Innovation by Information Technology Recombination: How Artificial Intelligence Progressive Web Apps Foster Sustainable Development

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Abstract: Artificial Intelligence (AI) and Progressive Web Apps (PWAs) represent two major trends in today's development of modern information systems. AI aims to automate intelligent behaviour whereas PWAs aim to provide fast, reliable, and engaging applications. The influence of these two key technologies on organisations and sustainable development on their own has already been explored. However, there is no research that merges these technologies in terms of recombinant innovation to show their joint potential. By conducting a systematic literature review this article reveals the positive impact of "Artificial Intelligence Progressive Web Apps" (AI-PWAs) on sustainability. It is shown that AI-PWAs can realise economic, environmental and social benefits and thus can support the achievement of the United Nations' Sustainable Development Goals.

Keywords: Artificial Intelligence, Progressive Web Apps, Recombinant Innovation, Sustainability, Systematic Literature Review.

1 Introduction

One of the most important challenges in modern economy and society are the United Nations' Sustainable Development Goals (SDGs) [Vi20]. To achieve these SDGs, the development of innovative business models with reinforcement by increasing digitization and data availability is necessary. This paper discusses the potential of information technology (IT) innovation for sustainable development by recombining Artificial Intelligence (AI) and Progressive Web App (PWA) technologies, which are two major trends in today's development of modern information systems.

On the one hand, AI represent a relatively mature research area that has already been extensively explored since the 1950s [MP43], [RN20], [Tu50]. Nevertheless, AI has been recently granted a huge potential to transform the present business landscape as its core due to increased computational power and new algorithmic approaches [So20]. The amount of publications, projects and funding regarding AI has risen sharply in past years [Pe2019]. While most AI research until now attempted to obtain state-of-the-art results in

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accuracy through the use of massive computational power without respecting sustainability goals [Sc20], the relationship between AI technologies and sustainability currently gains increasing attention [Fe21], [GT20]. On the other hand, PWAs represent a relative new concept that combines the advantages of traditional web and native applications to provide a better user experience while limiting the development costs [Mo20]. PWAs have also been granted a huge potential to transform the present business landscape as current companies can engage their customers while bypassing app stores [Cl21]. Due to its novelty, the relationship between PWA technologies and sustainability is in its infancy, but first research was already conducted.

The impact of AI on sustainable development has already been reviewed, analysed and discussed [Di20], [Vi20]. PWA technologies have also been reviewed and analysed [Mo20]. However, there is no research, which combine AI and PWAs to show their joint potential towards sustainable development. Based on the idea of recombinant innovation, the fusion of these known technologies can create a new innovation called Artificial Intelligence Progressive Web App (AI-PWA). Therefore, this paper aims to identify current use cases and implementations, where PWAs and AI are combined and analyses these cases towards their impact on sustainable development. The following research question (RQ) will be answered:

How can Artificial Intelligence Progressive Web Apps foster sustainable development?

To answer this RQ, the paper is structured as follows: In section 2, the foundations of IT innovation, sustainable development, AI and PWAs are elaborated as an introduction into relevant concepts. In section 3, the applied research method of the systematic literature review (SLR) is described. In section 4, the findings of the SLR are explained in detail including a discussion towards their impact on sustainable development. Section 5 concludes the paper and provides an outlook on further research activities.

2 Theoretical Foundations

2.1 The Role of Information Technology Innovation for Sustainable Development

A common view on innovation is to see it as a crucial factor for long-term successful business management [SMA17]. However, innovation can also be seen as a key driver for sustainability, because sustainable development is a pressing issue that requires immediate action from governments, businesses, and society [ST19]. To analyse the influence of innovations on sustainable development, it can be subdivided an economic, an environmental and a social dimension [Vi20]. Moreover, many recent innovations were enabled through IT [Le10]. Innovations through IT are commonly referred to as IT innovations. Research in this field explores organisational and technological factors (e.g. firm size, scope, technological competency and expected benefits) that determine IT adoption and diffusion [MR08]. Maturity models for concrete IT types including AI have

been developed and used to assess these factors [Fu21a], [We12]. To reach a higher organisational maturity towards a certain IT type and therefore discover new value creation opportunities, IT innovations are needed [GLS17]. But innovators rarely come up with completely new ideas and instead often recombine known ideas in order to innovate [La93]. This concept is known as recombinant innovation in literature [BM14], [FIZ12]. Therefore, innovation by recombining known IT components like AI and PWAs seem to be a promising way to foster sustainable development.

