Opportunities of responsible innovation approach in the spread of AV technology

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DOI: 10.3217/978-3-85125-932-2-13
Abstract. Although the vast majority of research related to autonomous vehicles (AV) is of technological and natural scientific nature, more and more social scientific research is being conducted in this topic. These works frequently draw attention to the wide range of uncertainties and open questions regarding AVs. It offers an excellent opportunity to approach social challenges concerning AVs through the conceptual system of responsible innovation (RI). Understanding the complex relationship of society and AV technology becomes much more significant to handle the uncertainties and ethical challenges of AVs.
In the light of the above, our theoretical research focuses on literature review, in which we address how responsible innovation framework can contribute to the most socially desirable outcome concerning Avs. The long-term objective of our research is to lay the foundation of a socio-technical integration which maximizes the advantages and minimizes the disadvantages of autonomous technology.
The examination of the relationship between RI and AV technology revealed several facts which suggest that the application of RI is justified. The literature highlighted that public engagement should be realised in a special socio-technical integration which is embedded in the framework of RI, thus it is important to involve the widest possible range of society in innovation processes[22].

Keywords: socio-technical integration, responsible innovation, emerging technologies, autonomous vehicles

1 Introduction

The question is no longer whether all road vehicles become completely autonomous but rather when (Grindsted et al. 2022, Threlfall 2018). Some authors draw attention to the traffic reducing advantages of AVs suggesting that sharing-based AV fleets will be able to move the same amount of traffic with using fewer vehicles compared to

[22] The study was prepared for the OTKA project with ID number K 13757, financed from the NRDI fund, National Research, Development and Innovation Office.

privately owned vehicles (Liljamo et al. 2021, Kesselring et al. 2020, Spurling - McMeekin 2014, Fagnant - Kockelman 2016, Alazzawi et al. 2018, Martinez - Viegas 2017, Overtoom et al. 2020). Other authors consider that a part of the advantages can be of economic and social nature (Threlfall 2018, Lipson - Kurman 2016, Litman 2017, Bezai et al. 2021): the hours spent driving can be transformed into productive time, the number of road accidents caused by human error can be reduced, safety and convenience can increase, environmental pollution and fuel consumption can decrease, and the mobility of disabled and elderly people can become easier (Litman 2017, Bezai et al. 2021). Combs et al. (2019) included the analysis of pedestrian fatalities in the United States and assessed the cases where tragic outcomes could have been avoided if AVs equipped with pedestrian warning systems had been used. The study showed that out of 4241 traffic-related fatal cases of pedestrian accidents, 3386 could have been avoided, which represents roughly 80% decrease in fatality rate. However, numerous challenges and concerns can be connected to AVs (Threlfall 2018, Bezai et al. 2021). For example, the transport system can become vulnerable to hacker attacks through digitalisation (Alfonso et al. 2018, Atzori et al. 2018). Another threat linked to AVs is the malicious cyber-attacks through an unreliable network (Kim 2018). Besides, the use of two modes of driving (manual and automated) may lead to unclear communication, which could lead to accidents (Straub Schaefer 2019). The acceptance and attitude of users can also represent an obstacle in the application of AV technology (Liljamo et al. 2018, Bezai et al. 2021).

This brings up an important question about how to handle the uncertainties related to autonomous vehicles, which are much more complex and significantly surpass the uncertainties of most of the emerging technologies and how the framework of responsible innovation[23] (RI) can help with this issue. RI is „taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al. 2013).

RI addresses situations in which the knowledge related to technology is uncertain and consensus has not been achieved in certain areas, thus the traditional approaches which manage responsibility subsequently with the instruments of responsibility or damages cannot function properly (Arnaldi et al. 2016). Instead, RI emphasises a more comprehensive approach of responsibility. Accordingly, RI can be an efficient response to this dual uncertainty (lack of knowledge and disputability of consensus).

Von Schomberg (2012) highlighted that the ultimate challenge lies in a more sensitive, more adaptive and more integrated management of the innovation process. The multidisciplinary approach involving stakeholders should lead to an inclusive innovation process in which technical innovators can respond to societal needs and in

[23] The responsible research and innovation (RRI) and responsible innovation (RI) frameworks differ in some way. RRI comes from an institutional setting while RI comes from academic field. In this paper, we will use the term RI meaning that substantive values and norms would guide the innovation process.

which social actors themselves also become responsible for the innovation process through constructive contribution provided in terms of defining socially desirable products.

