.2 hectares) are built over an entire township with clayey soils, recharge rates tend to be lower contributing to groundwater depletion. In another study, using linear extrapolation of changes in satellite imagery in the Flanders-Brussels region of Belgium, Poelmans *et al.* [56] forecast future development patterns and then apply a hydrologic model. The authors found that the spatial extent of urban expansion has a much higher negative hydrological impact than the type of urban expansion, and impacts are much greater on surface runoff than on evapotranspiration and groundwater recharge.

In the developing country context, the research linking sprawl to water resource impacts tends to frame the issues in a slightly different way. The loss of wetlands and the ecological services they provide is a prominent theme in three of the six publications considered [19,41], while water supply [34], and general watershed health [36] are also represented. China and India again dominate, with five of the six articles focusing on study areas from these countries. The lone exception focuses on Istanbul, Turkey which ranks as one of the densest cities in the world and whose geography and size make water accessibility particularly challenging. Küçükmehtetoğlu and Geymen [34] document the water resource basins available to meet Istanbul's demand, noting that with an average population growth rate of 4.5% and intense growth pressure to expand outward from the crowded core, water resources are severely constrained. Using satellite imagery and GIS to document and monitor land use changes, the authors found that leap-frog, low-density development has increased in recent decades due in large part to capital improvement projects designed to improve accessibility to the city core.

The impact of urban development on the physical characteristics of river networks is a recurring theme among the developing country articles. Wang *et al.* [36] use GIS to examine the relationship between urbanisation and watershed health near the city of Lijiang in southwest China. The density

and length of the river system decreased significantly between 1995 and 2009 due to branch reduction and alterations that accompanied rapid development. While anticipating a future decline in the rate of urbanisation in the watershed, the authors offer specific recommendations like constructing natural rainwater collection fields and embankments to maintain a basic level of ecosystem functions and ecological services. Similarly, Zhou *et al.* [41] focus on Shenzhen in China's Guangdong Province, which is located near the coast and has experienced rapid urbanisation since the mid-1980s due to market reforms and globalisation. The authors explore the temporal and spatial urban land change through remote sensing and GIS and detect river network alterations using hydrologic modelling, topographic maps, field surveys, and aeromagnetic and aerial photography. Kamini *et al.* [19] use GIS and remotely sensed imagery to study the relationship between land use/land cover change, wetlands loss, and flooding in the Mithi River catchment near Mumbai, India. Sprawl, understood as "rapid urbanisation" in the form of "slums, residential complexes and industrial units," has been linked to chronic flooding in Mumbai [19].

4.5. Causes of Sprawl

The preceding sections have established how the multidimensional nature of sprawl is reflected in the way recent studies have defined it and examined its environmental impacts. Although not all of the articles we analysed explicitly discuss the underlying causes of sprawl, those that do reveal a less fragmented, but still varied landscape. Many of the articles considered discuss sprawl as primarily a consequence of population growth. For example in Mumbai, population growth is viewed as the root cause of land reclamation along the Mithi River and subsequent expansion of "slums, residential complexes and industrial units" [19]. In Saharanpur, population growth is also identified as the chief driver of sprawling land development. This study in particular, acknowledges sprawl as both a cause of negative externalities (*i.e.*, the loss of prime farmland) and as a larger process with "the lack of employment opportunities in rural areas" as a significant component of urban growth in India [18]. The role of population growth as a central factor is echoed in a study of Dhaka, Bangladesh where "the urban core is already congested and badly polluted" and as a result "new development must take place in the fringe areas despite these being prone to flooding and containing highly productive farmland ([21], p. 283). Population growth is also seen as a key driver of sprawling development in southern France [20], which suggests that this understanding of the drivers of sprawl is not endemic to the developing world. In addition to population pressures, institutional factors are also common themes among the articles we reviewed.

