Sustainable Management of roadside: towards a research agenda

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Abstract

The relationship between road infrastructure and economic development are widely studied since 25 million kilometers of new roads will be built by 2050. Closely linked to the growth of road infrastructure, there has been an increase in the area dedicated to roadside. The roadside verges are a social interface between forests, wildlife, agricultural farms, rural communities, vehicles, communication networks, landscape, and many other aspects. The roadside has the potential to generate positive and negative effects on human health, environment, ecology, road security and energy. It is relevant to analyze how scientific researchers have studied the roadside management and to what extent they are integrated the ecological, social and economic sustainability. A systematic literature review is developed aiming of define the research trends about the relationship between sustainable management and roadside or roadside verge through graphical representation of bibliometric maps using VOSviewer, a visualization tool. Key issues are identified in recently published papers such as environmental, vehicular network, communication, security, health, energy and markets. These issues must be integrated in a research agenda to highlight the need to adopt a transdisciplinary and systemic approach concerning territorial studies. Furthermore, we must also remark that it is capital that a sustainable management of roadside verges develops a strong multidimensional vision from ecological, social, economic, technological and political points of view. Also, future developments need to be focused into non-deterministic or lineal models or strategies of roadside management and its integration in local dynamics, to fully contribute to the sustainability of territorial development.

Keywords— *Road edge, road verge, rational management, sustainability*

I. INTRODUCTION

The XXI century was characterized by an unprecedented road expansion. On a global scale, it is expected that 25 million kilometers of new roads will be built by 2050. It is expected that about 20% of all road construction to occur in developing nations, including county highly-biodiverse ones [1]. Roads are social, economic and political manifestation of a territory, such manifestation is correlated with the processes of landscape transformation, which finally affect the ecological environment. Likewise, road depends on social structures, and their board is influenced by landscape structure [2].

Closely linked to the road is the roadside, road edge or road verge, which has a very important impact on the safety of the route, the rural development, the attractiveness of the territories, the generation of local value, and biodiversity preservation. Roadside infrastructure typically consists of four major components, pavement, berms or shoulder, ditch and embankments [3]. In England, these specific environments are home to 35 plant species, about 20 mammals' species and 25 butterflies' species. In Walloon region (Belgium), the roadside are the habitat for more than 700 plant species, or 50% of the region's flora, including some protected species [4]. In France, represent 2,850 km^2 in the national roads and 2,000 km^2 for the dependencies of municipal roads. Roadside is thought to be the largest wilderness in France compared to the 3,450 km^2 of the six national parks [3].

An essential component of roadside maintenance is vegetation care, this natural vegetation becomes a buffer between traffic and the rest of the landscape, absorbing noise, particulate matter, dust, and water from path surfaces. However, roadside mowing and its management is complex, demand many technical and economic resources and high time-consuming. Maintaining roadside for safety, beautiful landscapes, keep the local regions competitive and attractive is an important issue at all levels of government [5].

Road edge also contributes to the quality of the road's own landscapes and their integration into the landscapes of the territory crossed [6]. Likewise, a majority of the population uses roads every day and the safety of users must remain a primary objective, especially by ensuring good visibility and allowing them to stop in case of emergency. Thus, roadside maintenance ensures optimal visibility and promotes road safety [3].

On the other hand, roadside is also a social interface between farmers and roadside maintenance workers and an interface between the agricultural world, in general, rural areas, and road users. This dual nature of the interface, which separates two environments at the same time as creating a continuity, here vegetable, can reflect the complexity of the relations that societies maintain with nature [7].

Different strategies of roadside mowing are applied, intensive, differentiated mowing and rational mowing, with or without waste biomass removal. Usually, mowing along the

978-1-5386-1469-3/18/$31.00 ©2018 IEEE

roadside edges of the tracks leaves the cutting products in place, which eventually decompose naturally. In doing so, a plant substrate accumulates gradually until it disrupts the flow of water in ditches, which requires specific maintenance. The substrate is also a fertilizer that favors the re-growth of unwanted species, such as nettles, at the expense of biodiversity [8]. In the management of roadside verges, the waste extraction from roadside mowing (grass and wood) could provide a beneficial feedstock for use in biogas systems, anaerobic digestion, composting, or combustion [9]. The possibility of roadside grass use for energy production becomes increasingly relevant [9]. As a consequence, the international renewable energy policies aim to increase the share of energy produced from renewable resources of non-purposely grown energy crops [10]. The report from the Commission to the Council and the European Parliament in 2010 on sustainability states the requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling, but it is not applied to waste and residues, should only comply with the GHG criteria. The minimum GHG savings from biomass should be at least 35% compared to the EU's fossil energy mix, increasing to 50% from 2017 for existing plants and 60% from 2018 for new plants [11].

Therefore, these green dependencies must be integrated within the framework of the territories in the sustainable management, with a holistic view. With the aim to rehabilitate the landscapes, the life spaces, and to study the road edge as crosscutting axe around which it is possible to create an economic, ecological, cultural and social attractiveness for the territory. Simultaneously developing a clean transport, making attractive territories for local residents and promoting eco-tourism and rural development [12].

Taking into account that the roadside could have positive, but also negative effects on the social, economic and ecological dimensions of a territory, there is need to analyze how scientific researchers have studied the roadside management and to what extent they are integrating the ecological, social and economic sustainability dimensions. So, this work develops a systematic literature review with the aim to explore what are the main fields of research that have been worked on, what are the research trends around the relationship between sustainable management and roadside or roadside verge through graphical representation of bibliometric maps. This type of representation is the keyword based on co-occurrence data using VOSviewer a visualization tool based on clustering algorithms [13].

We identified a strong agreement between the structure of the map and the obtained clusters that represent potential research fields and draw attention to the most important research areas. Finally, overlay visualization is explored to find the temporal evolution of this research field. As conclusion, the promising fields where sustainable management and roadside have interactions are highlighted. Furthermore, the main axis to be developed, in order to place the roadside verges as an integrative part of the territory, will be highlighted to propose a research agenda for the coming years.

