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The Transition towards a Sustainable Bioeconomy - Bioplastics in Germany and Italy: A Systematic Literature Review

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DEDICATION

This thesis is dedicated to God almighty for granting me grace and strength to complete this program. I also dedicate this work to my family, especially my beloved mother, Elizabeth Ajuba Mandor of blessed memory.

ABSTRACT

The unsustainable exploitation of the earth's fossil resources compromises the ability of future generations to meet their own needs given associated grand challenges such as climate change and food security. Therefore, a paradigmatic shift from the current fossil economy to the more sustainable alternative of a bioeconomy necessitated. As progress is being made in the transition towards a sustainable bioeconomy, one significant goal is the reduction of greenhouse gas (GHG) emissions through the use of bio-based products such as bioplastics. In this study, a comparative analysis of factors propelling the bioeconomy transition in Germany and Italy is conducted through the lenses of bioplastics whilst also exploring policy mixes that could accelerate the diffusion of bioplastics in the two countries and others. This study leveraged the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. After carefully assessing of records based on the study objectives and scope, 16 publications were selected for qualitative analysis. A significant finding of this study is that, while both countries do not possess a dedicated bioplastics strategy given the nascence of the bioeconomy in general, they demonstrate commitment to bioplastics use and diffusion. Of the two countries, Italy assumes leadership in the bioplastic transition. Nevertheless, socioeconomic factors, technical innovation in feedstock production and legislation were identified as the main drivers of the transition in the two countries. Industry proactivity, legislation, technological innovation and international collaboration were highlighted as important steps that can fast-track the diffusion of bioplastics in the two countries and others as part of the sustainable bioeconomy transformation. This study was limited by geography, in scope and timeframe which could serve as avenues for future research.

Keywords: Bioeconomy, Bioplastics, Transition, Policy, Italy, Germany

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GHG	Green House
HDPE	High Density Polyethylene
INCAS	Intelligently Navigated Complex Adaptive System
IPCC	Intergovernmental Panel on Climate Change
LDPE	Low Density Polyethylene
OECD	Organization for Economic Co-operation and Development
PBAT	Polybutylenadipat-terephthalate
PCL	Polycaprolactone
PE	Polyethylene-PE
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoates
PLA	Polylactic acid
PP	Polypropylene
PS	Polystyrene
PVOH	Polyvinyl alcohol
SDGs	Sustainable Development Goals
SLR	Systematic Literature Review
TPS	Polyethylene terephthalate
UN	United Nations

INTRODUCTION

1.1 Background of the Study

The traditional fossil-based economy has been responsible for the unsustainable exploitation of the earth's fossil resources, hence compromising the ability of future generations to meet their own needs (Bugge et al., 2016; Gottinger et al., 2020; Priefer & Meyer, 2019; Staffas et al., 2013). Against this backdrop, Korhonen et al. (2021) posit the commitment of Global leaders to the achievement of the United Nations (UN) Sustainable Development Goals (SDGs), the Paris Climate Agreement, and the European Green Deal aimed at a paradigmatic shift from a fossil economy towards the more sustainable alternative of a bioeconomy.

According to McCormick and Kautto (2013), the bioeconomy is synonymous with the "bio-based economy" and "knowledge-based bio-economy" (p.2590) and refers to an economic setup where materials, chemicals, and energy that are used in the economy are tapped from renewable resources such as plant and animal sources. Gottinger et al. (2020) highlight the importance of the bioeconomy in facilitating the transition towards a world of sustainable production and consumption. In fact, "the transition to the bioeconomy is often argued to play a key role in targeting grand challenges such as climate change, food security, health, industrial restructuring, and energy security" (Bugge et al., 2016, p.13), thus working effectively towards ensuring a better future state. Imbert et al. (2017) emphasize the relevance of the bioeconomy to the overarching European economy, as they report a 2.2 trillion euro annual turnover attributable to the bioeconomy and over 20 million jobs traceable to it. The authors further posit that, for the European Commission (EC), the bioeconomy presents an opportunity to use land efficiently, reduce CO_2 emissions, and propel economic growth by making the European Union (EU) a hub for technology and knowledge transfer regarding the bioeconomy.

As progress is being made in the transition towards sustainability, one significant goal is the reduction of greenhouse gas (GHG) emissions. Philp et al. (2013) in their study report that the plastics industry of the fossil economy contributes enormously to greenhouse gas emissions. According to the authors, the Intergovernmental Panel on Climate Change's (IPCC) goal of 80% reduction of emissions is potentially the greatest challenge to the future generation. The prevalence of plastics can be attributed to their low-cost nature, application in various sectors (Philp et al., 2013; Di Bartolo et al., 2021), and their widespread use across industries (Degli Esposti et al., 2021). This has created environmental problems such as the "landfill problem" and their "accumulation in oceans" (Arikan & Ozsoy, 2015). This, therefore, necessitates the adoption of bioplastics to improve the environmental credentials of plastics (Klemeš et al., 2021).

Friedrich (2021) in an in-depth expert survey on the benefits of sustainable development from the lenses of bioplastics in the food and textiles industry discovered an increasing pressure on the textile industry to adopt eco-friendly alternatives to petroleum-based plastics, whereas, in the food sector, significant strides had been made in the transition to bioplastics use. Alarez-Chavez et al. (2012) in their qualitative study on bioplastics report that, although bioplastics have the potential to decrease the use of fossil fuels and their associated challenges, none of the commercially used bioplastics and those under development are fully sustainable. They, therefore, suggest more research to produce more environmentally robust plastics to tackle the plethora of challenges that engulf the bioplastics industry. After analyzing networks of the bioplastics sector in Italy, Morone et al. (2015) argued that, although the bioplastics network in Italy seems highly connected with knowledgeable players, knowledge sharing has not been fully exploited, leaving great prospects for development in the industry. Imbert et al. (2017) highlight that in Germany, as part of the five focus areas aimed at positioning the country as an innovation pacesetter, there is an agenda towards the advancement of industrial use of renewable feedstock of which the bioplastics sector is an element.

Hagemann et al. (2016) highlight that the bioeconomy is gaining traction, and a key factor propelling the transition towards the bioeconomy and the adoption of bio-based products is a policy focus with an emphasis on technological innovation in biotechnology (Pyka et al., 2021). European Union member states have developed the most advanced sustainable bioeconomy policies (Dietz et al., 2018; Hagemann et al., 2015) and Imbert et al. (2017) acknowledge that, in capitalizing opportunities presented by technological innovations in the bioeconomy and mitigating associated risks, policies and regulations are employed in the transition process. In the instance of the European Bioeconomy Strategy, the advancement towards a bioeconomy has been contingent on policy efforts across a wide range of industries (Imbert et al., 2017) and a commitment by member states.

According to Imbert et al. (2017), the state-of-the-art literature on sustainability transitions underscores the rising interest in the concept of policy strategies or policy mixes for promoting transitions to more sustainable modes of production and consumption. However, a careful analysis of the literature reveals that although a lot of research has been conducted on bioeconomy strategies, they seem to be fragmented, heterogeneous, and inconsistent (Vogelphol et al., 2021). The literature review also revealed that, only a few studies address bioplastics and their relevance in the transition towards a sustainable bioeconomy. The few studies available however lack depth in addressing key factors influencing the transition towards a sustainable bioeconomy from the lenses of bioplastics or suggesting policy mixes that could accelerate their diffusion

1.2 Research Questions

This study is therefore aimed at addressing the limitations highlighted above by analyzing comparatively, the bioeconomy strategies of Germany and Italy with special emphasis on the subfield of bioplastics. These countries were chosen because they each possess a dedicated bioeconomy strategy. The main objective of this study is to pan out and highlight key transformation factors influencing the transition towards a sustainable bioeconomy from the perspective of bioplastics in Germany and Italy. Further, the study would explore what additional policy mixes can be proposed to speed up the diffusion of bioplastics in these countries as they transition into a sustainable bioeconomy. Consequently, the following research questions shall be answered.

I) What are the key transformation factors influencing the transition towards a sustainable bioeconomy through the lenses of bioplastics in Germany and Italy?

II) What additional policy mixes can be proposed to fast-track the diffusion of bioplastics in the two countries and others as part of the sustainable bioeconomy transformation?

1.3 Significance of the Study

The findings of this research would inform policy decisions in the bioplastics sector of the sustainable bioeconomy, especially policy mixes aimed at accelerating the diffusion of bioplastics in the sustainable bioeconomy. It will enable governments to develop more favorable bioplastic policies that would propel the transition towards a sustainable bioeconomy.

This study will be relevant to researchers as a contribution to the growing knowledge being generated in relation to the sustainable bioeconomy, by providing a detailed insight into the bioplastics aspect of the bioeconomy. It will benefit those in academia and other scholars researching in areas related to the bioplastics sector of the sustainable bioeconomy to advance knowledge in the field by serving as a reference material and a basis for other studies.

1.4 Organization of the Study

The study is systematically organized into six main chapters:

Chapter one constitutes the introductory chapter, and it comprises sections such as the background of the study, research questions, the significance of the study, and the organization of the study. Chapter two encompasses the theoretical framework where key concepts such as the bioeconomy and bioplastics would be defined and an overview of the state-of-the-art regarding the study provided. In chapter three, the methodology adopted for the study is espoused, with details such as data collection and evaluation procedures explained. Chapter four presents the results of the analysis, which would then be discussed in chapter five. The last chapter concludes the study, suggests recommendations for future studies, and reports the limitations of the study.

2. THEORETICAL FRAMEWORK

Jabareen (2009) defines a theoretical framework as a network of interrelated concepts that, as a whole, provide a holistic understanding of a phenomenon. The author suggests a qualitative approach to building a theoretical framework to enable a better understanding of phenomena, especially when linked to multidisciplinary studies.