A study of development patterns in the European Union asserts "sprawl is not an inevitable consequence of economic growth, but rather a result of specific government policies" that allow, and in some cases promote, unsustainable development ([22], p. 287). This sentiment is echoed in Power [23] who views "hidden government subsidies" (p. 731) as a key contributor to urban sprawl in the United Kingdom. Overly permissive land development regulations have been cited as "the main cause for sprawl" in the Mascalucia region of Italy ([24], p. 530). In India, sprawl is attributed in large part to government policies aimed at decongesting city centres, yet the overall result is unplanned, poorly connected residential areas. A lack of "systematic regional land-use planning" coupled with "the fragmented local government structure within each metropolitan area" has fuelled suburban

sprawl on the periphery of Indian cities ([14], p. 404). Küçükmehtetoğlu and Geymen [34] contend that a lack of planning and enforcement of existing regulations designed to protect water supply watersheds has led to sprawling development within the Istanbul metropolitan area. In China, a lack of planning is not generally considered to be an underlying driver of urban sprawl, but rather the result of the inability of central planners to consider the full range of impacts associated with development decisions [14,37]. As these studies attest, policy decisions can have far-reaching and unanticipated consequences with uncoordinated or otherwise inadequate planning efforts as commonly cited contributors to sprawling development across geographic contexts.

A smaller group of studies acknowledge the number and interrelatedness of sprawl drivers including “the growth and restructuring of the urban economy, the growth of tertiary and quaternary activities, automobile and highway development, increased urban income, and growing demand for open space and recreation” ([38], p. 1598). This expansive understanding is echoed by Haase and Nuissl [48] who assert that urban sprawl is driven by demographic and economic forces as well as the “common beliefs, values, and norms of conduct as well as the organisational and legal setting of a society” (p. 4). Studies like these suggest that an effective response to urban sprawl will require further research that directly investigates how various factors contributing to urban sprawl interact with one another and how those relationships are shaped by context.

4.6. Controlling Sprawl

In general, the recommendations offered for curbing the negative environmental impacts of urban sprawl in the articles we analysed are consistent with expectations, drawing heavily upon the Smart Growth canon of encouraging more compact development [64], investing in transit [15,39], balancing jobs with housing [40], and ensuring that the true costs of development are passed on to the direct consumers [14]. A prime example is Zhao and Lu [39] who advocate for growth management policies that rein in sprawl by increasing density, encouraging land use mixing, and reducing automobile dependence along the periphery of Beijing. However, a more measured approach can be seen in Fazal [18] who rather than simply calling for tighter growth controls, recommends that inventories and maps of land productivity be made and used to strategically channel outward expansion of Indian cities onto less fertile parcels. This similarity in responses to sprawl from two of the fastest growing developing nations is evidence of convergence across geographic contexts that transcends the familiar developed-developing country dichotomy. Although embracing the tenets of Smart Growth are most frequently suggested as the way forward, there are also articles that question the overall efficacy of such a strategy.

Robinson *et al.* [3] find that growth management policies like urban growth boundaries have been successful in raising interior densities, but have failed to curb the proliferation of “sprawling low-density housing in rural and wildland areas” (p. 51). Similarly, zoning and development regulations alone have not been enough to protect agricultural land from urban sprawl in Spain’s Bilbao region and market-based mechanisms, like transfer of development rights, have been suggested as a possible solution [25]. La Greca *et al.* [24] also emphasise the importance of market-based policies that capture the externalities of sprawling development and send the correct signals. Haase and Nuissl [48] conclude that land use planning is at best able to shape development patterns, but only by changing the

underlying drivers of urban sprawl through incentives and policies that target individual behaviour can the negative consequences be truly mitigated. In addition to questioning the efficacy of Smart Growth policies, not all studies concede that urban sprawl is a threat to be mitigated in the first place. For example, Garcia and Riera [29] recommend relaxing existing development regulations in the Barcelona region that are “overcorrecting the environmental externalities caused by outward urban growth” (p. 1934) so that conditions can better approximate the preferences of residents. Holden and Norland [49] find evidence of a limit to the benefits of compactness—a tipping point beyond which increased density and size begin to be associated with increasing energy consumption—as a further critique of one of urban planning’s core tenets.