II. Method

Regarding the roadside influence on the landscape, maintenance ecological environment, social structures, road safety, economic development, attractive territories, and potential profitability of biomass waste from roadside mowing, the objective of this review research is to determine how scientific community has addressed the key challenges for sustainable management of roadside. Thus, a systematic literature review method composed by search strategy on scientific databases and applying VOSviewer® tool that implements the mapping technique, and co-occurrence data analysis.

Search strategy

In order to determine how other researchers have addressed the sustainable management of roadside, a search strategy was designed including the steps shown in table 1: (1) keywords and Boolean expression definition to perform the search in databases; (2) establishing sources of information to be employed (database); (3) delimiting the period to be explored.

TABLE 1. Search strategy steps

Steps	Description
keywords and Boolean expression	(Title-Abs-Key ("roadside") Or Title-Abs-Key ("road verge") Or Title-Abs-Key ("road edge"))
Sources of information	Scopus
Period of information	Pub year > 1999

A. VOS mapping technique

The map construction by VOSviewer consists of three steps; first calculate a similarity matrix, second construct a map, and third translate, rotate an reflect the map [13]. The first step, it is to calculate a similarity matrix based on the co-occurrence matrix; it uses a similarity measure known, as the association strength as shown in equation (1) and it is similar to the proximity index or as the probabilistic affinity index.

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \tag{1}$$

Where c_{ij} denotes the number of co-occurrences of items i and j and where w_i and w_j denote either the total number of occurrences of items i and j or the total number of co-occurrences of these items, for further discussion of the association strength we refer to [14].

The second step, it is the construction of a map based on the similarity matrix obtained in step 1. A simple open source computer program that implements the VOS mapping technique is available at www.neesjanvaneck.nl/vos/. The general aim of the VOS mapping technique is to minimize a weighted sum of the squared Euclidean distances between all pairs of items. The higher the similarity between two items, the higher the weight of their squared distance in the summation [13]. In mathematical notation, the objective function to be minimized is given by equation (2). Where the vector $x_i = (x_{i1}, x_{i2})$ denotes the location of item i in a two-dimensional map and where $\|\bullet\|$ denotes the Euclidean norm. Minimization of the objective function is performed subject to the constraint equation (3). Further information of how the constrained optimization problems of minimizing (equation 2) subject to (equation 3) is developed in [13].

$$V(x_1, \ldots, x_n) = \sum_{i<j} s_{ij} \|x_i - x_j\|^2 \tag{2}$$

$$\frac{2}{n\,(n-1)} \sum_{i<j} \|x_i - x_j\| = 1 \tag{3}$$

The step 3, VOSviewer transform the solution obtained for the optimization problem discussed in step 2, applies the following three transformations: first, the solution is translated in such a way that it becomes centered at the origin. Second, the solution is rotated in a way that the variance on the horizontal dimension is maximized. This transformation is known as principal component analysis. If the median of $x_{11},\ldots,x_{n1}$ is larger than 0, the solution is reflected in the vertical axis. Third, if the median of $x_{12},\ldots,x_{n2}$ is larger than 0, the solution is reflected in the horizontal axis. These three transformations are sufficient to ensure that VOSviewer produces consistent results [13].

B. Co-occurrence data analysis

The research fields are identified based on density and cluster view. The density view is represented by a color of a point in the map based on the item density. Let $\overline{d}$ denote the average distance between two items (equation 4), the item density $D(x)$ of a point $x = (x_1, x_2)$ is then defined in equation (5). Where $K:[0,\infty) \rightarrow [0,\infty)$ denotes a kernel function, $h > 0$ means a parameter called the kernel width, and w_i represents the weight of item i, that is, the total number of occurrences or co-occurrences of item i. The kernel function must be non-increasing. VOSviewer uses a Gaussian kernel function given by equation (6) [13].

$$\overline{d} = \frac{2}{n(n-1)}\sum_{i<j}\|x_i - x_j\| \tag{4}$$

$$D(x) = \sum_{i=1}^{n} w_i K\left(\|x_i - x_j\|/(\overline{d}h)\right) \tag{5}$$

$$K(t) = \exp(-t^2) \tag{6}$$

The item density is calculated of a point in a map separately for each cluster. The item density of a point x for a cluster p, denoted by *Dp (x),* is defined as equation (7), where *Ip(i)* denotes an indicator function that equals 1 if item *i* belongs to cluster *p* and that equals 0 otherwise.

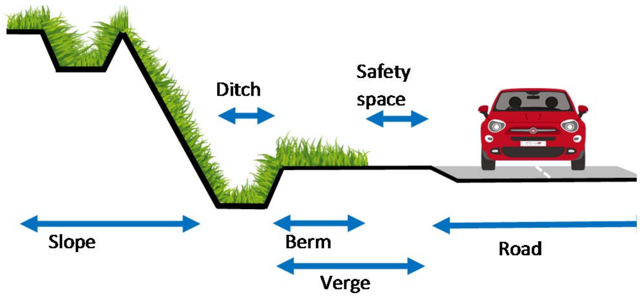
$$D_p(x) = \sum_{i=1}^{n} I_p(i) w_i K\left(\|x_i - x_j\|/(\overline{d}h)\right) \tag{7}$$

III. Roadside Background

Road dependencies consist of all the road public domain except for pavements and the emergency stop strip; it is are made up of road, safety space, berm, ditch and slope as shown in Fig. 1. Dependencies maintenance it is the work made or controlled by subdivision aimed to keep the user safety and maintain road schedules [15]. Roadside, their edge effect, their attractiveness to wildlife and their function of refuge for flora s these landscape features a role of ecological corridor. The possibility offered by the green dependencies to connect the various elements of the landscape, coupled with their continuous distribution across the whole of the territory seem to make essential links in the ecological network [16].