In this chapter, the key theories pertaining to this study would be discussed. An overview of the bioeconomy, the European Union bioeconomy strategy, bioplastics, and their relevance to the transition towards a sustainable bioeconomy would be espoused below.

2.1 Demystifying the Sustainable Bioeconomy- a Terminological Appraisal

According to Bonaiuti (2014, as cited in Birner 2018), the term "bioeconomics" was propounded in the late 1960s and was popularized by Georgescu-Roegen. Birner (2018) reports that an important factor in Georgescu-Roegen's use of the term "bioeconomics" was that infinite growth could not conform to natural law. The author highlights, the term "bioeconomics" as used by Georgescu-Roegen differs from the mainstream use of the term bioeconomy today which Birner (2018) indicates was popularized by Juan Enriquez and Rodrigo Martinez to mean the industrial and commercial use of biological knowledge.

Wohlgemuth et al. (2021) assert that, globally, the bioeconomy is defined as leveraging a knowledge-based approach in the production and use of bioresources that span all economic sectors through the use of innovative biological processes. Congruently, McComick and Kautto (2013), highlight that the bioeconomy is identical to the "bio-based economy" and "knowledge-based bio-economy" (p.2590) concepts and denotes an economic system where materials, chemicals, and energy used in the economy are tapped from renewable feedstock such as plant and animal sources. However, a review of the transdisciplinary literature that covers the bioeconomy highlights the complexity of the concept and reveals a lack of consensus on the definition of the bioeconomy (Bugge et al., 2016; Priefer & Meyer, 2019; Pyka et al., 2021) due to the ascription of various meanings to the concept by various scholars (Barañano et al., 2021).

Staffas et al. (2013) found the need to differentiate the bioeconomy from the so-called "bio-based economy" because the two concepts had almost become synonymous and used interchangeably. According to Staffas et al. (2013), while the latter focuses on the production of non-food bioproducts, the former encompasses the production of food and feed as well as the so-called bio-based economy. This suggests that the term bioeconomy is a more comprehensive term to use in this thesis compared to bio-based economy.

Regarding the plethora of definitions that engulf the concept of the bioeconomy, two key definitions stand out in the European context. On one hand, the Organization for Economic Co-operation and Development (2009) postulates that the bioeconomy can be envisaged as a global economic setup where biotechnology plays a significant role in economic output. On the other hand, according to the European Commission (2018), the bioeconomy encompasses all economic segments and systems that are reliant on natural resources such as microorganisms, plants, and animals which are derived from biomass, their functions, and principles. The commission posits the bioeconomy includes land and marine ecosystems and the role they play in maintaining balance across all primary production sectors such as forestry, agriculture, fisheries, and aquaculture, and all industries that leverage biological resources and processes in the production of food, feed, bio-based products, energy, and services. This definition is congruent with the one posited by Lewandowski (2018), who elucidates the bioeconomy to involve the sustainable and innovative usage of bio-based raw material and the use of biological knowledge to provide products and services.

A study by Branzova (2019) aimed at providing a terminological device in the bioeconomy field suggests that the term bioeconomy lacks lexical consensus because it is context-dependent and relies on the peculiarities of the jurisdiction in perspective to achieve a relevant connotation. In his study, he highlights country-specific definitions to emphasize the difference in focus on what the bioeconomy means in different parts of the globe. Branzova (2019) highlights that in Germany, the bioeconomy leverages a knowledge-based approach to the production and utilization of renewable resources to produce products, production processes, and services that span all economic sectors, within the economic setup to create a sustainable future. In the Italian context, the bioeconomy encompasses the parts of the economy that leverage renewable biological resources from land and marine sources, such as plants and animals, and largely microorganisms in the production of food and energy (Branzova, 2019).

It can be inferred from the definitions above that, although the approaches to defining the bioeconomy concept are different, the concept is rooted in the use of biological resources in economic activity, and in most cases, the so-called definitions are essentially descriptions of what the bioeconomy is in the various contexts.

In a recent study, Barañano et al. (2021) report that there is consensus on the fact that the bioeconomy is associated with the sustainable use of renewable biological resources and organic matter in the production of food and feed, bio-products, and bioenergy. However, Barañano et al. (2021), warn that sustainability is not an attainable state solely by the use of renewable resources. This stance is congruent with that of Pyka et al. (2021), who postulate that it is important to bear in mind; increasing adoption of bio-based technologies and products is not an automatic ticket for sustainable development.

Hinderer et al. (2021) underscore the bioeconomy is not sustainable in itself but ought to be hinged on sustainable development to achieve its set goals. Barañano et al. (2021) consequentially advocate for a sustainable resource base, sustainable production and consumption, and circularity of material flukes, if a sustainable paradigm is to be achieved. Keiner (2005) asserts that the concept of sustainability has gained prominence as a guiding principle for human development in the last millennium because of the World Commission on Environment and Development's (WCED) 1987 report, where sustainable development is defined as a kind of progress that allows the needs of the present generation to be met without jeopardizing the potential of future generations to meet their own needs. According to Bicchielli (2021), the sustainable bioeconomy is an "intersection between the bioeconomy and sustainability" (p.10). For instance, Lewandowski (2018) highlights that although the bioeconomy is defined in different ways across the globe and a unified definition is not a goal, it is worth noting that the perception of the bioeconomy "as the knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors" (Bioeconomy Summit as cited in Lewandowski, 2018, p.25) is a one held by many countries. This indicates that viewing the bioeconomy through the lenses of sustainability is a perception held by many countries.

There is currently “no comprehensive or standard definitions of sustainability, no ideal tools for measuring it, and no international agreement on the set of indicators needed to make measurements” (OECD, 2013, p.12). A review of the European Commission (2018) bioeconomy policy document themed Sustainable Bioeconomy also reveals no explicit definition of the sustainable bioeconomy. However, the sustainable bioeconomy is linked to the reduction of emissions in the European Energy Sector; reduction in greenhouse gas emissions; mitigation of the climate crisis and land ecosystem degradation; reduction of pressure on ecosystems such as soils, forests, and oceans; and central to the achievement of the SDGs.

For this study, bioeconomy, as defined by the European Commission (2018), will be adopted as it is more comprehensive and holistic while the sustainable bioeconomy as posited by Bicchielli (2021) will be used in the context of this thesis. For this study, bioeconomy and sustainable bioeconomy will be used synonymously.

2.2 The Sustainable Bioeconomy and European Union Bioeconomy Strategy

Hausknost et al. (2017) in an analysis of diverging techno-political choices regarding the bioeconomy drew narratives from policy maps, stakeholder consultations, and scenario modeling and espoused that, globally, the bioeconomy has been linked to the green economy with many countries jumping on the bandwagon and conceptualizing visions from sociotechnical and industrial perspectives. El-Chichakli et al. (2016) underscore that these visions are manifesting worldwide, leading to some US$ 1 trillion worth of goods and services attributable to the bioeconomy.

In a global cross-disciplinary study by Bugge et al. (2016) covering papers published between 2005 and 2014 on the bioeconomy, the authors identified three archetypal bioeconomy visions; biotechnology, bioresource, and bioecology. The premiere vision is contingent on research on biotechnology with a focus on the commercialization of innovations across sectors. The bioresource vision is hinged on knowledge generation with a Research and Development (R&D) focus tailored towards optimizing existing value chains and creating new ones around biological raw materials. The last vision, bioecology highlights the necessity of efficient use of energy and promotes biodiversity with the ultimate aim of protecting the planet (Bugge et al., 2016).

Hausknost et al. (2017) highlight that the visions are mapped around sociotechnical transitions and therefore do not paint a clear picture of the varying sociopolitical pathways that a bioeconomy transition might entail. For instance;

> The biotechnology vision and the bioresource visions are conceptually entangled as both may rely on biotechnology and a large renewable resource base, while neither vision questions the overall direction of growth-based capitalist development. The agro-ecology vision, too, may lean more or less towards the application of advanced technologies and a growth-oriented vision of development or a sufficiency perspective. (Hausknost et al. 2017, p.5).

The three visions highlighted below are hinged on innovation and value creation through sociotechnical transitions in a bid to arrive at a greener economy.

Table 1

Key Characteristics of the Bioeconomy Visions

	The Bio-Technology Vision	**The Bio-Resource Vision**	**The Bio-Ecology Vision**
Aims & objectives	Economic growth & job creation	Economic growth & sustainability	Sustainability, biodiversity, conservation of ecosystems, avoiding soil degradation
Value creation	Application of biotechnology, commercialization of research & technology	Conversion and upgrading of bio-resources (process-oriented)	Development of integrated production systems and high-quality products with territorial identity

Drivers & mediators of innovation	R & D, patents, Research councils, and funders (Science push, linear model)	R & D, patents, Research councils, and funders (Science push, linear model)	Identification of favorable organic agro-ecological practices, ethics, risk, transdisciplinary sustainability, ecological interactions, re-use & recycling of waste, land use, (Circular and self-sustained production mode)
Spatial focus	Global clusters/ Central regions	Rural/Peripheral regions	Rural/Peripheral regions

Note. From *What is the Bioeconomy? A Review of the Literature,* (p.10), by M.M Bugge, T. Hansen & A. Klitkou, 2016, Sustainability. Copyright 2016 by Sustainability.