In an attempt to address these limitations, many studies [22–24,26,28,51] advocate more proactive planning that is specifically driven by “core principles of sustainable development” ([21], p. 285) as a means for mitigating the negative impacts of urban sprawl. Conceptualising urban sprawl as a pattern of development unfolding over time that is incompatible with commonly accepted characteristics of sustainable development can potentially alleviate many of the difficulties that have plagued sprawl research, bridging the idiosyncrasies of growth across national contexts and alleviating the need to articulate a definition of sprawl that works everywhere. Another advantage of situating sprawl research within the context of sustainable development is an increased opportunity to connect with broader conversations and policy discourses.

5. Unifying Themes: Resilience and Justice

In this section, we consider the crosscutting nature of the studies reviewed to determine whether and how the evolution of research on the environmental impacts of sprawl is transcending barriers and to what extent they are responsive to the emergent challenges. We find many of the studies situated in the larger context offering direct or indirect linkages to other categories of environmental impact and connecting with broader conversations. For example, De Ridder *et al.* [46] adopt a highly technical approach in modelling the air quality impacts of urban sprawl, but rather than concluding the analysis there, the authors assess the specific implications of their work for low-income populations. Several of the articles considered here also make connections with food security [16,18,38] or energy scarcity [33,64], which further demonstrates the evolution and maturation of sprawl research. Overall, we identify two unifying themes—the first is preparedness and the vulnerability of sprawling urban areas to projected changes and future uncertainties, or resilience and the second is equity concerns related to disproportionate environmental impact on disadvantaged groups, or justice. Our analysis of emergent themes serves two purposes. It provides a mechanism to connect the lessons among studies that may be otherwise considered geographically and disciplinarily fragmented or occurring within “silos” and it helps to assess whether these emergent themes are responsive to the critical challenges that are commonly tied to the environmental impacts of sprawl. In that regard, it also provides some practical understanding to urban planners, whose decisions, howsoever limited in scope, often have broader implications.

We first characterise resilience and justice separately to establish their connections with the impacts of sprawl, then explore trends in the articles discussed above within that framework. For evidence of convergence across geographies or a wider approach to studying environmental outcomes, we discuss

articles that compare across developed and developing contexts or address more than one category of environmental impact. We also consider whether the authors explicitly situate their research within the broader framework of one of the emergent themes as further evidence of new directions in the sprawl literature. Table 3 provides a summary of our findings.

Table 3. Classification of studies reflecting themes of resilience or justice ($N = 16$).

Study	Theme	Research Approach & Focus
Brody <i>et al.</i> [32]	Resilience	Regression analysis, flood-related losses, development intensity, floodplain area, storm surge, wetland loss
De Ridder <i>et al.</i> [46]	Justice	Integrated computer simulations, human exposure to air pollution, population, employment, traffic flows, emissions
Domene and Saurí [47]	Resilience	Regression analysis, telephone interviews, residential water demand, household characteristics, housing unit characteristics, consumer behaviour
Fazal [18]	Resilience	Remote sensing, land use change, urban encroachment, loss of agricultural land
House-Peters and Chang [50]	Resilience	Surface energy budget model, water consumption, surface cooling, land cover change scenarios
Küçükmehtetoğlu and Geymen [34]	Justice	Remote sensing, land use change, encroachment on water supply resources
Pauleit <i>et al.</i> [55]	Justice	Remote sensing, land use change, hydrologic model, surface temperature
Poelmans <i>et al.</i> [56]	Resilience	Remote sensing, linear extrapolation of land use trends, hydrologic model, surface runoff, groundwater recharge
Power [23]	Justice	Trends analysis, social fragmentation, urban abandonment
Pucher <i>et al.</i> [14]	Justice	Comparative trends analysis, population density, urban form, transport infrastructure
Sietchiping <i>et al.</i> [15]	Justice	Comparative trends analysis, population density, urban form, transport infrastructure
Stone Jr. <i>et al.</i> [60]	Resilience	Statistical correlations, extreme heat events, surface temperature, urban form
Vallianatos <i>et al.</i> [16]	Both	Case study, trends analysis, agricultural production, land use change, childhood obesity
Xi <i>et al.</i> [37]	Justice	Cellular automata model, scenario analysis, loss of agricultural land
Xu [38]	Both	Regression, interviews, policy analysis, loss of agricultural land
Zasada <i>et al.</i> [31]	Resilience	GIS, land use change, demographic trends analysis, retirement migration