2.2 Artificial Intelligence and Progressive Web Apps

AI is an umbrella term for a type of IT, which has the capacity "to act intelligently or to imitate cognitive and intelligent behaviour" [Fu21a]. AI covers every aspect to automate intelligent behaviour and can be subdivided into various subdisciplines [RN20]. To innovate entire organisations with AI, different dimensions must be considered. AI maturity models can assess these dimension to foster the adoption and diffusion of AI within entire organisations [Fu21a]. Besides this management-oriented view, the relation between AI and sustainability gains increasing awareness in the research and business community [Fe21], [GT20]. One common way to assess this relationship is by researching how the use of AI can help to achieve sustainability goals [NKC20], [Vi20]. Another way is to find approaches to design the application of AI-based technologies themselves in a sustainable way [Dh20], [Sc20]. PWAs are responsive web applications that leverage the capabilities of browsers for continuous improvements based on the principle of progressive enhancement [Pa10]. In 2015, Alex Russell coined the term "Progressive Web App" to describe apps taking advantage of new features supported by modern browsers, that let users upgrade traditional web apps to PWAs in their native operating system [Ru15]. PWAs ensure a reliable, motivating, and native user experience through installation, offline functionality and push notifications [TJ18]. Once retrieved online, content can be very quickly displayed from the cache even without an internet connection (offline functionality) [BMG18]. PWAs can reduce the environmental thread by reducing its energy consumption with the help of cache and offline capabilities [Bu19]. With a well-designed service worker unnecessary network requests can be limited and this reduces the energy consumption [Ro20]. PWAs positively contribute to social sustainability as they can provide digital services with native app-like features to all end devices without eluding parts of society only limited to one type of device [We18a].

3 Research Method

To answer the RQ a complete overview over current combinations of AI and PWA technologies as well as an analysis towards their technical components and sustainability impacts is necessary. To identify and analyse all available research relevant to a particular research question or topic area the method of a SLR can be used [KC07]. In general, the SLR follows an multi-step process [Br09]. In the beginning, the review scope was defined

by using the six characteristics of the taxonomy of Cooper [Co88]. After defining the review scope, the first fundamental literature was identified and the topics were conceptualised via the method of concept mapping to derive relevant key terms for the search strings (cf. Fig. 1) [RS04], [SNB82]. The search was intentionally not restricted with any terms related to sustainability in order to identify as many publications as possible and to subsequently analyse all of them regarding their motivations and benefits achieved by the fusion of AI and PWAs. From these motivations and benefits the ones that have an impact on sustainability were identified to answer the RQ. The search strings were subsequently tested in the identified databases to guarantee their functionality.

