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# Foreword

In an era defined by rapid technological advancements and an urgent need for sustainability, the intersection of innovation and industrialization has never been more critical. The global economy faces an unprecedented challenge: how to achieve industrial growth without compromising the environment. This book, *Technological Innovations for Sustainable Industrialization*, explores this vital convergence, offering a roadmap for industries, policymakers and researchers striving for a greener future.

The pursuit of sustainable industrialization is a defining challenge of our time, requiring innovative technological solutions that balance economic growth with environmental responsibility. This collection of research, *Technological Innovations for Sustainable Industrialization*, brings together groundbreaking studies exploring novel approaches to industrial advancements across various sectors, from **nanotechnology and precision agriculture to infrastructure development and renewable energy integration**.

One of the highlights of this work is the emphasis on **bio-synthesis and eco-friendly technologies**, such as the use of **Iraqi propolis for the production of magnetic iron oxide nanoparticles**, which has shown promising results in treating iron deficiency anaemia. This innovation underscores the potential of **biotechnology and nanomedicine** in addressing pressing healthcare challenges through sustainable means.

Similarly, the role of **precision agriculture** as an enabler of **sustainable farming in developing countries** is explored in depth, emphasizing how mechanization, research and local innovation can transform smallholder farming. The research also delves into **anaerobic treatment of yeast processing effluent**, showcasing the impact of temperature on wastewater treatment efficiency—an essential aspect of industrial sustainability.

Beyond scientific and technological advancements, this book highlights the **importance of research-driven policies, entrepreneurship and academia-industry collaboration** in shaping a sustainable industrial future. The insights presented here offer valuable perspectives for **policymakers, researchers, industry leaders and entrepreneurs**, providing a roadmap for harnessing technology in a way that fosters both economic development and environmental sustainability.

As we move forward, the integration of cutting-edge technologies with sustainable practices will be crucial in addressing global challenges. This book serves as both a **testament to human ingenuity and a call to action** for stakeholders across industries to innovate responsibly and collaboratively for a better future.

The industrial revolutions of the past transformed societies, fueling economic progress but often at the expense of ecological balance. Today, as we stand on the brink of the Fourth Industrial Revolution, we have an opportunity—and a responsibility—to redefine the foundations of industrialization. Emerging technologies such as artificial intelligence, the Internet of Things, renewable energy, circular economy models, and sustainable manufacturing practices provide innovative solutions that can drive economic prosperity while minimizing environmental impact.

This book brings together insights from experts across various fields, illustrating how cutting-edge technologies can revolutionize industries, reduce carbon footprints, optimize resource use and promote inclusive economic growth. From smart factories and green supply chains to energy-efficient production techniques, the discussions here highlight practical solutions and future possibilities.

As you journey through these pages, I encourage you to reflect on the role each of us plays in shaping a sustainable industrial future. Whether you are an entrepreneur, a researcher, a policymaker or an industrial leader, the knowledge within this book will inspire action, innovation and transformation.

Sustainable industrialization is not just a choice, it is an imperative. The path forward requires collaboration, creativity and commitment to harness technology for the benefit of both industry and the planet. May this book serve as a guide and a catalyst for meaningful change.



October 2025

Thomas Varghese  
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# Preface

Sustainable industrialization stands as one of the most formidable challenges of the twenty-first century, lying at the intersection of technological advancement, environmental stewardship and social equity. As the world grapples with escalating pressures from climate change, resource depletion and social inequality, the urgency to adopt sustainable industrial practices has never been greater. Against this backdrop, the book *Technological Innovations for Sustainable Industrialization* offers a comprehensive exploration of technology's dynamic and multifaceted role in shaping a future where sustainable industrial growth aligns with environmental protection, societal well-being and economic prosperity. By focusing on practical applications, real-world case studies and cutting-edge innovations, this work intends to fill the critical gap in the existing literature, offering actionable insights and strategies for industries seeking to achieve sustainability goals.

This volume is the product of collaboration among a diverse group of leading experts, each contributing their knowledge and experience to address the most pressing challenges of sustainable industrialization. It provides an in-depth examination of how innovations can drive industrial growth while minimizing adverse environmental and societal impacts. The chapters in the book span a wide array of topics, including clean energy technologies, sustainable manufacturing practices, digital transformation in industries and the integration of advanced technologies into industrial systems. Beyond presenting cutting-edge research and emerging trends, the book offers practical applications and detailed case studies that demonstrate innovation's transformative potential in fostering sustainability across sectors.

The purpose of this publication is to synthesize a broad spectrum of perspectives, ensuring a holistic and inclusive exploration of how technological advancements can pave the way for a more sustainable industrial future. It not only highlights the challenges hindering sustainable industrial practices but also identifies actionable solutions adaptable to different contexts and scales. The contributions provide valuable insights into how sectors such as energy, manufacturing, agriculture and transportation can harness advanced technologies to build more sustainable and resilient systems. Furthermore, the book's interdisciplinary approach and diverse global perspectives make it an essential resource for stakeholders, including researchers,

technology developers, policymakers, industry leaders and students—committed to advancing sustainable industrialization.

At its core, this book recognizes that sustainable industrialization is not a static goal but an ongoing dynamic process requiring continuous adaptation, innovation and collaboration. As industries strive to meet the demands of a growing global population, technological innovation must align with principles of sustainability, resilience and social equity. Only then can we ensure that the benefits of industrial progress are equitably shared, securing long-term prosperity without compromising the well-being of future generations. When directed towards sustainability, technological innovation can propel us towards a future that is not only productive but also equitable and resilient—an industrial paradigm that serves both people and the planet.