In Europe, the British institutions were the first to become aware of the interest that represents the road edges for the conservation of their natural heritage. This awareness was initiated by "The Nature Conservancy" who makes, in 1967, a study on the floristic diversity of the side of the road showing that nearly 45% of the plant species in British territory are found on roadside [17]. As early as 1970, many areas of remarkable species are thus selected to their patrimonial and scientific interest: “special roadside verges”. The first protection measures appear in 1994 when the "Roadside Nature Reserves" were created in the County of Kent, England (134 reserves of roadside in 2013). Very quickly, the interest at the road edges was extend to other European countries. The Netherlands, the Sweden, the Switzerland or even Wallonia (Belgium) set up operations to study the roadside to set up proper management [3]. In France, it was in the early 1990s beginning the roadside perception as a sensitive natural spaces, so the first experiences of integrated management appeared in the departments of Calvados and Mayenne, particularly at the instigation of nature protection associations. In 2013, 24 General Councils set up differentiated management of their departmental roadsides, either systematically on all departmental berm areas or in a localized manner, particularly in cases where the objective is to preserve areas with a high heritage value. For some General Councils, differentiated management is even included in departmental Agenda 21 [3].

FIGURE 1. Roadside



The roadside management must consider multiple dimensions in the context of the territories, to rehabilitate landscapes, living spaces or to perceive the road edge as many areas of crosscutting. Around or create an attractive economic, ecological, cultural and social, along with developing clean transport, making desirable cities, and generate attractive areas for local residents and promote tourism, ecotourism and rural tourism [12].

Furthermore, the energy transition, which promotes local communities to create jobs in the field of green growth more effectively in counterbalancing effects of climate change, these are the priorities that need to bring all together [12]. In this context, the roadside management must contribute to improving the attractiveness of the territory and the creation of local value. In this respect, this type of management integrates the developing circular economies, through the valorization of biomass, green industries, organic agriculture, and the contribution to the local energy deficit reduction.

In many countries, there are legislative frameworks on the environment setting and legal obligations for road authorities and their suppliers. Although, no explicit recommendations exist on how to join the environmental aspects required for the management of the road heritage has been defined, there are several good examples of heritage management practices that take into account environmental considerations. For example, management of the value in the United Kingdom and management based on the risk in the United States consider environmental aspects as an integral part of the decision-making criteria [18].

Some agencies also adopted guidelines for sustainable maintenance, although the safety issues, the mowing cost or the availability means are the principal criteria to set up roadside management. There are many techniques as shown in Table 2. The roadside maintenance differentiation in space and time of a mode of extensive mowing is called integrated, the more often mowing is called intensive, and the minimization frequently way is named late-mowing [7]. Depend on the type of technique applied, the preservation and restoration of ecological corridors to encourage biodiversity to be guaranteed, without compromising road safety.

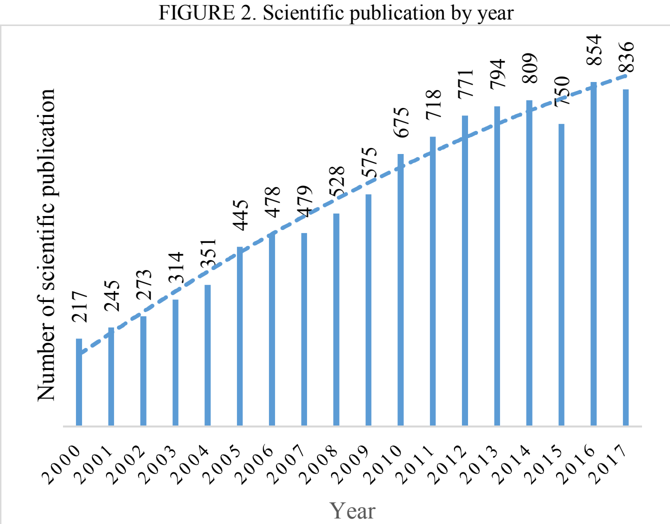
TABLE 2. Techniques of roadside maintain

Techniques	Type 1- Intensive	Type 2 – Integrated	Type 3- Late -mowing
Mowing frequency	≥ 3 twice a year	Maximum 2 twice a year	Maximum 1 twice a year
Cost	High cost	Medium cost	Low cost
General considerations in roadside management		It is in function of roadside space (berm, fosse, slope) and sensitive natural spaces	
		Greater potential for the collection and use of biomass waste	
	The use of phytochemicals is accepted	The use of phytochemicals is restricted	Phytochemicals are not used
	Fight against invasive plant species		

IV. Results

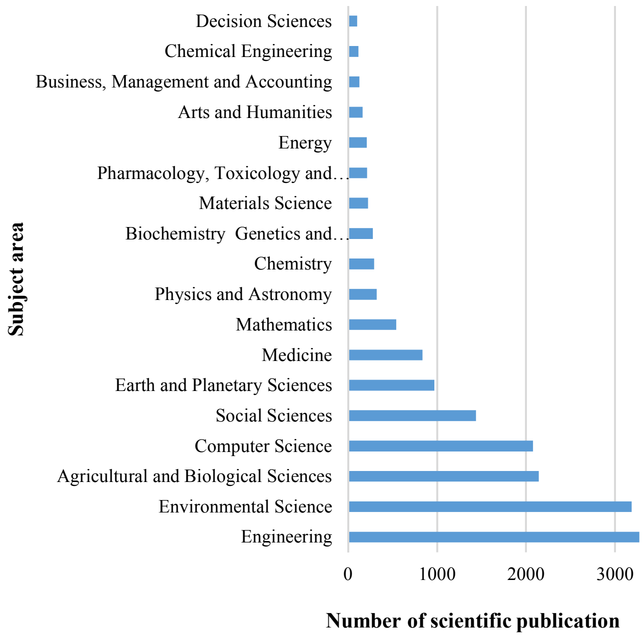
According to the search strategy above described, 10112 scientific publications were found thanks to the selected keywords and Boolean expression, in database SCOPUS, in period between 2000 and 2017. Due to the large number of scientific publications, a global approach is developed. The growing number of publications from 217 works in 2000 to 836 in 2017 evidence the scientific community's interest on the roadside subject. The number of scientific publications by year is shown in FIGURE 2.

FIGURE 2. Scientific publication by year



Keep up with the global approach of the present research, the different scientific areas represented on this set of papers are presented in FIGURE 3. Engineering, environmental, agricultural and biological, computer and social sciences are the top five of disciplines that tackle in their research field the roadside subject. Concerning the countries those whit the higher number of scientific documents published are the United States, China, United Kingdom, Japan and Canada. These five nations totaling over 5700 papers and account for 56% of total publication between 2000 and 2017.