5.1. Resilience

Resilience, as commonly used today, has its origins in ecology and was defined nearly four decades ago as “the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” ([80], p. 140). Within an urban planning context, the term resilience was closely associated with natural hazards mitigation for many years [81,82] and a community’s ability to function and recover following a disaster. This focus has now expanded to include responses to climate change impacts and broader shifts in conditions (e.g., economic, energy prices, *etc.*) that are critical to the functioning of urban systems. The application of the notion of resilience can also be seen more generally in scenario planning or other techniques that explicitly acknowledge the uncertainty inherent in planning for the future [83].

Nine of the 52 papers we analysed address resilience to varying degrees. Seven of those articles are from the developed country context and two are from the developing country context. We also find some of these studies use the term resilience in its traditional meaning, while others use it more broadly. Stone Jr. *et al.* [60] discuss vulnerability to climate change impacts and the focus on extreme heat events provides a connection to health outcomes. This article is one of a relative few that use the term “resilience” (p. 1427) and is also broader than their previous work Stone Jr. *et al.* [59] which focuses only on the air quality impacts. House-Peters and Chang [50] is another example of how recent sprawl research uses connections with global climate change to approach the resilience theme. Their article considers two of the four categories of environmental impacts (see Table 2) with respect to sprawling development patterns, linking land use change to water and energy consumption outcomes under different climate change scenarios for the city of Hillsboro, Oregon, USA. For the remaining developed country articles, connections to the resilience theme tend to be less direct. For example, Poelmans *et al.* [56] is potentially relevant to resilience if maintaining adequate water supply falls under its umbrella, but the authors are vague as to how their work is connected to shortages and planning for sustainable water supply. Similarly, Domene and Saurí [47] is relevant if we expand the understanding of the resilience theme to include water availability more generally and the same is true for Zasada *et al.* [31] and Küçükmehtetoğlu and Geymen [34].

In the case of developing country studies, direct connections are even less common. Fazal [18] focuses on the loss of farmland in India and talks about the long-term implications for maintaining agricultural productivity and by extension food supply, but never uses the term “resilience”. Xu [38] focuses on food security in China in the wake of development of the countryside and the general lack of rural planning. However, this article fits well with an expanded understanding of resilience that includes food security in much the same way that the water supply studies mentioned above could be interpreted.

5.2. Justice

The justice theme is rooted in the movements of the past that sought to demonstrate the negative and inequitable distribution of resources, opportunities and power, and higher vulnerability to future uncertainties [84]. These articulations are consistent with the postmodernist, post-colonial and feminist critiques of planning that seek to undo past harms [85–87], as well as the principles embodied in the

advocacy planning framework [88]. More recently, Fainstein [89] identifies democracy (participatory governance), diversity (physical and social heterogeneity), and equity (appropriately redistributive public policy) as the three fundamental dimensions of justice and argues that a key challenge for planners is to navigate the inherent tensions between these imperatives. Our findings suggest that justice can be taken as another compelling lens with which to examine environmental outcomes and as a way to identify patterns and new directions in this strand of the literature.