In a bid to deepen understanding of the bioeconomy through an analysis of various visions related to the bioeconomy, Bugge et al. (2016) suggest that, although the bioeconomy is purported to tackle "grand challenges" (p.13) that span various sectors and industries, the bioeconomy is a relatively nascent field. Bugge et al. (2016) further highlight that different knowledge fields are interwoven in producing knowledge relevant to the bioeconomy, although the fields of natural and engineering sciences take center stage with bioeconomy related knowledge. According to Bugge et al. (2016), the bioeconomy is accompanied by different objectives across different focus areas regarding socioeconomic value chains. This assertion corresponds with a recent study by Pyka et al. (2021) which maintains that the bioeconomy affects many industrial sectors and there is, not one, but many bio economies, indicating the traction gained by the concept, transcending industries and becoming a political reality (Toller et al., 2021).

Barañano et al. (2021) in their contextualization of the bioeconomy highlight that the goal of the bioeconomy is to foster an economic paradigm that innovatively creates value chains while ensuring the environment is protected. The researchers credit the advancement of the bioeconomy to three factors;

> (a) Advances in biological sciences; (b) policy objectives for climate change mitigation, energy self-sufficiency, rural development, and export promotion; (c) the fact that biodiversity and genetic resources are viewed as inputs critical to the discovery of pharmaceuticals and other bio-based products. (Barañano et al., 2021, p.2).

Hinderer et al. (2021) associate the bioeconomy with the same three visions postulated by Bugge et al. (2016); a biotechnology vision, a bioresource vision, and a bioecology vision which they underscore are not mutually exclusive but converge in the bioeconomy discourse. However, Hinderer et al. (2021) conceptualize two pathways to the achievement of a bioeconomy transition; a technological approach on one dimension, and a socio-ecological approach on the other dimension.

According to Hinderer et al. (2021), while the technological path has gained more traction over the socio-ecological path in the bioeconomy discourse, mere technological knowledge will not suffice for a transformation. The researchers suggest a consolidation of "systems knowledge (i.e., knowledge about how relevant systems work), normative knowledge (i.e., knowledge about the desired system states), and transformative knowledge (i.e., knowledge about how to transform systems)" (Hinderer et al., 2021, p. 3) to achieve the desired transformation.

According to El-Chichakli et al. (2016), an essential missing link stalling the desired bioeconomy transformation is a unified global approach and a harmonization of policies regarding the bioeconomy through international cooperation. The authors, therefore, suggest global collaboration between private and public sector actors to create knowledge, a framework to measure the actual contribution of the bioeconomy to the achievement of the SDGs, more strategic policy initiatives through intergovernmental collaboration, and an investment in education and R&D in order to bridge this gap (El-Chichakli et al., 2016). This indicates that although various counties may possess different approaches to their bioeconomy vision as their resource peculiarities and technical capacities may differ, international cooperation and collaboration could be the key that fast-tracks the transition.

Bößner et al. (2020) identify the Biofuture Platform, Global Bioeconomy Council, the United Nations (UN), the Organization for Economic Co-operation and Development (OECD), the Food and Agriculture Organization (FAO), and the World Trade Organization (WTO) among other global institutions as critical institutions essential to achieving a unified governance framework to address the grand challenges identified by (Bugge et al., 2016), and to create change via international trade agreements. The authors emphasize a harmonization of regulations regarding trade for biomass and bioproducts, which they elucidate to be essential in strengthening environmental governance.

In a global comparative study of national bioeconomy strategies, Dietz et al. (2018) discover that, although countries seek to advance their bio economies by capitalizing on a comprehensive political approach, it may be easier for countries to transition if they possess a developed and effective regulatory framework for the bioeconomy which many European Union member states qualify given the commitment of the European Commission to a unified bioeconomy framework.

For the EU, achieving a sustainable bioeconomy is part of an ambitious plan to become the first climate-neutral region by 2050 (Kirs et al., 2021). Patermann and Aguilar (2017) credit the advancement of the sustainable bioeconomy in the EU to change, necessity, and a sheer commitment of the European Commission to dedicate resources to research and programs dedicated to biotechnology. These projects were grounded in transnational participation across various industries to foster learning, which then culminated in policy (Patermann &Aguilar, 2017). Wozniak et al. (2021) adduced the importance of engaging all relevant stakeholder groups by liaising to produce ideas from different perspectives, expertise, and experiences to foster co-creation and mutual learning among these identified stakeholders. This creates an enabling environment for the achievement of the bioeconomy's full potential. It is, therefore, no surprise that the EU as a block assumes leadership in the bioeconomy as it addresses the drawbacks identified by El-Chichakli et al. (2016). This leadership is attributable to the unified approach of the EU to the bioeconomy, although there are inherent challenges and some countries seem to be far ahead of others.

Currently, the European bioeconomy is valued at 2.2 trillion Euros and employs over 20 million people (Imbert et al., 2017; McCormick & Kautto, 2013). Bell et al. (2018) acknowledge that, for the EU, the achievement of a sustainable bioeconomy, although an ambitious project, is necessitated by the need to cope with the global population surge and the pressure this puts on the environment. The EU bioeconomy strategy, which was launched in 2012, spans all sectors that leverage biotechnology in production. According to Bell et al. (2018), the EU bioeconomy strategy contrasts with the OECD (2009) bioeconomy strategy. While the OECD strategy is hinged solely on biotechnology, the EU strategy is hinged on the three pillars of investment in knowledge generation, a policy focus based on stakeholder engagement, an enhancement of markets and competitiveness as well as a clear plan for the strategy's implementation (Bell et al., 2018).

For the EU, the bioeconomy is to catalyze the establishment of a new economic paradigm, grounded in the use of renewable raw materials and energy in production, to mitigate fossil dependence (McCormick & Kautto, 2013). The strategy thus seeks to achieve a sustainable economy that leverages a systems approach to food production while ensuring sustainable biomass production, onboarding of citizens to the vision of sustainable consumption patterns and environmentally friendly purchasing, a reduction of CO_2 emissions, job creation, and value chains that innovatively use biological resources (Bell et al., 2018).

2.3 The Bioeconomy as a Complex Adaptive System

The review so far highlights the complexity of the bioeconomy but also emphasizes its relevance in the global quest to achieve a sustainable paradigm. Maciejczak (2017) describes the bioeconomy as a giant system that merges biomass, biotechnology, industries, citizens, and policy. The bioeconomy is accompanied by the emergence of new industries which complement existing ones to create value in such a way that one industry uses the by-products of others in its production (Maciejczak, 2017). According to Maciejczak (2017), the bioeconomy can be considered a complex adaptive system which relies on connections between players involved in a dynamic network that can metamorphose to suit new conditions as and when they occur.

Holland (1992) suggests complex adaptive systems have many autonomous parts that interact with each other and possess their own rules, which independently result in an outcome that influences the behavior of other parts of the system. "Complex adaptive systems also exhibit an aggregate behavior that is not simply derived from the actions of the parts" (Holland, 1992, p.19). According to the author, complex adaptive systems cannot function optimally but can function adaptively and efficiently to meet the exigencies of a particular situation. Levin et al. (2013) suggest that policy should be framed in such a way that players are incentivized to act in ways that propel the complex system to a socially desirable state.

Folke (2006) contributes to the complex adaptive systems discourse by making a case for resilience that involves the capacity of systems to renew, reorganize and develop. According to Folke (2006), disturbance is positive and could serve as a catalyst for the creation of novel approaches to doing things leading to innovation and development. In the case of the bioeconomy, R&D causes disruptions to the existing approaches to doing things thereby creating new pathways to sustainable development. This is done by leveraging biological feedstock in the creation of bioproducts such as biofuels and bioplastics which deviate from the established way of production.

Folke (2006) posits that complex adaptive systems are made up of heterogeneous players that interact in a complex way to achieve various plausible end states. The author further explores the characteristics of complex adaptive systems citing two prominent publications in the field; Arthur et al. (1997) and Holland (1995) and reports that, according to the former, complex adaptive systems have six characteristics comprising of cross-cutting hierarchical organization, far from equilibrium dynamics, perpetual novelty, dispersed interaction, continual adaptation and the absence of a global controller. In contrast, the latter identifies four characteristics of complex adaptive systems; aggregation, non-linearity, flows, and diversity.

Levin et al. (2013) postulate that complex adaptive systems are closely integrated and are complex in maintaining an ecological balance. According to Levin et al. (2013), there are four central features of complex adaptive systems; resilience, diversity, redundancy, and modularity. The authors emphasize resilience; the ability to function when intrinsic and extrinsic disruptions occur, and modularity; the extent to which system components may be disintegrated and reintegrated as key to the complexity discourse.

Although various authors have different views on the characteristics of complex adaptive systems, it can be inferred from their arguments that complex adaptive systems are hinged on non-linear pathways and continual adaptation to achieve multiple possible end states for which the bioeconomy is a quintessential example. Levin et al. (2013) highlight that, losing sight of non-linear pathways in complex systems is a recipe for disaster. Levin et al. (2013) further suggest that non-linear models are better in exploring socio-ecological systems such as the bioeconomy, and advocate for a precautious approach to dealing with risk and uncertainty that accompanies complex adaptive systems.

A study by Dabbert et al. (2017) based on data observations revealed a surge in global population, greenhouse gas emissions, energy consumption, etc., and a geometric progression of these factors, i.e. global population, greenhouse gas emissions, energy consumption, etc. The authors highlight that, although a viable planet is an achievable state, ecological and socioeconomic conditions that allow for self-organization are a prerequisite "in such a way that, outcomes of activities show sinusoidal patterns with aptitudes well within the boundaries" (Dabbert et al., 2017, p.35). Describing the bioeconomy as an intelligently navigated complex adaptive system (INCAS), the authors acknowledge the relevance of the complex systems thinking approach in addressing the current enigma of coexistence between ecology and economy. They profess the possibility of a plethora of end-states, thereby highlighting the evolutionary nature of the bioeconomy and its self-organizing potential.