FIGURE 3. Subject area by publications



A. *Network visualization*

Conditional specification was defined for applications in network construction and they are summarized in Table 3. For each keyword, a relevance score is calculated. Based on this score, the default choice is to select the 60% most relevant keywords, so the number of selected keywords for this particular case, were 163.

TABLE 3. Conditional specification

Specification	Condition
Number of total scientific documents:	10112
keywords:	20351
Minimum number of occurrences of a keyword:	20
Meet the threshold keywords:	163

For each keyword, the font size of the keyword's label and the area of the keyword's circle depend on its weight and it is displayed in Fig. 4. This weight usually it is equals the total number of occurrences or co-occurrences of the keyword [13].

B. *Cluster analysis*

In this view, each circle in the Fig. 3 has a color that depends on the density of items at that point. Five clusters were identified, and their description is shown in Table 4. The cluster 1 (green color), represents researches about subjects related to roadside, road ecology, management, biodiversity, bioenergy, biomass habitat fragmentation, species richness, agriculture, landscape, invasive species and connectivity. Whereas, the second cluster (yellow color) represents areas more related to soil contamination, heavy metals, polycyclic aromatic hydrocarbon, source apportionment, biomonitoring, and traffic pollution.

TABLE 4. Clusters description

Cluster	Principal Keywords	Keywords related
Cluster 1 (Green, 43 Keywords)	Roadside	Road ecology, vegetation, distribution, restoration, invasion exotic species and its dispersal, conservation
	Road ecology	Ecosystem service, farmland, management practice, forest, negative effect, landscape, bird, butterfly, pollinator, plant species richness, plant diversity, road verge, mowing, corridor,

Cluster	Principal Keywords	Keywords related
		herbicide, roadside management, management practice, connectivity
	Conservation	Management, landscape, habitat, diversity, monitoring, habitat fragmentation, agriculture, road ecology, road verges.
	Biodiversity	Species richness, road verges, distribution, GIS, habitat fragmentation,
	Invasive species	Diversity, distribution, connectivity, disturbance, invasion exotic species, roadside survey.
	Biomass	Productivity, bioenergy, simulation, wood, stump, chipping, whole tree, harvesting, residue, fuel, costs, supply chain
	Habitat	Forest, corridor, species richness, semi-natural grassland, biodiversity, woodland grassland, flora, conservation, diversity, bird, landscape, wildlife, invasion, restoration, seed,
	Management	Conservation, habitat fragmentation, agriculture, road verges, landscape, habitat, diversity, road verge, invasive species, disturbance, plants, land use, mitigation, traffic, environment, air quality, particulate matter, vehicular networks, roadside units, and safety management.
	Agriculture	Road verges, management, conservation, biodiversity, invasive species, landscape, land use, safety
Cluster 2 (Yellow color, 36 keywords)	Heavy metals	Roadside soil, urban soil, Runoff, Lead, road dust, land use, contamination, traffic density, traffic pollution, PAHs, biomonitoring, roadside - air pollution.
	Roadside soil	Heavy metal (lead, chromium, zinc), contamination (heavy metal, dust, PAH), accumulation (sediment, soil, salt, sodium, chloride, soil organic matter). Risk assessment, traffic pollution, vehicular emissions, spatial distribution,
	Soil contamination	Concentrations, leave (tissue, bacterium, salt), emission, pollutants, organic matter, uptake, PAH, health risk.
Cluster 3 (blue color, 36 keywords)	Vehicular Ad hoc Networks (VANETs[1])	Network, connectivity, urban environment, road safety, performance evaluation, warning, traffic Information, connectivity, infrastructure communication, Roadside Unit (RSU[2]), routing protocol, infrastructure, traffic flow traffic congestion, technology, innovation, intelligent transport systems, management systems, data dissemination.
	Security	Vehicular communication, VANET, authentication, privacy, RSU, vehicular networks, wireless communication, wireless sensor networks, global position systems (GPS), intelligent transportation, performant evaluation, safety.
Cluster 4 (brown color, 26 keywords)	Air pollution	Traffic emissions, particulate matter, deposition, nitrogen dioxide, PAH, ozone, benzene, carbon monoxide, exposure, air quality, particles, nanoparticles, monitoring, black carbon, street canyon, ultrafine particles, elemental carbon.
	Air quality	Air pollution, traffic pollution, road dust, polycyclic aromatic hydrocarbons, heavy metals, vegetation, road safety, vehicle emissions, particulate matter, and size distribution. Road Traffic noise, environnement, mitigation végétation.
	Particulate matter (pm)	Air pollution, air quality, pm10, pm2.5 source apportionment, dust, trace metals, biomonitoring, vegetation, remote sensing, urban, epidemiology, management, emission factor.
Cluster 5 (fuchsia color, 19 keywords)	Drug Alcohol	Driving, traffic safety, roadside survey, epidemiology, psychoactive substance, illicit drug, medical drug, legislation, crash, traffic accident, vehicle
	Traffic safety	Driver, cannabis, drugs, alcohol, roadside safety, design, road safety, mitigation, countermeasure, guardrail, crash data, collision, survivor, roadside barrier, roadside object, intelligent transportation systems
	Safety	Roadside, environment, monitoring, transportation, barriers, roadside survey, epidemiology, driving, simulation, GPS, VANET, cloud computing, security.
	Collision	Injury, law, vehicle network, landscapes, habitat, birds, wildlife.