On the basis of the above, in our present research we address the question: **how can responsible innovation contribute to the most socially desirable outcome of AVs?**

To get a better picture about the relationship of RI and AV technology, we conducted a systematic literature review, and tried to identify the main elements and common points that we need to focus to make the development and the spread of AV technology more socially desirable.

Our study is built as followings: in the first paragraph we analyse autonomous technology in the approach of responsible innovation with the help of systematic literature review. It is followed by the discussion of the results, and finally we close our study with the conluding thoughts.

2 Autonomous technology in the approach of responsible innovation

Autonomous vehicles can be categorised as an emerging technology due to several characteristics. Emerging technologies (such as gene therapy, robotics, or, for that matter, autonomous vehicles) can transform entire industries or strategies, furthermore, they can entail the creation of new industries (Day ¬ Schoemaker 2000). One of the specificities of emerging technologies is that new technologies often considerably disrupt the existing path of technical development by relying on new or different scientific bases and thus they require a lengthy improvement process of new competences. Nevertheless, it is important to emphasise that in the earliest stage of development it is often unclear what social advantages a new technology will realise later. Consequently, uncertainty is extremely high in this phase as there is no sufficient information in terms of the patterns and behaviours of consumer usage, in addition, there is also a lack of solid market knowledge, and the structure of market competition is rudimentary.

Several open questions have been raised regarding emerging technologies. In the case of these technologies, high uncertainty and ethical challengess must be taken into account, among others (Baumann et al. 2018, Lukovics et al. 2018). An increasing number of authors note that autonomous vehicles and their technological components (e.g., artificial intelligence) have special features which highlight the deficiencies in the conceptual system of responsible innovation.

In order to explore the relationship between self-driving or autonomous vehicles and responsible innovation, we conducted a literature review, in the course of which we collected and analysed the literary precedents written in this topic (Figure 1.). The basis of the analysis of international literature was provided by Google Scholar database.

We searched for the following keywords in the database: apart from responsible innovation, we studied the appearance of autonomous vehicle, autonomous car, and self-driving car in scientific articles. In accordance with the search parameters, we had 440 search results. We experienced when collecting literature that the scientific community have currently lack of information on this subject, thus this topic is worth exploring in more depth. In the next step, we further narrowed down the list of references and filtered the sources which were actually relevant in terms of our research. In this step we selected those literatures that highlight the relationship of responsible innovation and AVs or the main elements of autonomours vehicles (like artificial intelligence). Also, we selected those ones that examined how AV and the elements or dimensions of RI how can be in connection with each other (eg. ethics).

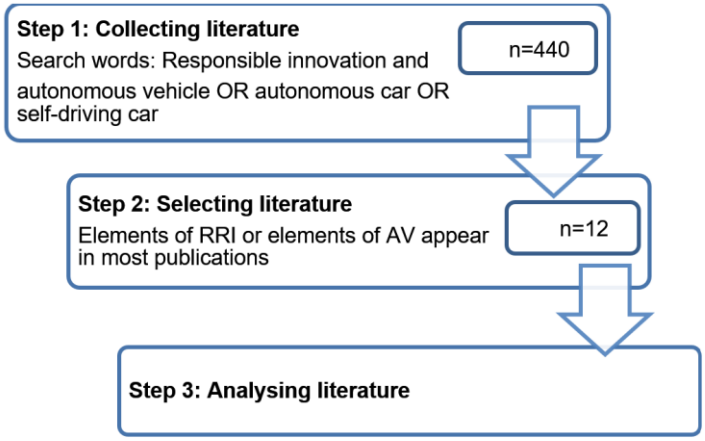

Fig.1 Research methodology

Source: own construction

Narrowing down the sources generated 12 search results in total (Table 1). Due to the novelty of the topic and rather limited number of search results, we broke down RRI and autonomous vehicles in our research, therefore, we also processed studies which examine certain key elements of RRI (for example, ethics) and autonomous vehicles, or, vice versa, focus on the analysis of responsible innovation and certain elements of autonomous vehicles (for example, artificial intelligence).