2.4 Bioeconomy Policy and Policy Mixes in Sustainability Transitions

Ball (2006) defines policies from a textual perspective as "representations which are encoded in complex ways (via struggles, compromises, authoritative public interpretations, and reinterpretations) and decoded in complex ways (via actors, interpretations, and meanings in relation to their history, experiences, skills, resources, and contexts)" (p.11). According to Ball (2006), "policies are textual interventions into practice" (p.12). Birkland (2005) defines public policy as ''the things government chooses to do or not do'' (p.188). Although there is an abundance of policy on the bioeconomy, there have been concerns as to whether or not the bioeconomy can be considered a distinct policy field (Toller et al., 2021).

While there are very few studies on whether or not the bioeconomy is a policy field, the bioeconomy has been described as such by many scholars in the bioeconomy discourse. Consequently, Toller et al. (2021) in a recent study sought to clarify the perception of the bioeconomy as a distinct policy field as held by experts (Hagemann et al.,2016; Meyer et al., 2017) in a bid to arrive at a reasonable assertion on the subject. The researchers conducted 60 expert interviews with actors across Europe using the definition by Loer et al. (2015) as a basis for their study.

Loer et al. (2015 as cited in Toller et al., 2021, p.154) espouse that, a policy field encompasses "a specific and long-term constellation of interrelated problems, actors, institutions and measures". Toller et al. (2015), decoded the definition and encoded problems to mean a deviation from the usual way of doing things or perception of issues different from the normative, especially in the political context; actors to mean formally organized groups that play a direct role in decision making regarding policy, which decisions go on to affect the normative ways of doing things in both political and non-political spheres such as businesses, administrative entities, and bureaucracies; institutions to mean a system of rules that allow certain actions and constrains others; and measures to mean specific programs aimed at disrupting the way information, money and law are controlled.

According to Toller et al. (2015), "if all four criteria are met, the political constellation in question is a policy field. If, on the other hand, not all criteria are met, then it is merely a current issue or topic" (p.154). Per their findings, within the EU, the bioeconomy does not meet the four criteria posited by Loer et al. (2015) to be considered a distinct policy field, at least in the interim. This is because, given the multidisciplinary nature of the bioeconomy, the concept cuts across many sectors and is purported as a solution in many industries in the sustainability transitions discourse. Per Toller et al. (2021) the bioeconomy can instead be considered an "umbrella for a number of already existing research and economic areas and policies based on biogenic resources" (p.160). This stance is consistent with the position of Imbert et al. (2017) who posit that "the bioeconomy does not represent a discrete policy domain or sector, but it spans a variety of traditional and emergent policy fields and industrial sectors" (p.71)

The figure below indicates the increasing adoption of bioeconomy policies globally, especially in Europe.

Figure 1.

Bioeconomy Policies around the World

Note. From *Bioeconomy: Shaping the Transition to a Sustainable*, *Biobased Economy* (pp. 17–38), by R. Birner, (2018). In I. Lewandowski (Ed.). Copyright 2018 by Springer International Publishing.

While evidence from the study by Toller et al. (2021) suggests the bioeconomy cannot be considered a distinct policy field, evidence from Birner (2018) suggests that there are over forty bioeconomy policies of sorts globally. According to the OECD (2016), including the G7, about fifty nations have adopted policies on the bioeconomy. Although this evidence may not be sufficient to elevate the bioeconomy to the position of a distinct policy field, what is clear is that, countries are increasingly adopting bioeconomy policies with European countries leading the charge in sustainability transitions.

Markard et al. (2012) assert that a key challenge in sustainability transitions is the understanding of transition-related policy and politics in general. Rogge and Reicchardt (2016) adduce that in responding to this challenge, scholars have advocated for policy mixes. Policy mixes are basically a combination of several policy instruments and how they converge and interact (Lehmann, 2012). Lehmann (2012) posits that policy mixes are superior to single policy because, while the former promotes a holistic approach to sustainability transitions by focusing on environmental as well as technological aspects, the latter is inefficient and has the potential of incentivizing stakeholders only to a certain extent because of its narrow scope.

Rogge and Reicchardt (2016) argue that, in the context of sustainability transitions, prevailing studies on policy mix are not exhaustive in highlighting the dynamics of policy mixes. Therefore, policy mixes must be dedicated to the complexity of real-world scenarios which manifest in the emergence of policy strategies and instruments (Rogge & Reicchardt, 2016). According to the authors, strategies involve defining areas of focus with long-term targets, while carving principal pathways to their achievement. Secondly, they highlight instruments; which are tools and techniques critical to the achievement of the overall policy strategy as relevant in studies regarding policy mixes. Rogge and Reicchardt (2016) conceptualize that instruments are associated with goals which are long-term objectives broken down into achievable milestones.

2.5 Bioplastics in the Sustainable Bioeconomy

Plastics refer to an extended family of polymers, usually extracted from fossil resources and possess a wide range of characteristics and properties (Narancic et al. 2018). According to Narancic et al. 2018, plastics have contributed significantly to economic growth and the improvement in standards of living and quality of life over the last fifty years. Watkins and Schweitzer (2018) estimate that, from the 1950s till now, about 8,300 million metric tonnes of pure plastics have been manufactured globally. The ubiquity of plastics, which have been dominated by fossil-based ones, and their widespread use across various personal and industrial purposes has made them a subject of scrutiny in the past decades (Nandakumar et al., 2011).

Mekonnen et al. (2013) envisage that petro-based plastics would gradually make way for bioplastics and eventually be replaced by them over the next few decades.

The authors report that worldwide annual plastic production was expected to surpass 300 million tons by 2015. Jogi and Bhat (2020) highlight that global production of petro-based plastics rose to 360 million tons in 2018, of which 61.8 million metric tons, accounting for 18.5% could be traced to Europe (Filho et al., 2020). The global production capacity of bioplastics, however, stood at 2.01 million tons in the same year (Jogi & Bhat, 2020).

According to Narancic et al. (2018), although bioplastics continue to remain a small niche accounting for an infinitesimal percentage of total plastic production globally, there is an agenda towards having them become more mundane. Narancic et al. (2018), highlight that given the surge in demand for biodegradable plastics in countries such as Brazil, China, and India, "the global biodegradable plastic market is projected to reach US$6.73 billion by 2025 from $3.02 billion in 2018" (Narancic et al., 2020; p.4).

Kakadelis et al. (2021) postulate that, of the over 300 million metric tonnes of plastics produced annually, only a fraction find their way back into the supply chain as most of them end up in landfills and the environment in general. Dobrucka (2019) asserts that the EU is the second-largest plastic producer after China. However, only 30% of plastic waste generated in the EU is recycled. Packaging accounts for 65% of plastic usage in Europe, followed by the building and construction, automotive, and electronic sectors, which account for 20%, 9%, and 6% respectively (Watkins & Schweitzer, 2018).

Gironi and Piemonte (2011) highlight that for the environmental effect of plastics to be mitigated especially with greenhouse gas emissions, agricultural products such as wood, sugar, starch, and cellulose ought to be used in plastic production. Alarez-Chavez et al. (2012) buttress this stance by indicating that, bioplastics, i.e. plastics manufactured from renewable natural materials such as starch from corn, vegetable oil, and non-food raw materials such as grass or residual biomass are good for the environment. In a study of volatile fatty acids production from food wastes, Strazzera et al. (2018) suggest that biorefineries present an opportunity to achieve a better environment because, products that were once seen to be waste become the raw materials for the production of bioproducts such as bioplastics. The authors underline food waste as raw materials and report that, in the then EU 28, 89 million tons of food was going to waste annually and ending up in landfills. Strazzera et al. (2018) argue that this could be used in the production of volatile fatty acids which are substantially needed in the production of such bioplastics as polyhydroxyalkanoates.

The complex nature of the bioeconomy makes the subsect of bioplastics a complex one to grasp (Kakadelis et al., 2021). Dabrucka (2019) asserts that bioplastics is a collective term that encompasses different groups of materials; i.e. materials from renewable resources, as well as materials from partially renewable and partially non-renewable resources. In the European Bioplastics (2018) fact sheet, "a plastic material is defined as a bioplastic if it is bio-based, biodegradable or features both properties" (p.1). It is further explained in the document that, "bio-based" as used in their definition denotes a material derived from biomass, whereas biodegradable refers to the chemical process by which microorganisms break down materials into natural substances.

Bioplastics are a category of plastics made from renewable resources and composed of carbon dioxide sequestered by plants (Klein et al., 2020). According to the European Bioplastics (2018) fact sheet, bioplastics encompass a whole family of materials that possess unique properties and applications.

The "members" of this family include partly or wholly bio-based, non-biodegradable plastics (Polypropylene-PP, Polyethylene-PE, Polyethylene terephthalate-PET), biodegradable plastics (Polylactic acid-PLA, Polyhydroxyalkanaoates-PHA, Polybutylene succinate-PBS), and plastics produced from fossils but are biodegradable (Polybutylenadipat-terephthalate-PBAT). It is imperative to address the need for the use of bioplastics in the transition to a sustainable bioeconomy in this thesis, and since this study is focused on EU countries, the concept of bioplastics is to be understood as intended in the European Bioplastics factsheet.

The table below shows the energy requirements as well as the CO_2 emissions per kilogram of petro-based plastics and bioplastics.

Table 2.

Energy Requirement and CO_2 Emission Figures for Plastics

Type of plastic	Energy requirement, MJ/kg	Global warming, kg CO_2 eq/kg
		From non-renewable sources
HDPE	80	4.84
LDPE	80.6	5.04
Nylon 6	120	7.64
PET	77	4.93
PS	87	5.98
PVOH	102	2.7
PCL	83	3.1
		From renewable sources
TPS	25.4	1.14
TPS + 15% PVOH	24.9	1.73
TPS + 60% PCL	52.3	3.6
PLA	57	3.84
PHA	57	Not Available

Note. From *Bioplastics and Petroleum-based Plastics: Strengths and Weaknesses, Energy Sources, Part A* (p.1952), by F. Gironi & V. Piemonte, 2011, Recovery, Utilization, and Environmental Effects. Copyright 2011 by Recovery, Utilization, and Environmental Effects.