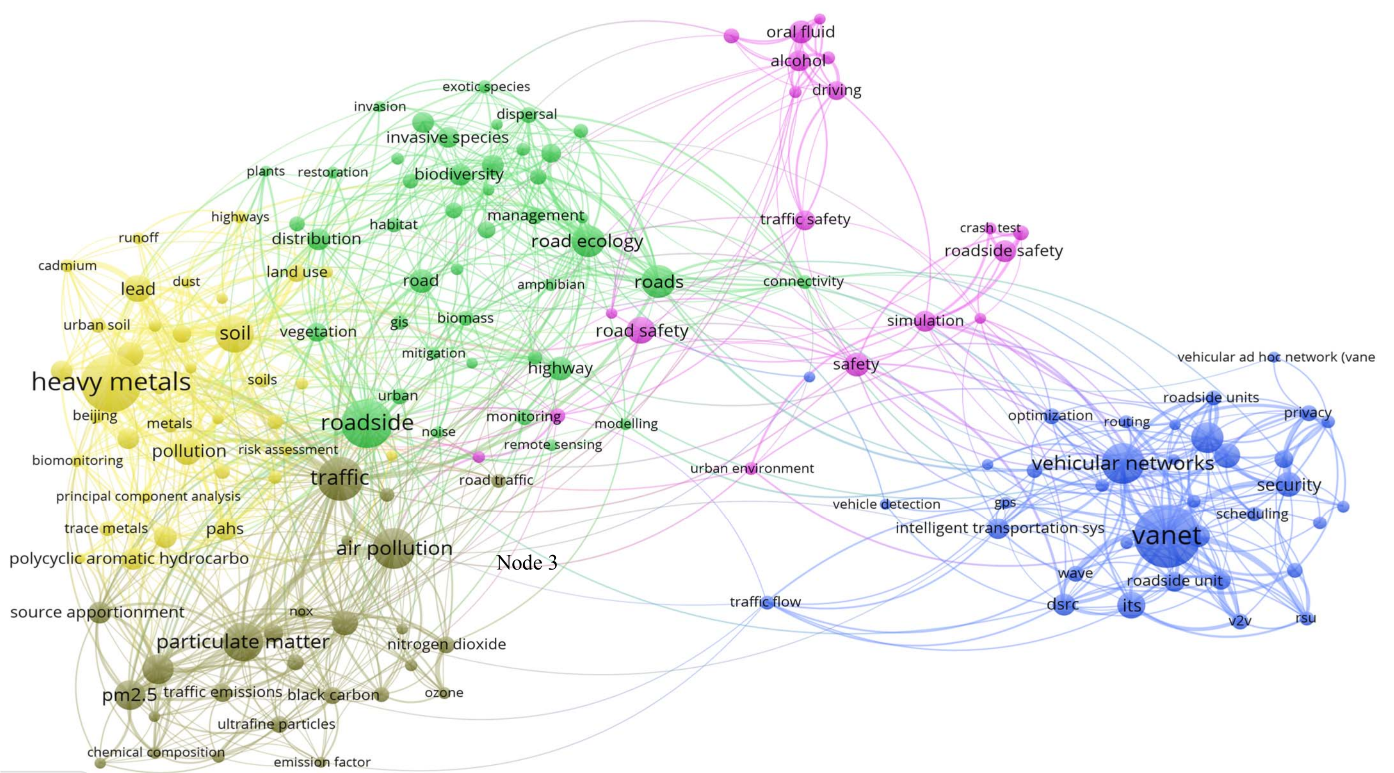
The third cluster (blue color) is about vehicular networks, intelligent transportation, traffic flow, cloud computing, security, vehicular communication, and management system. The fourth cluster (brown color) concerning air pollution (pm10, PAH[3], NO_2, NO_x), air quality, particulate matter, source apportionment, emission factor and traffic. The fifth cluster (fuchsia color) represents researches about drivers linked to drug consumption, crash, collision, roadside safety, traffic safety and urban environment.

[1] Vehicular Ad hoc Networks, also known as VANETs, enable vehicles that are not necessarily within the same radio transmission range to communicate with each other. VANETs also allow vehicles to connect to Roadside Units (RSUs) [64].

[2] Roadside Unit (RSU): Computing device located on the **roadside** that provides connectivity support to passing vehicles

[3] Polycyclic aromatic hydrocarbon

FIGURE. 4. Network visualization



C. *Towards a research agenda*

In the cluster analysis, we have highlighted how the research on the road edge, they are observed five focuses, ecology, soil contamination and heavy metals, air pollution and air quality, vehicle networks and traffic safety. It remains now to establish how the interest of researchers has evolved around these focal themes. For this purpose, it is possible to address an overview about the keywords that were considered in previous research under a temporal perspective, based on time evolution of research keywords shown in Fig. 5.

The keywords considered in the scientific documents between 2000 and 2010, they are represented in Fig. 5 by the blue color. It is observed that the cluster 1 about road ecology, conservation, biodiversity, invasive species, biomass, management, agriculture and the cluster 2 concerning heavy metals, roadside soil and soil contamination, and some keywords of cluster 5 about traffic safety, roadside safety and drugs, were the most studied topics during this period.

Between 2011 and 2013, the most representative keywords that were considered by researchers are shown in Fig. 5 in green color. They are related to models of spatial distribution of contamination, air pollution, particulate matter, heavy metal, and invasive species, as well simulation in urban environment of air pollution. Also, source apportionment of pollution, roadside soil, soil pollution, risk assessment. Regarding ecology issues, the keywords considered are connectivity of biodiversity and habitat fragmentation. Finally, in this period the keywords related to the simulation of safety, especially in urban environments, crash-test, design of roadside units and vehicular networks.

The keywords considered between 2014 and 2017 are represented by yellow and orange colors in Fig. 5. These keywords are described in Table 5 and are classified in four key issues, environmental, network - communication, security - health, and socioeconomic.

As we have discussed, research on roadside verges offers important insights into roadside contamination and other anthropogenic disturbances. The environmental research has a trend to whom roadside effect on biodiversity, connectivity, ecosystem fragmentation and soil contamination. However, there is a growing body of literature about the potential of a roadside verge to generate benefic impacts such as suitable habitat, promotion of ecosystem services, wildlife and biodiversity preservation, soil and air quality, noise reduction, invasive vegetation control, pollutant emission mitigation and their connection with human health. Also, inundations regulation, promotion of road safety, production of bioenergy based on biomass and attractive territory, are emerging areas that are gaining interest among the scientific community.

Other relevant subjects were vehicular and transportation networks, intelligent systems of communications and connectivity. Lesser extent, the research on security, health risk assessment, energy efficiency, local development roadside management, and how roadside verges are integrated into global flows of capital, culture, connectivity, landscape planning, territorial management and supply chain. The research subjects about smart cities, farmers' market, roadside infrastructure, biomass, bioenergy an energy efficiency, are emerging as promising topics for future research.