Author	Central argument of the article
Brundage (2016)	The author examines the relationship of artificial intelligence, as one of the basic technologies of autonomousvehicles, and responsible innovation.
Santoni de Sio (2016)	The author directly examined the relationship between responsible innovation and AVs.
Cohen et al. (2018)	The authors addressed how policymakers can be made to commit in terms of the opportunities of autonomous vehicles while examining the relationship between responsible innovation and AVs.
Stilgoe (2018)	In terms of the relationship of AVs and responsible innovation, the author puts a major focus on the role of machine learning and social learning in governmental measures.
Baumann et al. (2019)	The authors studied the issues and dilemmas considering the insurance of autonomous vehicles from the perspective of responsible innovation.

González González et al. (2019)	The authors examined self-driving technologies and their effect on and relationship with urban transport from the perspective of responsible innovation.
Nogués et al. (2020)	They address how urban planning could support the spread of AV technology with a backcasting methodology.
EC (2020)	The report examines the interpretation of AVs in the context of responsible innovation.
Stilgoe Cohen (2021)	The authors studied the relationship between one of the key elements of responsible innovation, public engagement, and autonomous vehicles.
Buhmann Fieseler (2021)	The article aimed to study artificial intelligence as an emerging technology defining AVs in the conceptual system of RI.
Grindsted et al. (2022)	The authors conduct a critical investigation on the role of autonomous vehicles in the plans about urban future in the context of responsible innovation.
Stahl (2022)	The author examines the relationship between artificial intelligence as one of the building blocks of AV technology and ethics as one of the key elements of responsible innovation.

Table 1. Summary of the literature review

Source: own construction

After processing the literature, we categorised the selected sources into two main groups: one group contains the articles investigating the direct relationship between responsible innovation and AVs, while the other group involves the ones studying the relationship between one of the most important technologies of AVs, artificial intelligence and responsible innovation.

2.1 Responsible innovation and autonomous vehicles

Santoni de Sio (2016) examined the relationship of responsible innovation and autonomous vehicles directly. In the article, the author presents some of the main ethical issues raised in the case of automated driving systems (ADS) and provides recommendations. The author proposes the approach of responsible innovation and value-sensitive design to manage ethical challenges. The concept of meaningful human control was introduced, and the author refers to it as the basis of a policy approach which prevents the morally unacceptable risks of human safety and foresees the issues of ethical and legal responsibility for accidents.

The article points out that in broader social terms, autonomous vehicle developers, who must consider complex socio-technical values, may face several challenges. It is a significant concern regarding autonomous robots and vehicles that their use may lead to unacceptable “responsibility gaps”, i.e., circumstances in which a serious accident happens where nobody can be held accountable due to the unpredictability or non-transparency of the process leading to the accident. Therefore, the system must be designed to prevent the hazardous behaviour of self-driving technology, and when it still happens, somebody can be held responsible and punished.

Santoni de Sio (2016) put together a package of proposals, which emphasizes the need to acquire and apply the methodology of responsible innovation and value-sensitive design in the development of autonomous technology, which enables to create the conditions for interdisciplinary foresight analyses which aims to embed

ethical values into future socio-technical automated driving systems. The author recommends the application of a more comprehensive ethical approach, which intends to improve safety by decreasing the number of accidents caused by human error and avoiding new risks (new fatal accidents) negatively influencing human safety; as well as to enhance human moral and legal responsibility and respect individual rights.

Stilgoe (2018) mentions that autonomous vehicle as an emerging technology is a very important tool of the development and application of machine learning. The emergence of autonomous vehicles represents a test for social learning, which refers to how society and its institutions interpret the novelty. Stilgoe (2018) studies and analyses the public debates about the innovation of autonomous vehicles, with special attention to problems, solutions, and concerns about the technology.

In his research on autonomous vehicles, Stilgoe (2018) relied on some informal online discussions between users involved in the process of random social learning. In this respect, he emphasises that the insistence of innovators and developers on the idea that in the development of autonomous vehicles, the answer is to be found in continuous autonomy and the development of algorithms leads to the rejection of new forms of governance and refers to substantial privatisation of learning. It may jeopardise public confidence on the part of society, as well as the long-term potential of technologies which would represent a significant advantage for society. In his analysis, Stilgoe (2018) points out several governance opportunities which intend to focus on social learning in the case of autonomous technologies, including sharing of data, in particular.