It can be inferred from Table 2 above that, while petroleum-based plastics have remained the status quo, they have contributed significantly to global greenhouse gas emissions due to their chemical composition, and consume more energy in production compared to bioplastics. Filho et al. (2020) highlight that petroleum-based plastics tend to seep into the food chain as micro plastics that pose a threat to living organisms. Experts have therefore made a strong case for the adoption of bioplastics as an environmentally friendly alternative to the status quo (petroleum-based plastics), a prerequisite for the transition towards a sustainable bioeconomy (Philip et al., 2013; Filho et al., 2020) and a means to minimize the micro plastic phenomenon that has affected the food chain (Mashood et al., 2021).

In a study of the strengths and weaknesses of bioplastic and petroleum-based plastics, the literature reviewed by Gironi and Piemonte (2011) revealed a general superiority of bioplastics over petro-based plastics in terms of resource consumption and greenhouse gas emissions. Dubrucka (2019) reports that bioplastics demonstrate more mechanical competencies and transparency compared to their fossil cousins. Bioplastics have gained credence not only because they can be recycled and produced using energy-efficient production processes compared to petroleum-based plastics, but most importantly because they are produced from renewable feedstock (Alarez-Chavez et al., 2012).

Mashood et al. (2021) identify macroeconomic, regulatory, technological, and social factors as critical factors influencing the growing demand for bioplastics. The researchers report that an increase in Gross Domestic Product (GDP) generally results in a surge in the production and consumption of bioplastics. The second factor advanced by Mashood et al. (2021) is the regulatory factor where they posit that environmentally sustainable policies such as subsidies for bioplastics manufacturers have the tendency of reinforcing markets for bioplastics goods. Technological factors account for the fourth demand influencers identified by Mashood et al. (2021). According to the authors, an upgrade of technical competencies and learning effects would result in more robust bioplastic processing methods being built over time. Lastly, Mashood et al. (2021) highlight customer awareness and desire to spend on more environmentally friendly products as a highly important factor influencing the demand for bioplastics. The researchers attribute this to an awareness of the risks associated with petroleum-based plastics and the sense of ecological responsibility customers possess.

Filho et al. (2020), in an assessment of attitudes towards plastics and bioplastics in Europe, report that there is significant awareness of the plastic problem among the European citizenry and a willingness to adopt the environmentally friendly alternative of bioplastics. The authors report that of all the associated problems, those associated with water pollution were of greatest concern to consumers. Watkins and Schweitzer (2018) highlight that about 150,000 to 500,000 metric tonnes of plastic waste enter the ocean from the EU annually, which is a plausible reason for the findings by Filho et al. (2020).

According to the OECD (2013), over the last few years, an increasing number of governments have formulated strategies and policies in support of the transition towards a sustainable bioeconomy. While a lot of these policies support the advancement of bio-based products or the bioeconomy in general through research and innovation, "only a few countries have developed a specific set of policies targeting the development of bioplastics" (OECD, 2013, p.34). Philip et al. (2013) postulate that, while policy has been far-reaching for biofuels, with significant R&D investment and continuous support for commercialization, it has been insufficient in the case of bioplastics. The authors thus make a case for the relevance of policy interventions for bioplastics from a policy vantage point of view to support the production of bioplastics over their more successful fossil counterparts, in the quest to achieve a sustainable bioeconomy.

According to Philip et al. (2013), because resources related to biomass and technological advancement are located sparsely over the globe, biomass and its resulting products would have to be traded among countries which may lead to trade wars. The authors, therefore, advocate for international harmonization for policy regarding bioplastics. This is congruent with the European green deal, which spells out that reaching the set targets calls for coordinated investment in eco-friendly technology and collaboration of global partners to improve global environmental standards (European Comission, 2019). It is also congruent with the suggestion by El-Chichakli et al., (2016) that, a unified global approach and a harmonization of policies regarding the bioeconomy through international cooperation is essential to the bioeconomy transformation.

3. METHODOLOGY

This chapter presents the various methods and procedures used in the collection of research data with details of research design, research approach, research instruments, and procedure for analysis of data. This study focuses on the bioeconomy of Germany and Italy. The researcher decided to conduct a comparative study of the two countries because they are well versed with the bioeconomy and possess very advanced bioeconomy strategies although they approach the bioeconomy differently.

3.1 Data Collection

This study was conducted by employing a Systematic Literature Review (SLR) which follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The PRISMA Statement comprises a 27-item checklist and a three-phase flow diagram, which allows for a funnel approach to selecting studies to be reviewed. Petticrew and Roberts (2006) describe a Systematic Literature Review as "literature reviews that adhere closely to a set of scientific methods that explicitly aim to limit systematic error (bias), mainly by attempting to identify, appraise and synthesize all relevant studies (of whatever design) in order to answer a particular question (or set of questions)" (p.6). According to Weed (2005), SLR differs from Traditional Literature Review because it is objective, replicable, systematic, and comprehensive. Xiao and Watson (2019) highlight that this methodology enables the researcher to understand an existing body of knowledge and existing gaps holistically. Using an SLR methodology ensured that all steps in the review were documented and made transparent. A protocol was drafted to improve the reliability of the systematic literature review and ensure consistency with the primary research question.

The national dedicated bioeconomy strategies of the selected European counties (Germany and Italy) were fundamental to the study. Given the interdisciplinarity of the bioeconomy, the approach to data collection was aimed at reaching as many scientific journals as practicable. To ensure this objective is met, the Scopus database was chosen because of its holistic coverage of papers from revered scientific journals. The selected database provided a strong basis for identifying high-quality studies needed for this study. The keywords "bioeconomy" "transition", "bioplastics", and "policy" served as a basis for the search for papers. Papers were sought using the advanced search "title-keyword-abstract" format on Scopus, with the search string *(bioeconomy OR bioplastics AND trans* AND policy OR Italy OR Germany)*. Studies were eligible for inclusion if they addressed an issue related to one of the research questions posed in this study regarding the sustainable bioeconomy, leveraged an empirical approach, and had research questions focused on the transition towards a sustainable bioeconomy. These inclusion criteria were adapted from Gottinger et al. (2020). Peer-reviewed papers authored in English between 2011 and 2021 were considered for this research. Articles from the last decade were considered for this study because the bioeconomy discourse has intensified in the last decade. All other publications, such as research notes and book reviews that did not conform to these standards, were exempt from the selection.

Table 3

Inclusion Criteria for the Review

Criterion-Type	Inclusion Criteria
Topic	Literature must address at least one of the research questions
Recency	Literature should have been published between 2011 and 2021
Continent	Literature must focus on Europe
Research base	Literature must be based on an empirical research approach
Reliability	The findings of the study must have been proven reliable

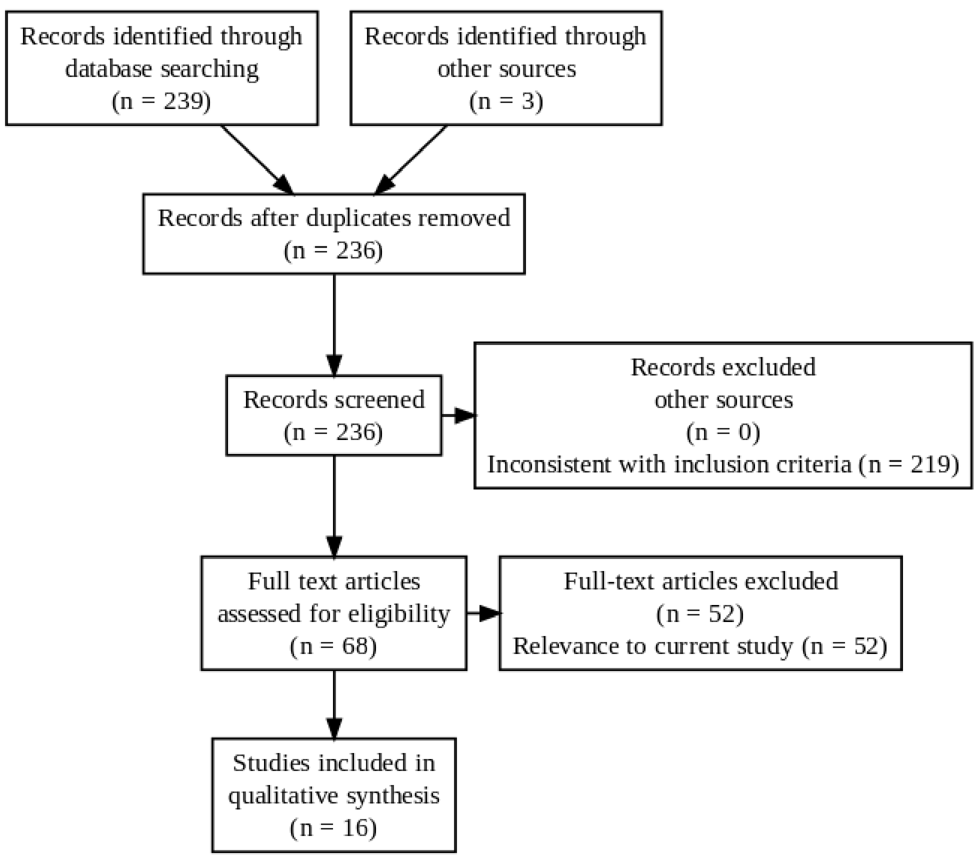
Note. Own elaboration

The search in Scopus after field limitations were applied yielded 239 articles. During the evaluation process, the studies identified were screened against the defined inclusion criteria above and any study that did not satisfy the criteria was excluded from the Systematic Literature Review.