FIGURE 5. Evolution in time of research keywords on roadside verges

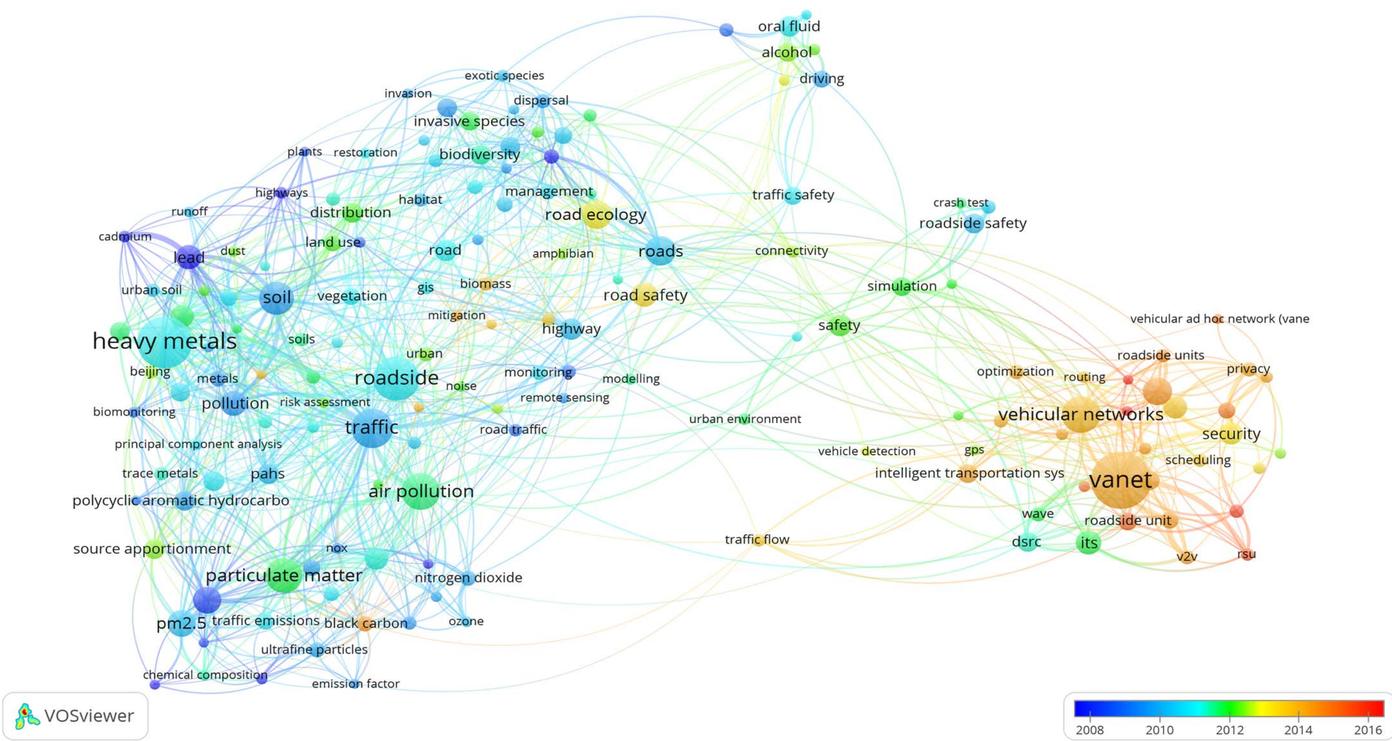


TABLE 5. Key issues identified in recently of research keywords on roadside verges

Issues	Period: 2014-2017
Environmental	Black carbon linked to air quality and air pollution, traffic and urban soils. Trace element in contamination Magnetic susceptibility about pollution and heavy metals Road ecology and its effects on habitat fragmentation, biodiversity, conservation, vegetation barrier and barrier effect barriers, amphibian. Also, road ecology linked to suitable habitat or semi-natural habitat. Road traffic noise, anthropogenic noise Ecosystem services, pollinators, wildlife, leaf water potential, Connectivity: biodiversity, invasive species, road ecology, fragmentation, mitigation, restoration. Distribution, connectivity and diversity of alien plant species, invasive alien plant, nonnative species. Potential ecological risk Urban green space Landscape feature Forest chip, Wood chip, Biomass burning
Network and communication	Vehicular Ad hoc Networks (VANET) and keywords related as performance evaluation and optimization, connectivity, simulation, roadside units, traffic flow security in relation to vehicular network, routing, wireless sensor networks, VANET, privacy and authentication. Roadside unit, its deployment and connection with intelligent transportation systems, traffic flow and wireless sensors Routing protocols ant their links with VANET and wireless sensors. Connected vehicle
	Cloud computing associated with roads, safety, roads units, privacy and vehicular networks. Traffic efficience Infrastructure communication
Security and Health	Epidemiology related to air pollution and alcohol, drugs and cannabis. Road traffic injury Assessing safety hardware Roadside accident, crash risk, roadkill Road safety simulation Security issue, alcohol, drunk driving Routing protocol Health risk assessment
Energy and market	Biomass, bioenergy, productivity and simulation Smart city Farmers' market Roadside infrastructure Supply chain Energy consumption and efficiency

When carrying out a more detailed analysis of the keyword "management", a sample has been collected, in which 45 documents were identified in the period 2017-2018. For each document the sustainability dimensions considered were identified, the methods or tools applied and related keywords; these relationships represented in Table 6. Also, with the aim to obtain the relationship of management with other keywords, a zoom was made on this keyword in the VOSviewer displayed in Fig. 6.