Cohen et al. (2018) intended to find out how policymakers can be made committed to autonomous vehicles. The study aimed at extending the debate about the governance of autonomous vehicles and thereby expanding the disputes over responsible innovation. The authors focus on currently neglected questions which provide a basis for a constructive debate about technology governance. They outline a new vision regarding the role of public bodies in developing the future of autonomous technology. The authors point out that AVs, as experimental technology are suitable to provide a rich understanding of social sciences related to emerging technologies and responsible innovation (Cohen et al. 2018). The authors believe the case of autonomous vehicles reveals some deficiencies in current studies about responsible innovation. A key challenge is to connect experimenting and forecasting.

Cohen et al. (2018) emphasise that every approach of governance and government decisions which relies on technologically determinist assumptions probably cannot be efficient enough, thus preliminary assumptions should be avoided. It is difficult but essential for governments to prevail over technological hubris. It is important that the adequate governance of AVs cannot take a competitive form, we must not compare our situation to others. It is crucial that they formulate coherent ideas about a desirable future transport already in the early stage and manage autonomous vehicles

accordingly. It requires the management of disruptive and utopian innovations with organised incremental policies.

They also emphasise that instead of a traditional risk-based regulation, a constructive relationship with an uncertain future may require a new model of "experimentalist governance" (Cohen et al. 2018). The authors point out that there is room for open reflection processes regarding AV technology and the main challenge will be to connect government forecast with the governance of ongoing self-driving tests. The authors note that innovation and investment related to AV technology clearly requires an active engagement of management bodies, which rely on critical social science research.

Baumann et al. (2019) studied the issues and challenges related to the insurance of autonomous vehicles from the perspective of responsible innovation. The authors point out that insurance companies can be considered as stakeholders with a great influence in negotiation and introduction processes related to autonomous technology. Insurers face issues regarding ethical or social consequences, which may arise not only in connection with the promotion of the technology but also with insurance models which can contain discriminative elements (e.g., "pay as you drive" model, where the insurance model changes depending on the driving style). The concept of responsible innovation can be a suitable tool to involve and guide insurance companies, policymakers, and other stakeholders in a responsible negotiation process, which can be beneficial for everyone. The RI approach can help stakeholders learn about the soft factors influencing innovation (such as ethical, societal, or historical factors), as well as the necessity to involve these aspects in their activities responsibly.

One of the authors' important findings is that existing regulations are insufficient to prevent the potential damages which can be caused if the companies producing and using the data from the vehicles fail to take ethical and social issues seriously in terms of self-driving technology. Thus, responsible innovation is crucial for insurance companies to be able to define their responsibility and then act accordingly without losing the trust of their clients. The authors note the significance of mutual response, which would mean making their insurance practice transparent for the public, in addition to a role of active cooperation with other stakeholders and active engagement in the social discourse about autonomous driving.

González-González et al. (2019) studied AV technologies and investigated its impact on and relationship with urban transport. The authors reveal that divergent and sometimes contradictory estimations and opinions cause considerable uncertainty among urban policymakers and can occasionally lead to planning issues and doubts. The authors intended to show the potential offered by AVs in the implementation of attractive, healthy, and sustainable urbanisation opportunities. In their study, they use the so-called backcasting approach to examine whether the potential effects of AV implementation can support or jeopardise urban development policy goals. This method allows to identify the conflicts between policy objectives. Planners and urban

policymakers need to start elaborating adaptive plans and programmes in order to project future changes caused by AV technology. Backcasting approaches can help forecast planning measures which could be the most favourable and reduce occasional negative consequences.

The authors highlight the importance of a mixed land use policy, the development of urban facilities and services, the acceptance of shared mobility services, and the necessity for a high-quality multimodal transport system (González-González et al. 2019). This set of principles can help policymakers and other stakeholders and actors understand the introduction of AVs and make decisions. In the context of participatory governance, urban stakeholders cooperating with authorities have a key role in the development of these policy frameworks and objectives.

Nogués et al. (2020) also investigated the potential of AV technology application in an urban environment. The authors note that the future introduction and use of autonomous vehicles in cities may have substantial positive and negative effects on sustainability and, on that basis, the main aim of the article is to study these effects and assess which policies would be the most efficient to achieve a desired urban scenario. For this they rely on backcasting planning methodology. Authors suggest that it is important to make political decisions which can reduce negative effects the most efficiently. Authors also described that the majority of the interviewed experts believed that the presented programmes of policy measures could mostly be efficient to achieve the most desirable scenario. It is thus important that the implementation of AVs should not subordinate but reinforce the sustainable mobility and land use policy already in preparation in an urban area.