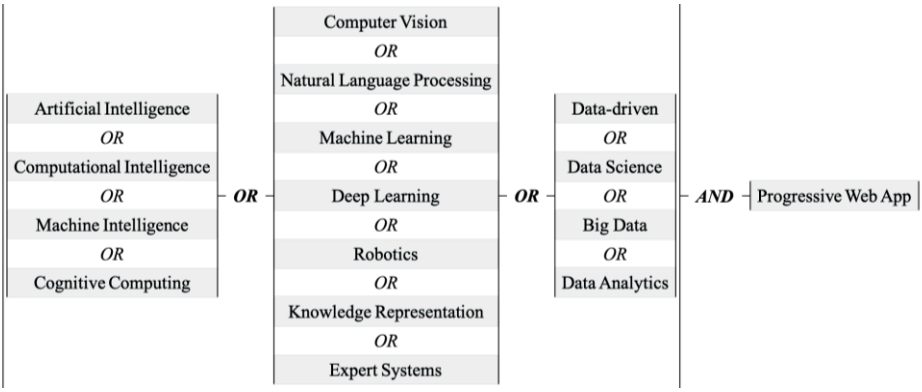

Fig. 1: Search terms for the systematic literature review

In total, the literature was searched via ten different scholarly databases providing access to leading journals. Since the topic of combining AI with PWA is relatively new and immature, we also included patents, whitepaper and technical reports and thesis instead of relying only on scientifically accepted journals. This ensured that scientific as well as practical top-tier sources from various domains were considered. On the contrary, this led to a number of 603 search results including irrelevant articles (cf. Fig. 2). After eliminating all duplicates and results that were not primarily written in English or German 251 distinct articles remain. To exclude all irrelevant articles, the results were scanned based on their titles [Dy08]. In line with the inclusion and exclusion criteria, many articles, whose titles were not referring to AI or PWA concepts could be sorted out. In the next step, abstracts and complete texts of the remaining articles were intensively analysed. The final backward and a forward search based on the resulting articles resulted in no additional relevant article [WW02]. All articles were analysed and synthesized using two concept matrices [SNB82], [WW02]. For transparency, supplementary material including all 62 sources and the complete concept matrices is provided in Fukas and Thomas (2021) [Fu21b]. Finally, a definition of AI-PWAs including their technical components (cf. section 4.1) and their implications towards sustainable development (cf. section 4.2) were elaborated.

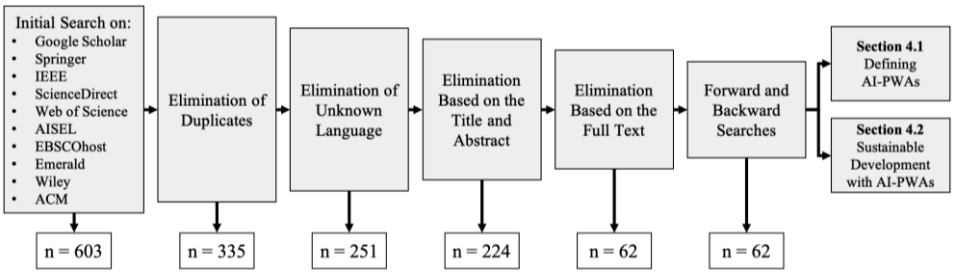

Fig. 2: Search, elimination and analysis steps of the systematic literature review

4 Results

4.1 Defining Artificial Intelligence Progressive Web Apps

To fully understand and define the innovation of AI-PWAs, 62 publications were identified and analysed towards their combination of AI and PWA technologies (cf. Fig. 3). The majority of these publications are journal articles and conference proceedings (39 out of 62 articles). A significant amount of theses and dissertations were also included (14 out of 62 articles). The minority of articles are book chapters, patents and technical reports/whitepapers (9 out of 62 articles). An increasing trend from 2017 until today can be observed (excluding the number of articles from 2021 for the trend analysis, since the SLR was conducted in the first quarter of 2021). Thus, it can be assumed that AI-PWAs already represent an emerging innovation.

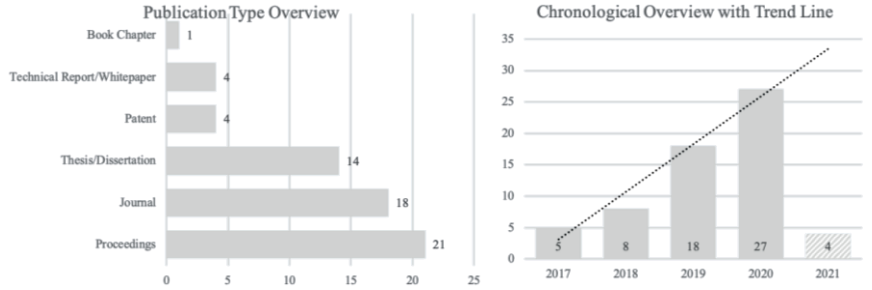

Fig. 3: Publication type and chronological overview with trend line of retrieved articles