FIGURE 6. Related keywords with roadside management

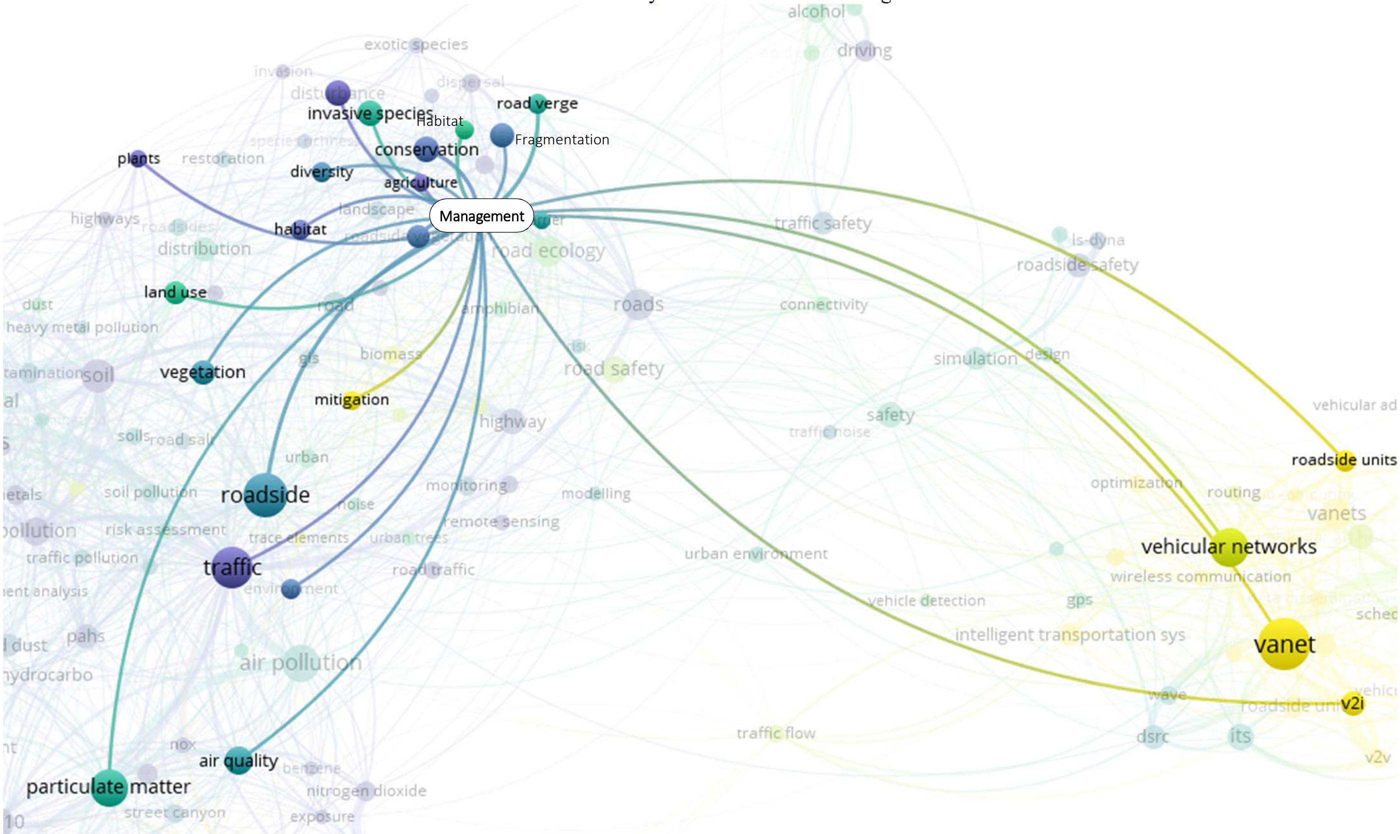


TABLE 6. Roadside management linked to keywords
Social (So), Ecological (Ec), Economical (En), Technological (Tc), Political (Po)

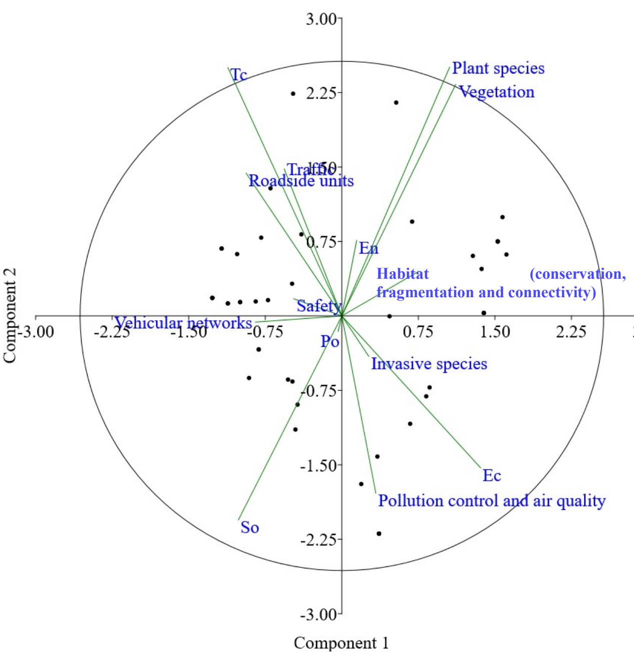
	Year	Dimension	Method/tool	Invasive species	Plant species	Habitat (conservation, fragmentation, connectivity)	Vegetation	Pollution control and air quality	Safety	Traffic	Roadside units	Vehicular networks
[19]	2017	Ec	Organic matter sources		x		x	x				
[20]	2017	So+Tc	Mechanism of the Flow Management							x		x
[21]	2017	So+Tc	Vehicular ad hoc network									x
[22]	2017	Ec+So	Predict hotspot locations			x			x			
[23]	2017	So	Privacy-Preserved						x		x	x
[24]	2017	Ec+So+Tc	Spatially explicit individual-based models		x	x	x		x			
[25]	2017	En+Tc	Forest chip supply system		x		x					
[26]	2017	So+Tc	Risk factor		x		x		x	x	x	
[27]	2017	So+Tc	Optimization traffic guidance							x		x
[28]	2017	So+Tc	Potential risk assessments						x		x	x
[29]	2017	Ec	Systematic map of roadside biodiversity		x	x	x					
[30]	2017	Ec	Plots		x		x					
[31]	2017	So+Tc	Semi-Markov decision process (SMDP)								x	
[32]	2017	So+Tc	Estimation based on data from acoustic sensors							x		
[33]	2017	So+Tc	New privacy preserving anonymous authentication						x		x	x
[34]	2017	So+Ec	Biodiversity inventories			x	x					
[35]	2017	So+Tc	Self-Sustaining Caching Station									x
[36]	2017	So+Po	Roadside advertising						x	x		
[37]	2017	So+Tc	Mobile cloud, ITS*						x	x	x	
[38]	2017	Ec	Hierarchical models - rates of population change			x						
[39]	2017	So+Tc	Vehicular Cloud network						x		x	x
[40]	2017	Ec+So	Agent-based system					x				
[41]	2017	Tc	5G software defined vehicular networks									x
[42]	2017	Tc	Software defined architecture for VANET								x	x
[43]	2017	Tc	Framework							x		
[44]	2017	Ec	Strategic habitat conservation		x	x	x					
[45]	2017	Tc	Signal Advisory System (ITSAS)							x	x	