The European Commission (2020) prepared a report which aims to facilitate a safe and responsible transition to connected and autonomous vehicles (CAV) by supporting stakeholders in the systematic integration of ethical aspects during the development and regulation of CAVs (EC 2020). The report applies the approach of responsible innovation on CAVs. This approach acknowledges the potential of CAV technology in achieving the advantages of autonomous vehicles, but it also recognises that technological development alone is not sufficient to realise this potential. In order to achieve desired results, the vision about CAVs must integrate a broader range of ethical, legal and social considerations into the development, installation, and use of CAVs.

According to the approach of responsible innovation, the design and implementation of connected and automated vehicles must rely on ethical directives based on socially accepted basic ethical, and legal principles (EC 2020). The authors emphasise the establishment of clear ethical and legal standards of responsibility. Furthermore, inclusive deliberations allow every social group’s perspective to be heard and nobody to be ignored. Consequently, the design and development of CAV systems must support inclusive deliberation processes engaging stakeholders and the wider public and must be implemented as their outcome.

Stilgoe and Cohen (2021) studied the relationship between autonomous vehicles and the key element of responsible innovation, public engagement. In their article, they outlined a dominant public engagement model relying on increased awareness of the public, which can lead to the acceptance and adoption of technology. The authors concluded that public dialogue could contribute to changing the ideas formed about technology and public, however, this process requires openness on the part of policymakers and other stakeholders. Instead of considering public dialogues as individual practices, it would be better to evaluate the governance of emerging technologies from whether it takes place "in a dialogue", i.e., the widest possible range of stakeholders are involved in the process of creating and developing the technology. Stilgoe and Cohen (2021) therefore analyse how the views of innovators and policymakers about the public are connected to their views about autonomous vehicles. The authors drew optimistic conclusions, namely that public dialogue can contribute to the constructive change and development of debates related to the tools and goals of technology, as a part of the social learning process. For this, however, it is first important to identify the assumptions embedded at institutional level which can hinder willingness and inclination to change. In the course of a public dialogue, the authors intended to find out how citizens imagine the future of AVs and how more democratic approaches of governance can enable greater consistency between technological visions and public values. The authors emphasised that the application of social science (especially psychological) aspects in debates about autonomous vehicles can be considered a crucial factor. Furthermore, they claimed that the more the public learns and knows about a technology, the more uncertainty is reduced. Consequently, a technology can be best known in the context of testing. Public dialogues can be an important part of how policymakers interpret new technologies and how they can change their own views by public opinion.

Grindsted et al. (2022) conducted a critical investigation on the role of autonomous vehicles in plans about urban future. In their study, they examine the urban plan of 10 European capitals in terms of expected promises and threats of autonomous vehicles. The authors propose a practice-based view of automation to facilitate sustainable mobility transition. In the examination, the authors concluded that none of the plans of the studied 10 capitals addresses the possibility of aligning AV technology with means of public transport or renewable energy sources. An important finding of the article is that AVs are very likely to further individualise and reinforce the current mobility system and harmful emissions will probably increase in the near future. To avoid this, the authors emphasise that urban policy making has a significant role in the application of AV technology and it is their important task to discuss the existing technology-centred concept of autonomous vehicles in order to facilitate the sustainable development goals of cities.

The authors note that the field of mobility can raise several dilemmas and challenges and they emphasise the consideration of environmental aspects in the process of

urban mobility planning (Grindsted et al. 2022). It is essential to rethink urban transport according to the new mobility paradigm and to focus on connecting different modes of transport, in the framework of which the shift from ownership to access and use of vehicle (Mobility as a Service ¬ MaaS) can have a crucial role. It can be concluded that the urban planning process of autonomous vehicles may entail planning paradoxes, several advantages, and a broad scale of threats/dilemmas (Grindsted et al. 2022).

2.2 Artificial intelligence and responsible innovation

Stahl (2022) in his publication relies on the debate about the ethics of artificial intelligence to explore how responsible AI innovations ecosystems can be developed and implemented. In his study, the author argues that the current innovation ecosystem discourse does not pay sufficient attention to ethical issues. The author suggests that discussing responsible innovation and integrating it into the literature and practice of innovation ecosystems to discuss and consider ethical and social awareness is crucial. The author emphasises that RI takes place within innovation ecosystems, but it also shapes these ecosystems and can result in new innovation ecosystems. The publication attempts to examine whether it is possible to create a responsible innovation ecosystem and if yes, how it would be constructed. For providing practical background and illustration, the article applies the conceptual framework of innovation ecosystems and RI on artificial intelligence, with special attention to the current debate about the ethical and human right aspects of artificial intelligence.