As already mentioned earlier, AI can be divided into different subcomponents (cf. section 2.2). In the identified literature, the authors combined one or more of these subcomponents with PWA functionalities in order to provide an innovative solution to their respective research problem. Tab. 1 summarises these AI components including the number of sources mentioning the corresponding AI component (No.) and a selection of reference publications:

AI Component	Short Description	No.	Reference Publications
Computer Vision (CV)	CV describes the automatic processing and recognition of visual inputs.	15	[Bi19], [Hu19], [Wi19]
Deduction, Reasoning, Problem Solving (DRP)	DRP imitates step-by-step reasoning that humans use when solving puzzles or drawing logical conclusions.	6	[EKK19], [Gr20], [Kh17], [Sa19a], [Sa19b]
Knowledge Representation (KR)	KR model intelligence in form of knowledge-based systems.	13	[EKK19], [Gr20], [HZ18], [Kh17]
Machine Learning (ML)	ML describes the automatic generation of knowledge from experience.	36	[Al17], [Ch20], [Me19], [VGG20]
Natural Language Processing (NLP)	NLP describes the processing of natural language by a machine.	14	[HB19], [Ka20], [Ly18], [Pa17]
Planning (P)	Planning describes the automatic decision making in achieving goals.	11	[Ea19], [La18], [VGG20]
Robotics (R)	R creates systems for a sovereign interaction with natural environment.	2	[Da21], [Ma18]
Social Intelligence (SI)	SI aims to recognise, interpret, process or simulate human affects.	3	[Ai18], [Ga19], [Sp19]

Tab. 1: Overview of AI components in AI-PWAs

Further, the SLR showed successful examples how AI-PWAs can be implemented. The development follows mostly two recombination strategies. In the first strategy, AI components are developed independently of the PWA. Then, the PWA was developed aiming on a cost efficient, intuitive and cross-platform deployment as well as a central user interface (UI), where users can interact with AI components [HZ18], [Pa17]. In the second strategy, first the PWA is developed consisting of non-AI functionality to engage users. Then, the existing PWA was enhanced by AI components aiming on better UI, efficiency gains or higher service quality [Kh17], [La18]. Finally, the following definition and technical overview of AI-PWAs (cf. Fig. 4) was derived from the findings of the SLR:

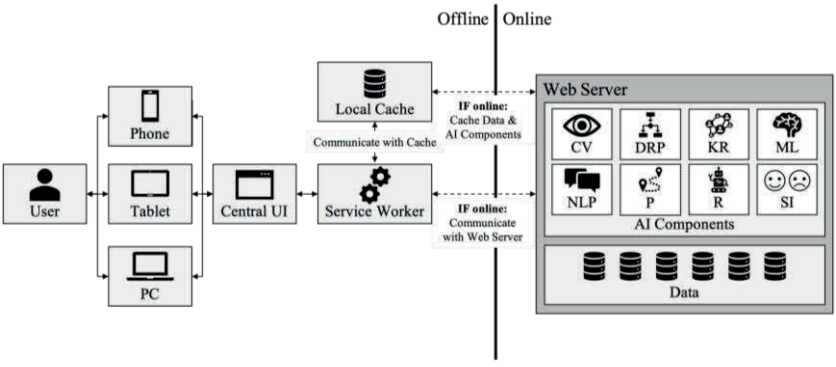

Fig. 4: Basic structure of Artificial Intelligence Progressive Web Apps

Definition: *Artificial Intelligence Progressive Web Apps are information systems that combine one or more Artificial Intelligence components, e.g. computer vision, natural language processing or machine learning, with one or more Progressive Web App functionalities, e.g. offline ability, push notifications or native app experience.*

4.2 Sustainable Development with Artificial Intelligence Progressive Web Apps

Based on our definition, the impact of AI-PWAs on sustainable development were examined. A common way to analyse the influence of innovations on sustainable development is by structuring it into an economic, an environmental and a social dimension [Vi20]. Therefore, the motivations and benefits of AI-PWAs were inductively analysed in the identified literature of the SLR and then related to the three sustainability dimensions. We found, that the sustainability impacts of AI-PWAs can be described by six characteristics, which are further explained in Tab. 2:

Sustainability Impact	Short Description	No.	Reference Publications
Process Efficiency	Process Efficiency describes the productivity gain of AI-PWA users compared to users of other IT systems.	11	[EKK19], [PSM20a], [PSM20b]
Cost Efficiency	Cost Efficiency describes the lower financial resources that have to be invested to develop and operate AI-PWAs compared to other IT systems.	2	[Bi19], [Me19]
Consumption Optimisation	Consumption Optimisation describes the optimisation of resource consumption achieved through the use of AI-PWAs.	3	[Al17], [Ch20], [VGG20]
Usage Optimisation	Usage Optimisation describes the lower resource usage of AI-PWAs themselves compared to other IT systems.	9	[Ea19], [HZ18], [La18], [Ly18]
Enabled Society	Enabled Society describes the assistance provided to users in achieving their desired goals, which would not be possible without the use of AI-PWAs.	20	[Gr20], [Hu19], [PSM20a], [PSM20b], [Wi19]
Engaged Society	Engaged Society describes the ease of involving a large number of AI-PWA users compared to the more difficult user engagement in other IT systems.	17	[Ai18], [Ga19], [Kh17], [Sa19a], [Sa19b], [Sp19]

Tab. 2: Overview of sustainability impacts of AI-PWAs

These six characteristics directly relate to sustainable development and the economic, environmental and social dimensions. The sustainability impacts are illustrated in Fig. 5 and explained in detail including examples from the SLR in the following:

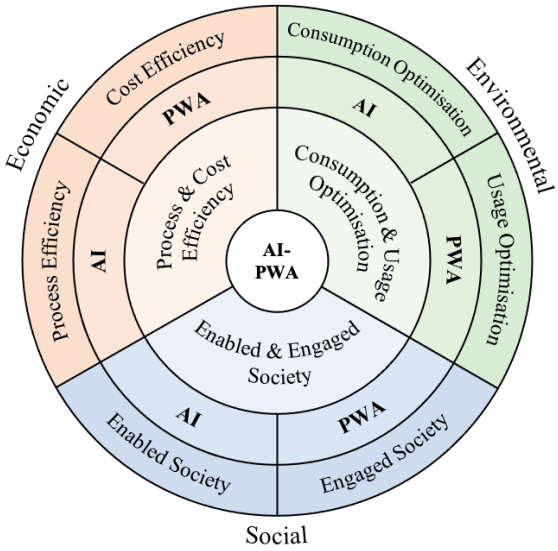

Fig. 5: Sustainability impacts of Artificial Intelligence Progressive Web Apps

Economic sustainability is supported by an AI-PWA mainly on two ways. On the one hand, most articles of the SLR considered the use of AI to reach a higher *Process Efficiency*. AI is linked to a net positive impact associated to increased productivity [Vi20]. For example, incorporation of CV to automatically recognize image features and thus automate manual, error-prone actions directly can improve process efficiency [PSM20a], [PSM20b]. On the other hand, the deployment as a PWA was often chosen due to avoiding the cost of developing multiple native applications by still ensuring the same usability [Bi19], [Me19]. By using PWA technologies, only one single web-based application needs to be developed, which can be used on every device with native-like features instead of developing an own, separate native applications for every operating system. In some instances, this can drastically reduce the investment by gaining the same value proposition and result in a better *Cost Efficiency*. The development of an AI-PWA can combine these two advantages to enhance economic sustainability.

Environmental sustainability of AI-PWAs can be considered in two ways as well. The AI components of AI-PWAs can be used to optimise the consumption of resources (*Consumption Optimisation*), e.g. electricity, water or food [Vi20]. It can also underpin low-carbon systems, for instance, by supporting the creation of circular economies and smart cities that efficiently use their resources [Ne19]. For example, concrete AI-PWAs were already developed for optimising waste management or water usage [Ch20], [VGG20]. The PWA components of AI-PWAs can be used to optimise the usage of the app itself (*Usage Optimisation*). Through PWA technologies, a better usability and optimised program code can ensure a more energy efficient use of the app itself [Ea19]. PWAs allow caching and offline functionalities, which reduce the unnecessary data

transfer [Bu19]. With a well-designed service worker unnecessary network requests can be limited and this reduces the energy consumption [Ro20]. AI-PWAs therefore can realise environmental advantages regarding their operation as well as their implementation purpose.