Nine of the articles we evaluated address justice directly or indirectly and unlike the resilience theme, a larger proportion focus on developing countries. For example, Xi *et al.* [37] is related to justice in that it assesses the potential conflicts between China's Building a New Countryside initiative with farmland protection and the impacts on the ability of poor farmers to support themselves. Similarly, Küçükmehtetoğlu and Geymen [34] focus on water resources for Istanbul and present an on-going issue with illegal squatting on land near the city's surface water reservoirs. They argue that the government has failed to enforce existing regulations to protect water supply basins and also to "direct the transition from an agrarian rural society to an industrialized one" (p. 578), which has driven the growth of illegal settlements within the city. Sietchiping *et al.* [15] is also relevant to the justice theme because it explicitly talks about income and gender as important factors in understanding travel behaviour and as a legitimate compass for transportation investment and policy.

In addition to these direct references, a number of other developing country studies warrant mention for their less obvious ties to the justice theme. For example Xu [38], mentioned in the preceding resilience section, notes the hypocrisy of "protectionist regulations and policies" designed to protect prime farmland and the reality that these resources are "often sacrificed to capital accumulation by the state" (p. 1613), which speaks to the participatory governance aspect of Fainstein's [89] notion of justice. Similarly, Pucher *et al.* [14] briefly consider the implications for the poor and segues from the discussion into policy recommendations (p. 396).

As for developed country studies, Pauleit *et al.* [55] calculate an index of multiple deprivations and consider how the loss of open space varies across more and less affluent areas, concluding that the environmental costs of development are not uniformly distributed. This work clearly fits with the justice theme. Vallianatos *et al.* [16] is related to the justice theme in that it speaks to Fainstein's [89] third dimension of justice—appropriately redistributive public policy. Namely, the article focuses on local food production as a sprawl mitigation strategy but also as a way of "improving the health and nutrition of school-age children, particularly low-income youth" (p. 415). Power [23] is more descriptive than explanatory in approach, but nevertheless makes the connection between sprawl and social exclusion in England and Wales. Lastly, De Ridder *et al.* [46] is a clear example of how sprawl can be understood as an equity issue and the central finding is that more affluent suburban residents have lower exposure to potentially harmful air pollution than those who reside in central cities (p. 7077).

5.3. Emergent Themes

While 16 of the 52 articles we considered engage themes of resilience and justice, limiting our discussion to these articles may underestimate the degree of silo-busting or convergence in the recent literature. In order to capture other important trends, we also identified articles that draw contrasts

across the developing-developed country divide, that consider multiple categories of environmental impact, or that situate themselves within larger, but related conversations.

Surprisingly few studies were found that are comparative in nature and work across national boundaries. Lehmann [64] compares Berlin with Shanghai and demonstrates that many of the consequences of sprawl and conversations around the themes transcend the familiar developed-developing dichotomy. Hamlin and Gurran [30] also provide a comparative case study, albeit between developed country contexts (U.S. and Australia) and like Lehmann [64], clearly focuses on the climate change issue. We also found a few studies that, though not comparative, draw references or implications for other contexts. For example, Zhao and Lu [39] mention the developed-developing world dichotomy in the first sentence of their article and focus specifically on transportation policies to limit carbon emissions in Beijing. Similarly, Paül and Tonts [17] mention the developed-developing world dichotomy and discuss at length the loss of rural character and agrarian lifestyle in the wake of sprawling development (p. 11, p. 21) in the Barcelona region. These studies offer some evidence that the familiar developed-developing world dichotomy is becoming less relevant for sprawl research. It is also possible that comparative sprawl research is being conducted more frequently, but is not appearing in urban planning journals. Cross-boundary studies such as the EU SCATTER and PROPOLIS projects [90,91] come to mind as relevant efforts to combine knowledge of existing relationships between land use and transportation outcomes, expert understanding of policy connections, and future scenarios using simulation models but have not been published in peer-reviewed outlets.