The author points out several ethical challenges which can be associated with artificial intelligence (Stahl 2022). Regarding the characteristics of certain artificial intelligence techniques (namely, machine learning), broader concerns arise with regard to how artificial intelligence can support other socio-technical systems and how they influence our lives.

Buhmann and Fieseler (2021) in their study examined the relationship of responsible innovation and artificial intelligence (AI) as the basic technology operating autonomous vehicles. They used a deliberative approach to provide a framework for the relationship of artificial intelligence and responsible innovation. This framework focuses on discourse principles which aim to help counterbalance the challenges related to the non-transparency of technology.

According to Buhmann and Fieseler (2021), one of today's greatest challenges is the sustainable facilitation of artificial intelligence. This challenge could be resolved by procedures of participatory technological design and public forums, in which systemic compromises related to AI governance can be discussed and agreed upon. While tackling this challenge, however, in terms of reflecting on responsible innovation, it is important to consider how weak transparency, explicability, and accountability of artificial intelligence can be counterbalanced to enable responsible AI governance.

In their article, the authors address the prospects and challenges of artificial intelligence in terms of responsible innovation (Buhmann Fieseler 2021). In particular, they focus on the role and functions of public forums in order to explore the paths leading to engagement in technological design and give recommendations about how a society could deliberate the systemic compromises related to AI governance and what agreement they could reach.

Regarding the relationship of artificial intelligence and responsible innovation, the authors note that communicative and deliberative approaches can provide adequate solutions for unintended negative consequences of artificial intelligence and the apparent non-transparency of the technology (Buhmann Fieseler 2021). The authors emphasise that deliberation seems to be a necessary but contested process to facilitate the responsible innovation of artificial intelligence. In this context, they highlight the role of stakeholder engagement.

Brundage (2016) studies the relationship of artificial intelligence as one of the basic technologies of autonomous vehicles with responsible innovation. The author points out that the literature of responsible innovation can substantially enrich the analyses about the social dimensions of artificial intelligence. Brundage (2016) suggests that the framework of responsible innovation offers a useful approach to integrate the understanding of social dimensions of artificial intelligence into the innovation ecosystem more deeply.

Brundage (2016) mentions two main reasons according to which the limitations regarding the social dimensions of artificial intelligence must be addressed and the responsible innovation of artificial intelligence requires a more comprehensive approach. One of the reasons is that the nature of artificial intelligence research will develop over time, as well as its potential social consequences. Thus, a deeper integration of anticipation, reflexivity, and other aspects of responsibility into the practice of research itself is essential to take care of the future. The other reason is that the clearly structured, flexible framework of the responsible innovation of artificial intelligence can help identify the deficiencies of existing efforts and thereby facilitate the productive future work on the social dimensions of artificial intelligence.

2.3 Results of literature analysis

The literature analysis revealed that the approach of responsible innovation would lead to significant results in exploring and addressing the social dimensions of autonomous vehicles. The analysis of the results of the literature review is based on the RI keys and dimensions. To make abstract definitions of RI more concrete and practical, theorists and policy makers have sought to operationalize the concept in terms of content and process. Regarding the process of responsible innovation, four main dimensions can be distinguished: anticipatory, reflective, deliberative and responsive dimension (Stilgoe et al. 2013). The European Commissions identified 5 main key

elements, the consideration of which can also help us to develop responsible innovation processes: public engagement, ethics, gender equality, science education and open access (EC 2014). The gender equality key was not relevant in case of our study, thus we only take into account the other 4 factors.

The authors also note that out of the four dimensions of RI, anticipation and reflexivity are of particular importance. Some pieces of literature highlight the importance of ethical issues and formulate recommendations considering some main ethical questions.

The reviewed literature encourages the interpretation of AVs in the approach of responsible innovation, in which a wider range of ethical, legal and social considerations must be integrated into developments related to autonomous vehicles. In this regard, the authors prioritise inclusive deliberation and stakeholder engagement, deliberative approach, and the process of participatory technological design.

Table 2 illustrates that the processed sources came to similar conclusion concerning on several points. The majority of the processed sources deal with some ethical concern or issue and emphasise how crucial it is to outline and discuss ethical issues in the design process of AV. Another important agreement in the above-mentioned references is that they give priority to the significance of public engagement.