	Year	Dimension	Method/tool	Invasive species	Plant species	Habitat (conservation, fragmentation, connectivity)	Vegetation	Pollution control and air quality	Safety	Traffic	Roadside units	Vehicular networks
[46]	2017	Ec	Biodiversity inventories	x	x	x	x					
[47]	2017	Ec	Biodiversity inventories	x	x		x					
[48]	2017	Ec+Tc	Nest tenacity			x						
[49]	2017	So+Tc	Wireless networking and sensor technologies							x	x	
[50]	2017	So+Ec	Feed–forward artificial neural network (ANN)					x				
[51]	2017	Ec+En	Cost-effective management		x	x	x					
[52]	2017	So+Tc	Decision-making intelligence								x	x
[53]	2017	Ec+So	Potential distributions based on ecoclimatic models	x					x			
[54]	2017	Ec+So	Spatiotemporal patterns of air pollution					x				
[55]	2017	Ec	Risk assessments	x								
[56]	2017	So+Tc	Cellular-Assisted Vehicular Communications						x	x	x	
[57]	2017	Ec	Simulating roadside infiltration swales		x		x	x				
[58]	2017	So+Tc	VANET								x	x
[59]	2017	Ec	Roadside bioretention systems		x		x	x				
[60]	2018	So+Ec	Pollution index and Potential ecological risk index					x				
[61]	2018	So	VANETs-Based ITS								x	
[62]	2018	So	ITS									x
[63]	2018	Ec	Targeted surveys		x	x	x					

*Intelligent Transportation Systems -ITS

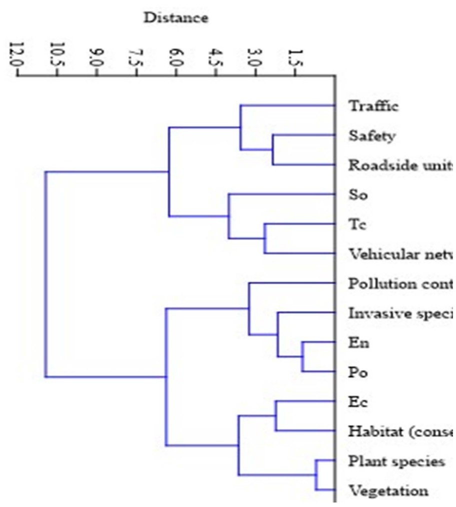
In order to establish correlations between sustainability dimensions and keywords, a principal components analysis was applied. Fig. 7 shows a high correlation between the roadsides management and plant species, vegetation, habitat and economic dimension. Also, a high relation with traffic, roadside units, safety, vehicular network and social and technological dimensions could be underlined. Moreover, a high correlation between invasive species, pollution control and air quality with social, political and economic dimensions was found.

FIGURE 7. Principal component analysis (PCA)



In an overview based on an ascending hierarchical classification presented in Fig. 8, two marked trends are observed in the roadside management. The first trend is the management of traffic to reduce route times, road measurements through roadside units and the integration of information in vehicular networks, which is related to the social dimensions by increasing the safety route and the development and use of technologies. The second trend is habitat, plan species and vegetation management, and their relationship with invasive species control, pollution control, mitigation and reduction, air quality amelioration, and the ecological, political and economic implication.

FIGURE. 8. Hierarchical ascending classification (HAC)



Recent trends of roadside verge research allow to highlight the need to adopt a transdisciplinary and systemic approach concerning territorial studies. Furthermore, we must also remark that it is vital that sustainable management of roadside verges develops a strong multidimensional vision from ecological, social, economic, technological and political points of view. Also, future developments need to be focused into non-deterministic or lineal models on strategies of roadside management and its integration in local dynamics, to fully contribute to sustainability territorial.

The ecosystem services promotion it is a future approach to sustainable management to roadside. For instance, services such as regulation of pollutant emission, noise damper, hydrological regulation, climatic change mitigation, sediment reduction in watercourses, soil decontamination, habitat maintenance, and ecological corridor, regulation of invasive species, and biological control. These ecosystem services that are insufficiently identified in the investigations and therefore their importance in route management is not considered to be significant. Also, ecosystem services of biomass production from mowing to give raw materials for bioenergy or compost, and cultural ecosystem services from roadside verges like landscapes, recreation, tourism, and sources of knowledge.

We need to explore further how roadside verges are imagined and experienced, and see relations such as local–global or provincial–cosmopolitan impact on the way they are understood the management. Every branch of roadside verge studies stands to be enriched by this agenda. Studies of roadside environment, road safety, ecology, intelligent network and communication systems, will all find new subject connection through research on roadside.

V. Conclusions

In view of the above discussion, the research analysis about roadside management is addressed in a fragmented and disciplinary way. There key issues identified in recently of research on roadside verges such as environmental, vehicular network, communication, security, health, energy and markets. These issues must be integrated in an ecological, social and economic sustainability management of roadside.

The roadside research agenda that we have suggested in this article, it has a long way to go to make connect roadside management with territorial planning. In this way, first, the roadside verge might be a promising space for sustainable links between social, economic, ecological and technological dimensions. Second, turning our attention to challenges like economical valuation of positive effects that sustainable management of roadside verges, such as the role that roadside has in soil and air decontamination, noise barriers, ecological connection. Third, energetic valuation of roadside biomass, taking into count that it reconciles the biodiversity promotion and road safety goals. Fourth, the connection between roadside verge, local development, landscape and well-being for communities must be further addressed.

Acknowledgment

Special acknowledgment to the project GID-Route (Innovative management of roadside verge), supported by Noremat.

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