The researcher independently read the titles and abstracts of each article to exclude articles that were not consistent with the inclusion criteria, resulting in 68 articles being considered for further evaluation. The choice of studies to be included in the systematic literature review was the sole decision of the researcher. The screening process continued along multiple stages; a superficial review of the text was done, after which a holistic appraisal of the whole study text with more attention to specific details was conducted. The trustworthiness of the results of studies was judged by conducting a last check for the methodologies used in the studies. This was done to ensure selected papers are relevant for this study. This process resulted in 16 publications being selected for this Systematic Literature Review. The multi-stage screening process was repeated by the researcher but did not yield different results or lead to changes in this Systematic Literature Review. The procedure was repeated to improve reliability as suggested by Gwet (2008) in his work on Intra-rater Reliability.

Figure 2

Literature funneling process



Note. Pictorial depiction of the process of identifying relevant papers to be used for systematic literature review.

3.2 Data Analysis and Critical Appraisal

The analysis was carried out by evaluating findings in selected studies relevant to the transition towards a sustainable bioeconomy. A thematic approach was leveraged to synthesize findings as suggested by Thomas and Harden (2008). For the two core themes of the analysis- transformation factors and potential factors that could accelerate the diffusion of bioplastics, sub-themes were pre-developed and subsequent themes were added as and when they occurred. Thorough descriptive themes which served as a basis for the analysis were then developed to serve as a final guide for the researcher. For this study sensitivity analysis was not conducted because of the limited time frame.

For each study included, the methodology and findings were outlined. Variables such as study design and key characteristics related to the research questions were key areas of focus. For research question 1, data needed to report factors propelling the bioeconomy transition through the lenses of bioplastics were extracted. For research question 2, the researcher focused on suggestions made in selected studies on the mix of policies that would accelerate the diffusion of bioplastics in bioeconomy transition. The simplified framework proposed by Imbert et al. (2017) was adapted to compare the policy strategies of Germany and Italy. This study assessed the factors propelling the transition to bioplastics use in the two countries separately before a comparison is done to pan out the differences and similarities in the transition factors. After, a comparative analysis was conducted between the two countries looking out for similarities and differences in the key transformation factors influencing the bioeconomy transition with particular reference to bioplastics. The qualitative comparative assessment of the two countries was carried out by adapting the transition analysis conducted by Bosman and Rotmans (2016) to suit the modalities of the study.

4. RESULTS

4.1 The National Bioeconomy Strategy of Germany

In the National Bioeconomy Strategy (2020) of the Federal Republic of Germany, the bioeconomy "refers to the production, exploitation, and use of biological resources, processes and systems to provide products, processes, and services in all economic sectors within the framework of a sustainable economic system"(p.10). With the National Bioeconomy Strategy (2020), the federal government of Germany intends to tackle prevailing grand challenges of the 21st century such as food security given the surge in global population and shielding the earth against the climate change phenomenon while ensuring the preservation of biodiversity. Some other aims of the overarching bioeconomy strategy of Germany include successfully integrating economy and ecology while ensuring associated opportunities and challenges are fairly distributed; a transformation of the current fossil-based paradigm to one hinged on sustainable development to allow future generations meet their own needs, and action steps aimed at effective and timely contribution to the Paris Agreement on climate protection. These fundamental tenets are congruent with the argument advanced by Bugge et al. (2016) that the bioeconomy plays a key role in addressing grand global challenges.

Two guiding principles are carved for the achievement of a bioeconomy in Germany. Firstly, leveraging biogenic knowledge as well as responsible innovation to achieve sustainable, climate-friendly development. Secondly, the use of biological raw materials for sustainable, circular production and consumption, which is where bioplastics come to play. The goals of the bioeconomy as identified in the National Bioeconomy Strategy (2020) are to develop bioeconomy-relevant solutions in line with the 2030 agenda for sustainable development, identify and harness the prospects of the bioeconomy within ecological boundaries, enhance and apply biological knowledge, establish a sustainable raw material base for industry, and promote Germany as the leading hub for innovation when it comes to the bioeconomy (p.5).

4.2 Key Transformation Factors-Transition towards Bioplastics in Germany

A review of the National Bioeconomy Strategy (2020) of Germany reveals no clear policy regarding bioplastics in the transition towards a sustainable bioeconomy. However, a review of a preceding document published in 2015 by the Federal Ministry of Education and

Research and the Federal Ministry of Food and Agriculture themed the National Bioeconomy of Germany- Opportunities for bio-based and sustainable future indicates a commitment of stakeholders to the use of bioplastics. These findings are congruent with the findings of Imbert et al. (2017) who report that, in Germany, there are no dedicated policies or strategies that target the promotion of bioplastics, yet " the two main national strategies related to the transition towards a bio-based economy support the growth of the bioplastics sector" (p.74).

The National Bioeconomy of Germany- Opportunities for bio-based and sustainable future (2015) indicates that, of the close to 14 million tons of packing implements produced annually in Germany, 40% which accounts for about 5.5 million tons consists of plastics, primarily petroleum-based. However, it is suggested in the document that bio-based alternatives are gaining ground across industrial and domestic purposes with industry at the forefront of the transition towards bioplastic use. Analysis of various publications related to the German bioeconomy reveals some evidence regarding core factors accounting for the transition towards a sustainable bioeconomy from the lenses of bioplastics. The studies illuminate relevant themes resulting in the surge of bio-based products of all forms in recent years as the country transitions into a sustainable bioeconomy.

Generally, macroeconomic factors, resulting in socio-economic development have contributed greatly to the transition towards a sustainable bioeconomy in Germany. Sturm and Banse (2021) highlight that a significant surge in GDP facilitates investment in novel bio-based production processes and technology that results in commercially viable bio-based products such as bioplastics which have positive environmental credentials as well. An increase in GDP indicates that adequate investment in R&D can be pursued since the economy experiences increases in productivity and economic buoyance. Imbert et al. (2017) assert the commitment of Germany to entrench her position as a global bioeconomy pacesetter by creating technical know-how relevant to the transition towards a sustainable bioeconomy. Germany, therefore, invests significantly in its industrial and research ecosystem (Dieken and Venghaus, 2020). Thyssen Krupp is mentioned in the National Bioeconomy of Germany (2015) document to have invested over 20 million Euros within 5 years in a production plant for biochemicals in Leuna. Imbert et al. (2017) highlight that the government of Saxony-Anhalt devoted 50 million Euros to this same plant. The researchers underscore that, as of 2016, the bioeconomy had received 120 million Euros in public funds aimed at R&D although commercialization of many innovations has seen little progress. The automotive sector is cited as one of the largest bioplastic users, leveraging the material for car interior lining and seats.

Dieken and Venghaus (2020) stress that, with Germany, the biotechnology vision posited by Bugge et al., (2016) is critical to the transition towards a sustainable bioeconomy. Technical innovation in feedstock production has been linked to improved agricultural practices and significant yield of biomass for the production of bio-products hence facilitating the transition towards the sustainable bioeconomy in Germany. Sturm and Banse (2021) postulate that an increase in food and feed production, coupled with a reduction in food waste has contributed to the sustainable bioeconomy transformation by making feedstock available for the production of advanced bio-products such as biofuels and bioplastics. The authors posit that because a large amount of biomass produced is dedicated to feed and food purposes, technical innovation resulting in increased agricultural yield and the responsibility assumed by consumers towards a reduction of food waste facilitates the availability of biomass for the production of biofuels such as biodiesel and bioethanol, and to a large extent bioplastics as well. According to Sturm and Banse (2021) alternative, environmentally friendly carbon sources are phasing in, which are of great importance to the German organic chemical industry. The researchers highlight that in 2015, 2.5 million tons of biogenic resources, mainly from agricultural and forest biomass were used in the chemical industry.

Political dynamics, through legislation, have been substantial in the bioeconomy transition in Germany as well as bioplastics use given the dedication of the country to achieving a sustainable paradigm that merges economy and ecology. Imbert et al. (2017) assert that the market for bioplastics has attracted some legislative attention over the past few years. Some notable legislative instruments include the German Packaging Ordinance (VerpackV10) aimed at exempting biodegradable packaging with certification from charges and minimum recycling quotas under the Green Dot Dual System (Grüner Punkt), the Biowaste Ordinance (BioAbf) which regulates recycling streams of biowaste aimed at integrating biodegradable plastics into existing composting schemes and the Closed Cycle Management Act (KrWG) which mandates the separation of biowaste from other waste categories (Imbert et al., 2017). According to Imbert et al. (2017), the passing of EU legislation targeted at limiting the use of lightweight plastic carrier bags motivated Germany to put charges on plastic carrier bags. These charges are borne by retailers who usually transfer them to the consumer.

Consumers are stakeholders in the bioeconomy whose purchasing decisions have contributed to the diffusion of bioplastics in Germany. Stahl et al. (2021) postulate that German consumers possess a strong affinity for green products hence are intentional in their purchasing decisions. The authors report that German consumers prefer to buy articles made from bioplastics given their environmental friendliness in a bid to contribute to mitigating the adverse effects of fossil fuels such as climate change. Klein et al. (2020) highlight that, for German consumers, the materials produced from bioplastics provide higher marginal utility compared to those that are not. The researchers report that the marginal utility increases with every increase in the percentage of bioplastic used in the production of an item, and further increases if materials used in production are locally sourced. An improvement in the quality of life of the general populace results in citizens being conscious of the decisions they make regarding what to purchase and consume (Sturm and Banse, 2021). Certain actions such as the use of bio-based products become possible when consumers earn a sense of responsibility to the environment due to higher disposable income.