Social sustainability can be achieved by enabling and engaging the society. AI components can be used to enhance humans by providing automated assistance, reducing error-prone, manual tasks and teaching new skills (*Enabled Society*) [Hu19], [PSM20a], [PSM20b], [Wi19]. Moreover, AI components can help by supporting the provision of food, health, water, and energy services to the population by autonomously predicting the corresponding needs [Vi20]. PWA components are able to engage humans by a better usability, cross-platform capability and lower entrance barriers (*Engaged Society*) [Kh17], [Sa19a], [Sa19b]. They positively contribute to social sustainability as they can provide digital services with native app-like features to all end devices without eluding parts of society that are only limited to one type of device. Moreover, the attempts to provide AI-based social intelligence through a PWA UI [Ai18], [Ga19], [Sp19] or to engage social user behaviour through AI-based chatbots directly count towards the social dimension of sustainability [HB19], [Pa17]. Therefore, AI-PWAs can induce an enabled and engaged society.

5 Conclusion

The SLR showed successful examples how AI-PWAs can be developed and used. Different AI subdisciplines like CV, DRP, KR, ML, NLP, P, R and SI were deployed using PWA functionalities to achieve synergies and combine the benefits of both technologies resulting in a new type of IT innovation, namely AI-PWAs. AI-PWAs impact sustainable development in a positive manner. Therefore, the answer to the RQ is the following: Regarding the economic, environmental and social dimensions of sustainability, AI-PWAs can realise process and cost efficiency, consumption and usage optimisation as well as an enabled and engaged society. Moreover, negative impacts on sustainability by AI can be diminished by combining it with PWA functionalities. The social drawback of AI being unevenly distributed and not everyone being able to access AI functionalities since it requires specialised end devices is reduced by the cross-platform capabilities of PWAs [We18b]. The cost-intensive deployment of AI functionalities in native apps negatively impacting economic sustainability can be reduced by implementing AI-PWAs, as only one application needs to be developed for all end devices. Finally, the energy intensive use of AI components can be reduced by caching and offline features as well as better usability reducing negative environmental impacts of AI.

This paper directly contributes to the computer science and information systems body of knowledge by introducing the concept of AI-PWAs based on concrete evidence in literature. Moreover, novel insights to foster sustainable development by recombinant innovation are provided that not have been explored before. Our findings support the

theory of recombinant innovation as AI-PWAs represent a perfect example how innovations are achieved by recombining known ideas. In addition to the theoretical insights, practitioners can profit of the findings by gaining knowledge about a new technique to implement innovative business cases more effectively in a sustainable way. Moreover, by systematic structuring the relating literature, practitioners can learn from the experiences others made in implementing AI-PWAs. In relation to AI maturity models, AI-PWAs have the potential to increase the AI maturity of an organisation and to further diffuse AI technologies within it.

The SLR revealed further research opportunities regarding AI-PWAs. Only a few attempts concretely show how PWA caching mechanisms can be used to cache AI components locally and thus ensure a full offline capability of AI-PWAs. By intelligently caching actual AI models rather than just caching responses or data, AI functionality could be transferred from a computationally intensive server to a computationally light end device. This concept is known as edge AI. Edge AI does not yet cover PWA technologies although AI-PWAs show some promising advantages in terms of sustainability. In the future, caching of AI-functionalities through PWA technologies should be explored as this could contribute crucial insights to the field of edge AI. Moreover, this paper represents one of the first research items to elaborate the sustainability of AI-PWAs. In the future, sustainability impacts could be further explored by implementing concrete technical analyses and prototypical sustainability measurements in AI-PWAs. As this paper has presented promising AI-PWA approaches that can benefit various businesses to foster sustainable development, the transfer from AI-PWAs to concrete business model innovations is also worth exploring.

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