Ten of the studies examined discuss more than one category of environmental impact and several others make clear connections with broader scholarly discourses. Among those that fit the latter criterion, McEldowney *et al.* [26] specifically mention the convergence of land use and transportation policy initiatives in Belfast, Northern Ireland “as a means of delivering more sustainable patterns of development in terms of reducing car dependency and urban sprawl (p. 508)”. Haase and Nuissl [48] focus primarily on the impact of sprawl on water resources, but also conclude that “the environmental dimension of urban sprawl is connected to the societal sphere” (p. 11) and that opposition to sprawl in Leipzig is driven by a variety of concerns (e.g., NIMBY, social exclusion) that extend beyond its environmental consequences. Huang *et al.* [51] mention both globalisation and “global environmental change” as key drivers of the sprawling development that has threatened agricultural land and ecological functions in the northern region of Taiwan. Finally, Garcia and Riera [29], Barbour and Deakin [42], Bart [22], Tiwari *et al.* [62], and La Greca *et al.* [24] are all examples of articles that situate themselves firmly within the climate change conversation.

6. Conclusions

This article documented and synthesised sprawl literature from the past decade across four categories of environmental impacts, developed and developing country contexts, and considered resilience and justice as emergent themes. Our findings suggest that sprawl research has evolved and the key questions that define the sprawl debate have shifted from arguments over definitions and measurements to establishing broader linkages with present and future challenges. Emerging issues like climate change and the inequality associated with globalisation are increasingly used to frame and

inform urban planning research in general and to evaluate the impacts of sprawl. More specifically, we believe that this trend is motivated by several key factors. First, while past work on developing specific measures of sprawl enabled subsequent research, the inability of past work to fully address the emerging challenges from climate change and globalisation have also necessitated researchers to adopt less narrow and more interdisciplinary approaches. Second, the interconnectedness of human and natural systems demands greater consideration in planning decisions. For example, the dependence of sprawling development patterns on cheap and abundant energy is threatened by fluctuations in prices. Finally, governmental agencies and large funding organisations are increasingly emphasising the need for interdisciplinary and comprehensive proposals. It is therefore not surprising to see researchers responding to these signals.

We should also note a number of limitations with our review and synthesis. First, while we find that a large subset of the studies situate themselves in the literature on themes, some continue to be narrowly focused. This could be attributed to our approach of looking at journal articles only, given that this publication format may require researchers to present their work in certain ways. Next, we only considered English language planning journals that are overwhelmingly published in developed countries. These kinds of institutional factors may help to explain why we find more examples of articles from developed contexts and, to some extent, the convergence of research topics published in these journals. Finally, our analysis focuses specifically on the environmental impacts of sprawl and while these relationships are important, they represent only one aspect of the sustainable development paradigm. Economic and social dimensions of sustainable development are as important as environmental considerations and the true challenge for those who inhabit, manage, and study urban area is to somehow balance these three aspects. In that regard, the emergent themes of resilience and justice could be understood as principles that facilitate compromise and provide a link to economic and social impacts that are important, but fall outside the scope of our research.

Our evaluation indicates several encouraging trends in the recent sprawl-related research. We identify a number of empirical studies that consider impacts of sprawl across multiple environmental dimensions. We were also encouraged by the direct and indirect references to the unifying themes of justice and resilience and also find evidence of convergence in studies from developed and developing countries. However, this does not imply that context no longer matters and instead suggests that similar issues are gaining visibility around the globe. In the coming decade, we hope to see further research in a number of new directions in order to maintain the present momentum. We would like to see more comparative studies across developed and developing countries that achieve robustness by focusing on commonalities in environmental outcomes rather than fixating on their differences. Rather than perpetuate the dichotomy, such studies will be particularly instructive and provide useful guidance for planning practitioners. Finally, we find that justice has received less attention than resilience in the sprawl literature in the developed country context and *vice versa*. We hope to see more research that engages with and balances the two themes identified here across all geographic contexts in order to better guide policy and planning practice.

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Conflict of Interest

The authors declare no conflict of interest.

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