4.3 The National Bioeconomy Strategy of Italy

The official bioeconomy strategy of Italy, Bioeconomy in Italy-A strategy for a sustainable bioeconomy was published in 2017 and later updated in 2019. This document serves as the official strategic framework for Italy's sustainability transformation. The strategy adapts the European Commission (2018) definition of the bioeconomy and refers to the bioeconomy as "the set of economic activities relating to the invention, development, production, and use of biological products, services and processes across four macro-sectors; agrifood, forestry, bio-based industry and marine bioeconomy" (BIT II, 2019, p.7). The strategy aims to integrate sectors, systems, actors, and institutions around the ultimate goal of merging economy, ecology, and society to create sustainable value chains. To achieve this, the bioeconomy vision is espoused; a paradigmatic shift to systems that allow multidisciplinary collaboration of all sectors relevant to the bioeconomy. Creating value from local biodiversity, through technological advancement across value chains to shift the current economic paradigm to a sustainable bioeconomy.

The Italian bioeconomy is valued at 330 billion euros with the food industry being the most relevant sector, accounting for 41% of the entire bioeconomy. The bioplastics industry is one of the least contributing sectors accounting for 0.5% of the Italian bioeconomy but has seen significant investment. Per the BIT II (2019), by 2030, the Italian bioeconomy should have seen 15% improvement through an increase in the sustainable production of products across all sectors of the economy that come together to make up the bioeconomy. This increase is to be accompanied by investment in research and innovation, better stakeholder relationships at the national and continental levels, and a commitment by the general populace to the bioeconomy agenda.

BIT II (2019) highlights that the Italian bioeconomy is hinged on the blue economy, agro-food, and bio-based industry which are strategically positioned across regions of the country with respect to their particular endowments and productive competencies. With the strategy, the country aims to ensure food security through a sustainable approach to agriculture, sustainable marine ecosystems and forests, and bio-waste management.

4.4 Key Transformation Factors-Transition towards Bioplastics in Italy

The appraisal of studies on the Italian bioeconomy revealed that legislation has been extensive in the transition towards bioplastics promotion in the country. This finding is consistent with the findings of Imbert et al. (2017) who postulate that the bioplastics sector of Italy owes much of its advancement to state legislation. As of 2006, Italy had furthered a policy aimed at banning single-use, non-biodegradable plastic bags given the promulgation of Law 296/2006, 2007 Finance Act which has undergone several amendments. Penalties on infringements were introduced with the passing of the Legislative Decree 91/2014[F] (Imbert et al., 2017). According to Imbert et al. (2017), the passing of the legislative instrument led to a 50% reduction in single-use plastic shopping bags, making way for the shift to the more sustainable alternative of bioplastic bags. The authors highlight that, there are further steps aimed at progressively eliminating extremely lightweight plastic bags used in vegetable packaging. Fava et al. (2021) highlight that, national legislative initiatives such as the Environmental Annex to the 2014 Stability Law promote a green economy with signature instruments such as the Green Public Procurement (GPP) and the Italian Startup Act standing out. The Green Public Procurement sets the allowable environmental standards for purchases in the Italian public sector (Fava et al., 2021), while the Italian Startup Act enables startups to access public guarantees up to 80% on loans from banks to the tune of 2.5 million euros to pursue biochemistry related ventures (BIT II, 2019).

In the dedicated bioeconomy strategy of Italy, the bio-based industry is given great credit regarding the bioeconomy transition in general and the specific case of bioplastics. Fava et al. (2021) assert that, the bio-based industry has been critical to the development of innovative production processes for the manufacture of bio-products such as bioplastics from biomass and bio-waste. There is a deliberate agenda by Italian authorities to convert defunct industrial sites to bio-refineries, with the country assuming leadership when it comes to high-tech environmental requalification (Imbert et al., 2017; Fava et al., 2021). The BIT II (2019) reveals that industrial sites located in Piemonte, Emilia Romagna, Umbria, and Lazio have been converted to bio-refineries based on feedstock available in those areas and the productive competencies of the plants. These regions are strategically placed, and the development of bio-based industries in them facilitate the use of waste produced along the food chain and byproducts of other productive processes as feedstock for the local bio-industries (Fava et al. 2021). According to Imbert et al. (2017), in the Italian bioeconomy, there are private partnerships towards bioplastics production through biochemistry because of joint ventures between private bioplastics giants such Novamont and public industry leaders such as Mossi and Ghisolfi and ENI Versalis. The authors further postulate that the bio-refineries in Patrica and Matrica have a production capacity of 100,000 tons and 350,000 tons of bio-based material per annum respectively with an estimated 500 million euro investment in both facilities.

Imbert et al. (2017) posit that the Italian government provides incentives for bio-based feedstock production to serve as raw material for the chemical industry through initiatives such as “Strategic Plan for Innovation and Research in Agriculture, Food and Forestry, 2014–2020”. The goal of this incentive is to ensure an adequate supply of food and feed for industry as well as mundane consumption. Fava et al. (2021) postulate that given the richness of Italian biodiversity, the agricultural sector has much impetus for contributing to the transition towards bioplastics use. The BIT II (2019) highlights the significance of agriculture and forestry to the enhancement of residuals and the production of bio-products such as bioplastics. The document highlights cross territorial links and interregional value chains to ensure adequate supply of feedstock to bio-industries for the production of bio-products of which bioplastics are a core element.

In Italy, various special programs have facilitated the transition towards bioplastics diffusion in the country. BIT II (2019) mentions the existence of the Cluster of "Green Chemistry" SPRING10, which is a national platform that assembles important stakeholders of the green chemistry value chain, irrespective of their form or size. This platform is aimed at fostering collaboration between private and public stakeholders, as well as research entities to enhance resilient value chains in bio-industries with the bioplastics sector being one of the main sectors of focus. Fava et al. (2021) also mention the formation of the CEN Technical Committee in 2011 with such responsibilities as conducting Life Cycle Assessments of biomass used in production. According to Imbert et al. (2021), one of the important efforts towards the bioplastics transition in Italy are actions aimed at building requisite skills needed for the bioplastics sector and the bioeconomy in general. They mention that in 2016, the first Master's Degree in the country dedicated to the bioeconomy was launched. This program is spearheaded by four universities; the University of Milano-Bicocca, University of Bologna, University of Naples Federico II, University of Turin, and industry giants such as Novamont, Intesa Sanpaolo, GFBiochemicals, and PTP Science Park of Lodi (Imbert et al., 2021).

4.5 Policy Mixes Proposed to Fast-track the Diffusion of Bioplastics

An increase in bioplastics use in the packaging industry has been a major driver of the industry's growth (Mashood et al., 2021). Therefore, Friedrich (2021) advocates for a massive shift from petro-based plastics to bioplastics use in the food, automotive, pharmaceutical, and technology sectors since a significant amount of plastics are consumed by packaging in those sectors. The development of bio-based polyethylene terephthalate (PET) bottles for fizzy drinks is a good example of this (Mashood et al., 2021). According to Friedrich (2021), food packaging should be switched to bioplastics as much as possible with adequate measures put in place to ensure waste management streams are able to handle the recycling of bioplastics.

Filiciotto and Rothenberg (2021) postulate that policies have the potential of redirecting the attention of companies towards sustainability transitions. The researchers, therefore, propose a regulatory framework for bioplastics to be implemented to ensure the diffusion of bioplastics and to ensure the phasing out of petro-based plastics. Like Friedrich (2021), Filiciotto and Rothenberg (2021) suggest that local waste management streams should be improved to accommodate bioplastics while advocating for fees to be imposed on fossil-based plastics in order to discourage their production around the globe. According to Filiciotto and Rothenberg (2021), while such fees [50-250 Euro per ton] are enforced in Europe under the Extended Producer Responsibility (EPR) legislation, the concept isn't commonplace in many countries around the world. The researchers further adduce that in Europe, the imposed fees are inadequate to serve as a deterrent to producers of petro-based plastics and make them more responsible. Mashood et al. (2021) consequently make a strong case for political law in accelerating the diffusion of bioplastics, especially in the European context.

Lettner et al. (2017) stress the importance of technological innovation and the need for research to fully exploit bioplastics to make them more mundane. The researchers advocate for new processing technologies especially in the argic sector to ensure crops that contain the requisite properties for use in bioplastics production are enhanced and increased. Mashood et al. (2021) further this argument by highlighting that nations ought to bolster their innovative policies to support the bioplastics sector so as to increase bio-plastics manufacturing capacity. Filiciotto and Rothenberg (2021) assert that large scale production of bioplastics is accompanied by technical challenges as well as cost concerns, therefore innovation has the potential of reducing the cost associated with the production of bioplastics and increasing their production volume to accelerate their diffusion in the sustainable bioeconomy (Lettner et al., 2017).

According to Filiciotto and Rothenberg (2021), since customers can only recognize a bioplastic when a label is placed on the product, as bioplastics are physically no different from their petro-based counterparts, countries should put measures in place to ensure labels recognizable to consumers are placed on bioplastic products. This is to make them more recognizable to consumers. Filiciotto and Rothenberg (2021) mention that in Austria for instance, certified labels are provided by organizations such as TUV AUSTRIA and DIN Certo with different conformity levels depending on the environment and type of plastic. The authors advocate for the measure's replication in other countries as well in order to differentiate bioplastics from petro-based plastics.

Mashood et al. (2021) posit that, except for the strategy of banning single-use carrier bags which have largely been adopted by many countries, there are no coherent global policies around bioplastics or a global coalition researching bioplastics. The researchers, therefore, suggest a coherence in policy regarding bioplastics around the globe to ensure bioplastics become more commonplace as the world makes a transition towards sustainability. This will mitigate the adverse effects of fossil-based plastics on the environment.