RI factors	Buhmann Fieseler (2021)	Cohen et al. (2018)	Santoni de Sio (2016)	Baumann et al. (2019)	EC (2020)	Stilgoe (2018)	Brundage (2016)	Stilgoe Cohen (2021)	Grindsted et al. (2022)	González-González et al. (2019)	Nogués et al. (2020)	Stahl (2022)
Ethics	x	x	x	x	x			x	x			x
Public engagement	x	x	x	x	x	x	x	x	x	x	x	
Open access				x								
Scientific education												
Anticipatory dimension			x				x			x	x	
Reflective dimension							x					
Deliberative dimension	x	x		x	x	x	x	x	x	x	x	
Responsive dimension	x			x	x	x	x	x	x	x	x	x

Table 2 Appearance of the elements of responsible innovation in each AV publication

Source: own construction

Several authors mentioned the importance of participatory technological design, stakeholder involvement, proactive cooperation and engagement and the application of a deliberative approach. Furthermore, the majority of the articles also considers it important not only to listen to the opinion of society members but also to integrate it into technological design and application.

In the course of literature research, it became obvious that several authors mention – or at least refer to – that in the contexts of autonomous vehicles, the framework of responsible innovation may have shortcomings. Most authors connect these deficiencies to ethical challenges, which we find totally justified. Especially in the light of the fact that, based on 40 million responses in 233 countries around the world, the famous Moral Machine research of the MIT, that failed to produce results which could have shown a clear direction for the machine ethics development of autonomous vehicle developers (Awad et al. 2018). In addressing the ethical challenges related to autonomous vehicles, Santoni di Sio identifies the deficiency of responsible innovation, and proposes the approach of Value-Sensitive Design to complement RI methods.

Another apparent finding of our analysis on the literature intending to explore the relationship between responsible innovation and autonomous vehicles was that considering "public engagement" key element of RI, the authors predominantly focused on autonomous vehicles as a means of passenger transport and formulated their statements accordingly. In their work they mostly study the vehicle from inside, which resonates with the mainstream trend of technology acceptance analyses related to autonomous vehicles.

3 Conclusions

The significance of the application of RI in the development of autonomous vehicles may be more important than ever. One of its reasons is that AV technology affects the life of all people living in modern societies regardless of whether they are active users of AV technology or not. Given that it is an emerging technology associated with a high level of uncertainty, several questions can arise during the development, adoption and acceptance of the technology and addressing them requires the approach and concepts of responsible innovation. The examination of the relationship between responsible innovation and technology revealed several facts which suggest that the application of RI is justified. The literature highlighted several deficiencies which can be addressed by using the framework of RI.

One important finding is that technological development alone is not sufficient to make a technology safely applicable in practice, thus the various ethical challanges must not be ignored, they must be considered and addressed in a proactive ethical approach. Nevertheless, it is to be noted that it requires a joint effort. Therefore, in this respect, the process of participatory technological design, a deliberative approach, as well as

active cooperation and engagement are all essential, engaging the widest possible range of stakeholders and the public in the process of technological design and urban planning in order to create solutions which fully comply with the expectations and interests of society. Public forums and workshops can provide a suitable framework for this.

We believe that public engagement should be realised in a special socio-technical integration which is embedded in the framework of RI. This framework allows everyone to tell and explain their own position, opinion, and experience about the entire ecosystem of autonomous technology. On the other hand, for innovators and policymakers in charge of a safe and responsible implementation of technology, it would mean an intensive input gathering process, in which the information and recommendations could be considered, discussed, and integrated in later stages for technology development, and could affect future developments as a sort of learning process. Therefore, we suggest that it is important to involve the widest possible range of society in research and innovation processes conducted within the framework of responsible innovation from the initial stage, extended to the entire autonomous vehicle ecosystem, as well as to encourage active cooperation and responsibility in order to produce socially accepted innovation results. In the next phase of the research, we will conduct its operationalisation.

It is important to highlight that our study has some limitations. First of all, the number of studies available in the field of AV technology and the RI concept is limited, and many of the above-described papers concerns the relationship of RI and AV in a theoretical way, and in many times just elements of RI or AV are examined, and not the whole phenomenon in a complex way. Moreover, our study is based on theoretical background, thus the empirical evidence is missing. Thus, the next step is to make some empirical research to support our findings.

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