This book is the result of collective effort, and we extend our deepest gratitude to all who contributed to its realization. We sincerely thank the authors whose expertise and dedication have made this publication possible. Their insightful work provides invaluable resources for addressing some of the most critical challenges facing industries worldwide. We also acknowledge the reviewers, whose constructive feedback refined and enhanced each chapter, ensuring the book delivers accurate, timely and relevant insights.

Our special thanks goes to Dr. Amitava Bandopadhyay, Director General of the NAM S&T Centre, along with the concerned staff members, for their steadfast support in facilitating the technical and administrative aspects of this publication. Their contributions were instrumental in bringing this work to fruition.

We hope that this book, published by the NAM S&T Centre, New Delhi through Springer Nature, Singapore, will benefit readers from diverse backgrounds by offering practical guidance and actionable insights. In particular, the book addresses key aspects of the UN Sustainable Development Goals (SDGs), with a strong focus on *SDG 9: Industry, Innovation, and Infrastructure*. By highlighting innovative solutions that drive sustainable industrialization, the publication aims to contribute to the global efforts to build resilient infrastructure, foster innovation, and promote inclusive and sustainable industrialization. As the world navigates the complexities of sustainable industrialization, collective action and shared expertise remain our most powerful tools for overcoming challenges and seizing opportunities.

We trust that the ideas presented here will accelerate the global transition towards a more sustainable, equitable, and resilient industrial future for all.

Masvingo, Zimbabwe  
Bulawayo, Zimbabwe  
Stellenbosch, South Africa

Xavier Poshiwa, Ph.D.  
Vennan M. Sibanda, Ph.D.  
Boitumelo Ramatsetse, Ph.D.

# Introduction

In the era marked by rapid technological advancements, global urbanization, and escalating environmental challenges, the need for sustainable industrialization has never been more urgent. However, for industrialization to be sustainable, it is essential to leverage cutting-edge innovations and at the same time, address the dynamic challenges of climate change, resource depletion and urbanization. As we seek to transform the process of industrial development, whether in energy, transportation, agriculture or manufacturing—innovation will be a key driver of success.

The concept of *Technological Innovations for Sustainable Industrialization* underscores the transformative potential of emerging technologies and creative solutions in reshaping the way we manage, design and build our industry and infrastructure. Innovations—ranging from renewable energy technologies and advanced materials to digital tools and automation—are pivotal in enhancing the resilience, efficiency and environmental sustainability of the development process. In particular, these innovations can play a crucial role in driving industrialization in developing economies, where rapid urbanization and population growth often outpace the ability to build adequate infrastructure. By integrating cutting-edge research and innovation into infrastructure planning and industrial development, we can ensure that growth is not only sustainable but also inclusive and equitable.

To address these issues, the Centre for Science and Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre) presents this publication titled *Technological Innovations for Sustainable Industrialization* which brings together contributions from scientists and experts from seven countries, viz., India, Iraq, Mauritius, Myanmar, Nigeria, South Africa and Zimbabwe.

Through its 14 chapters, the book aims to provide both a detailed overview and actionable insights into how innovations can reshape the future of infrastructure and industrialization. By highlighting pioneering research and case studies, it offers valuable lessons for policymakers, engineers, entrepreneurs and researchers working towards building more resilient, inclusive and sustainable industrialization.

The book is structured into three key parts, each addressing different aspects of leveraging innovations for infrastructure and industrial development. First Part focuses on foundational technologies that support sustainable industrial development, including innovative solutions for addressing public health challenges, agriculture technologies and wastewater treatment systems. Second Part explores the relationship between research, innovation and entrepreneurship, highlighting how innovation-driven ecosystems, educational reforms, and the development of IT skills for business students can drive industrial growth and entrepreneurship, particularly in developing economies. Third Part examines the application of advanced technologies, with case studies on agro-processing, space technology, digitalization, energy transition challenges and revitalization of traditional sectors like textiles, showcasing how these technologies contribute to sustainable industrialization.

I extend my heartfelt gratitude to all the contributors for sharing their expertise, which has made this compilation possible. I specially thank the editorial team—Dr. Xavier Poshiwa [Zimbabwe], Dr. Vennan M. Sibanda [Zimbabwe] and Dr. Boitumelo Ramatsetse [South Africa] for their relentless efforts in reviewing and refining the chapters, ensuring that the information presented is both accurate and impactful. I am also grateful to some other experts for their help in reviewing a few papers included in the book.

I am also immensely grateful to Mr. Thomas Varghese, Ex-Business Head—Textiles, Acrylic Fibre and Overseas Spinning, Aditya Birla Group, Mumbai, India, for kindly agreeing to our request to write the Foreword of this book in spite of his very busy schedule.

I am thankful to Dr. Loyola D'Silva, Executive Editor, Springer Nature, Singapore, for his kind support and guidance towards bringing out this publication and Mrs. Kavitha Palanisamy, Production Editor, Springer Nature, Singapore, for managing all the technical and administrative responsibilities for the publication process.

I would like to take this opportunity to express my sincere gratitude to Mr. Madhusudan Bandyopadhyay, Senior Adviser at the NAM S&T Centre, for his invaluable advice and guidance throughout the planning and execution of this important publication. I also thank Ms. Nidhi Utreja, Programme Officer, NAM S&T Centre, for her tireless efforts in coordinating the work on this publication. I also wish to acknowledge the hard work and support of the entire NAM S&T Centre team, especially Mr. Pankaj Buttan, Data Processing Manager, and Ms. Abhirami Ramdas, Programme Officer—whose contributions have played a vital role in bringing this publication to completion.

I hope that the book will inspire new collaborations, spark further research initiatives and ignite actions towards application of technological innovations for sustainable industrialization and achieving the global sustainable development goals.



Amitava Bandopadhyay, Ph.D.  
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