5. DISCUSSION

The purpose of this study is to conduct a comparison of the German bioeconomy and the Italian bioeconomy through the lenses of bioplastics in order to pan out key similarities and differences in the transformation factors leading to bioplastics adaptation as both countries transition into a sustainable bioeconomy.

A careful analysis of the findings of this study indicates that both Germany and Italy assume leadership in the transition towards a sustainable bioeconomy. The countries possess dedicated bioeconomy strategies with core visions and frameworks aimed at propelling the sustainable bioeconomy transition considering their respective strengths in terms of research competencies and factor endowments. In congruence with the findings of Barañano et al. (2021) this study also revealed that, although both countries approach the bioeconomy differently, they demonstrate commitment to the sustainable use of organic matter and biological resources in the production of goods and services as they depart the fossil economy into the more sustainable alternative of a bioeconomy. Both countries also demonstrate commitment to merging biomass, biotechnology, and policy while ensuring commitment from their citizens as they navigate the complex transition towards a sustainable bioeconomy. Given the heterogeneity of stakeholders of the bioeconomy in both countries, evidence from this study indicates a pragmatic adaptation of value chains by integrating the biotechnology, bioresource, and bioecology visions to suit the transition towards a sustainable bioeconomy in line with the bioeconomy visions espoused by Bugge et al. (2016). This study revealed that while the biotechnology and bioresource visions are more prevalent in the German context, the bioresource and bioecology visions stand out in the Italian context.

In contrast to expectations regarding bioplastics, both Germany and Italy do not possess a dedicated bioplastic strategy. This can be attributed to the nascence of the bioeconomy field as postulated by Bugge et al. (2021). However, both countries demonstrate commitment to the transition towards bioplastics use in their national policy mixes although Italy assumes a leadership ahead of Germany in this aspect. The commitment of the two countries to transition towards bioplastics across various industries can be attributed to macroeconomic factors. Germany and Italy rank amongst the top three EU countries with the highest GDPs which allow the countries to pursue capital and R&D investments aimed at generating new knowledge and innovations in their bid to transition towards a sustainable bioeconomy.

The leadership position assumed by Italy in the EU regarding bioplastics can be attributed to the country's robust framework and factor endowments for bioplastics assimilation in the transition towards a sustainable bioeconomy. Italy earns this leadership because the overarching policy strategy of the country is multifaceted and spearheaded by public actors such as Mossi and Ghisolfi and ENI Versalis as well as private actors in the bioplastics industry such as Novamont. This structure and approach bolsters the industry and gives it the impetus to absorb possible shocks that may occur, allowing the industry to function in a very dynamic way. In Germany however, there is a strong reliance on the Federal Government to lead the charge when it comes to knowledge generation and innovation in the bioplastics industry since that remains the primary approach of the country to the bioeconomy transition; a state-led R &D focus.

The bioplastics sector in Italy is hinged on its biochemical industry which has seen some investment through strategic programs such as the conversion of defunct industrialized sites into biorefineries. The refineries in Patrica and Matrica alone received about 500 million euros in investment indicating a commitment by Italy to revamp the country's traditional chemical industry through the country's biorefineries. Italy has programs aimed at supporting the development of clusters for knowledge sharing and collaboration among stakeholders in the bioplastics industry. This formalized approach which is connected to the Smart Specialization Strategy makes room for the prioritization of innovations related to bioplastics and a bottom-up approach to research and innovation given the localization of factor endowments leveraged in production. Although an entrenched chemical sector exists in the German context, the sector has not been adequately exploited in the production of bioplastics. However, steps are being taken by the federal government to ensure the chemical industry takes on its place as a relevant stakeholder for Germany's long-term vision of achieving a sustainable bioplastics paradigm. Investments such as the 50 million euros from the government of Saxony-Anhalt and the 20 million euros from Thyssen Krupp to the Leuna production plant are key steps taken to ensure the chemical industry becomes buoyant for the production of bioplastics and biochemicals in general.

Political action through legislative instruments is common between both countries in the transition from petro-based plastics to bioplastics and limiting the use of the former in tandem with the EU legislation aimed at reducing consumption of lightweight plastic carrier bags. Italy has implemented stringent legislation such as the national ban on petro-based plastic carrier bags to be replaced by sustainable, bioplastic alternatives as highlighted in the findings of this study. Similarly, Germany has legislative instruments in place directed at limiting the use of lightweight plastic carrier bags by placing charges on them. In this respect, Italy possesses more comprehensive, holistic, and crosscutting legislations towards bioplastics use compared to Germany. The legislations in Germany are mostly tailored towards exemption fees for recycling of bioplastics and having the current bio-waste management streams accommodate bioplastics. However, it is a pressing concern of both countries to manage bioplastics in such a way that they can be accommodated by the bio-waste management systems currently in place. This concern is consistent with the position of Hinderer et al. (2021) who advocate for normative knowledge as well as transformative knowledge in order to achieve a desired transformation.

In both Italy and Germany, innovation in the agricultural sector plays a significant role in the bioplastics sector. Technical innovation in feedstock production has been credited with the improvement in agricultural practices leading to a significant yield of biomass for the production of bio-products. The agricultural industry plays a critical role in both countries in the transition towards a sustainable bioeconomy by ensuring an adequate supply of biomass to accommodate household as well as industrial needs. This is aimed at averting competing interests when it comes to available feedstock. This technical innovation has ensured an adequate supply of feedstock to be used by bio industries in both countries to produce bioplastics and other bio-products such as biofuels.

This study also revealed that while specialized programs such as the Cluster of “Green Chemistry” SPRING10 and educational programs like the Master Degree dedicated to bioeconomy with commitment from stakeholders in the bioplastics industry exist in Italy regarding the transition towards bioplastics use, there is little evidence of such programs in Germany. In contrast, Germany possesses a strong sense of consumer responsibility for the bioplastics transition compared to Italy. This study provided more evidence of German consumers having a strong affinity towards bioplastics products than it did for consumers in Italy. It was almost as if in the Italian context, consumers were bound to use bioplastics, while in the German context, consumers generally felt responsible for the environment which influenced their purchasing decisions with regards to bioplastics.

In a nutshell, inferring from the results obtained, macroeconomic factors, technical innovation in feedstock production, and legislation were identified as the main drivers of the transition in the two countries.

6. CONCLUSION, RECOMMENDATION, AND LIMITATIONS

This study leveraged a systematic review of literature to conduct a comparative analysis of the bioeconomy strategy of Germany and Italy through the lenses of bioplastics. Key transformation factors propelling the transition towards a sustainable bioeconomy from the perspective of bioplastics are highlighted as well as a suggestion of policy mixes that could serve as a catalyst for the diffusion of bioplastics. The results obtained indicate that, while both countries possess dedicated bioeconomy strategies and can be described as pioneers of the bioeconomy in the EU, they both do not possess dedicated bioplastics strategies. However, evidence from this study indicates a strong commitment of both Germany and Italy to the transition towards a sustainable bioplastics paradigm. Of the two countries, Italy assumes leadership in the bioplastics transition employing a mix of legislation, technical innovation in feedstock production, a strong commitment to revamp the country's ailing chemical industry through her bio-industries and special programs run by the state to foster stakeholder engagements in the bio-chemical sector in general. In Germany, the transition towards bioplastics could be attributed to macroeconomic factors, legislation technical innovation, and a strong sense of customer responsibility to green purchasing.

To ensure an accelerated diffusion of bioplastics in the two countries as well as others, the results of this study suggest a mix of significant investment in technical innovation coupled with legislation and a strong sense of customer responsibility towards the environment as well collaboration from global institutions in research and innovation tailored towards bioplastics. These efforts should culminate in a global policy framework for bioplastics to ensure a unified global approach to bioplastics use and diffusion.

Undoubtedly, the results of this study should serve as a genesis for other studies. Especially studies related to bioplastics in the case of the countries sampled or others as cumulative knowledge is being built regarding the transition towards a sustainable bioeconomy. In future research efforts to better understand the bioeconomy, issues of concern such as the inherent challenges and opportunities presented by bioplastics in the transition towards a sustainable bioeconomy should be a key area of focus. Another area worth exploring further is how these identified challenges can be surmounted and opportunities exploited. Again, future studies can be focused on intercontinental comparative studies and how the various approaches to bioplastics diffusion can be unified into a global roadmap.

Given the nascence of the bioeconomy in general and the specific case of bioplastics, this study was fraught with limited literature for the systematic literature review. Further, the study was conducted by a single researcher which could lend this study to bias although efforts were made at its mitigation. Future studies of this nature can be conducted by two researchers in order to reduce a possible risk of bias.

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APPENDIX

i. Declaration of Originality

I,

Kemeh, Victor 867773

declare that I have followed the Principles of Good Scientific Practice while writing the present

☐ Bachelor's thesis. ☑ Master's thesis,

☐ seminar paper. ☐ Diploma's thesis.

I have written the paper/thesis independently and have used no other sources or aids than those given and have marked the passages taken from other works word-for- word or paraphrased.

Supervisor:
Prof. Dr. Andreas Pyka

Topic of the paper/thesis:

The Transition towards a Sustainable Bioeconomy-Bioplastics in Germany and Italy: A Systematic Literature Review

I furthermore declare that the submitted unencrypted electronic document exactly and without exception corresponds to the contents and wording of the printed copy of the paper/thesis. I give my consent to this electronic version being checked for plagiarism with analytical software.

Stuttgart, 15th February, 2022.

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* This declaration is to be included into the independently written paper/thesis as an annex. Papers/theses not including this declaration will not be accepted.