Sustainability Handbook

VOLUME 08
January 2024

Sustainability Handbook Volume 08 - January 2024

EDITOR
Peta de Jager

PRODUCTION EDITOR
Shannon Manuel

EDITORIAL ENQUIRIES
PdeJager@csir.co.za

CONTRIBUTORS
Benoît Le Roy, Wandile Sihlobo, Khensani Nkatingi, Emmanuel Marume, Dr Ryneth Mbhele, Chris Campbell, Antony Cooper, Dr Martin B Mgangira, Dr Karen Surridge, Catherine Larkin APR CMILT, Mr David Nicholls, Vishaal Lutchman, Georges Mturi, Hiten Parmar, Priaash Ramadeen, Jill Whyte, Mandla Dlamini, Melusi Simelane, Johan O'Connell, Nozonke Dumani, Refiloe Mokoena, Thapelo Phiri, Stephen Lamb, Andrew Lord, Dr Gerard Leteba, Mark Alexander

LAYOUT & DESIGN
Monique Petersen

PROJECT COORDINATOR
Beverley Stone

DIVISION HEAD
David Itzkin

SALES TEAM
Charmaine Meyer
Colleen La Gorce
Gordon Campbell

DIRECTORS
Robert Arendse
Andrew Brading

PUBLISHER
alive2green
www.alive2green.com

The Sustainability Series Of Handbooks

PHYSICAL ADDRESS:
Alive2green
Cape Media House
28 Main Road, Rondebosch
Cape Town, South Africa, 7700

TEL: 021 447 4733
FAX: 086 6947443

Company Registration Number:
2006/206388/23
Vat Number: 4130252432

ISBN No: 978 0 620 45240 3. First published 2012.

IMAGES AND DIAGRAMS:
Space limitations and source format have affected the size of certain published images and/or diagrams in this publication. For larger PDF versions of these images please contact the publisher.

ENQUIRIES
beverley@alive2green.com

PRINTER
FA Print

CALL FOR PAPERS

Dear Prospective Author

Thank you for considering contributing a chapter or article to the Sustainability Handbook.

The handbook is collected work, assembled from many scholars in the field of sustainability of the built environment and industry across Africa, featuring both refereed and non-refereed (popular interest) chapters and articles. The purpose of the handbook is to disseminate original research and new developments within the field and to advance scholarship. The most recent edition of the Sustainability Handbook series can be viewed by clicking on the link.

Refereed chapters are thematically arranged for water, waste, green building, energy or sustainable transport.

The featured themes for Volume 9 are circular economy, and Environmental, social, and corporate governance, although any sustainability topics relevant to the built environment and industry will be considered. For a chapter or article to be published in the handbook it should be clearly written, be of interest to readers and be methodologically and technically sound. It must reference source material and not violate copyright. For a chapter or article to be considered as a refereed item, it should also make a new contribution to knowledge.

STEP 1: submit a title and 500 word abstract describing what your paper intends to cover by the abstract deadline. This will be received by the editor who will check that it is suitable. Refereed chapters are peer reviewed by subject matter experts identified by the publisher/ editor. If the item seems suitable, authors will be invited to prepare a full chapter manuscript.

STEP 2: Authors submit a 5000 word full chapter to the editor by the deadline indicated and this will be redacted to remove identifying features and sent to between one and three experts in the field. Authors will be provided feedback from their anonymous reviewers (via the editor) a few days after the review deadline and will be provided a limited time to respond to reviewers' feedback. Authors may be required to arrange independent professional language or grammar edits, at their own cost.

STEP 3: The editor reviews amended chapters received and if they are of good quality will release them to the publishers for layout and digital publishing. Photos and brief biographies of authors are included in the front-matter of the handbook. The publisher and editor reserve the right to make minor adjustment and will provide a final proof before publishing.

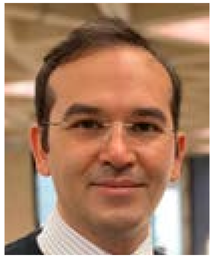
Whilst every effort is made to comply with Department of Higher Education and Training, Research Outputs Policy of 2015, this is not guaranteed, and prospective authors are advised to seek confirmation from their institutional offices in this regard.

Don't hesitate to contact me for further information.

Peta de Jager Pr.Arch. MA

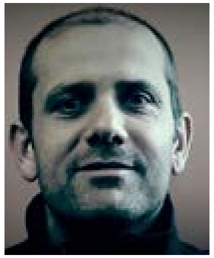
pdejager@csir.co.za

CONTENTS



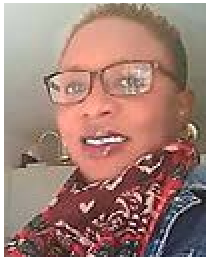
ABDOLHOSSEIN NAGHIZADEH

Abdolhossein Naghizadeh, PhD, PrEng (IRCEO), is a senior lecturer in the Department of Engineering Sciences at the University of the Free State, specializing in structures and concrete materials. He holds a BSc (Eng) and an MSc (Eng) with Distinction from Azad University, Iran, as well as a PhD from the University of Johannesburg. With over 17 years of experience in both industry and research, Dr. Naghizadeh is a dedicated researcher and a registered professional civil engineer (IRCEO). His expertise encompasses various fields, including concrete technology, alternative cements, geopolymer binders, 3D printing of concrete, as well as structural design and analysis.



TOBIAS VAN REENEN

Tobias van Reenen's career is rooted in R&D and quality assurance, making him a domain expert in indoor environmental quality, contamination control, and industrial HVAC disciplines. His expertise is sought after by government and industry, influencing regional and international standards, regulation, and policy. He currently heads the Thermal Systems Research team at the Council of Scientific and Industrial Research, focusing on enhancing energy efficiency in industrial thermal systems.



DR REBECCA ALOWO, PHD

Dr Rebecca Alowo is a Lecturer of Water Engineering at Doornfontein. She holds a doctorate from Central University of Technology in Bloemfontein, Free State. She also holds master's from University of Cambridge in Engineering for Sustainable Development and a Bachelor of Science in Civil Engineering from Makerere university in Kampala Uganda. She is a member of the Engineering Council of South Africa (ECSA) and the Uganda Institute of Professional Engineers (UIPE). Her doctoral studies were on sustainable groundwater management through modelling of selected hydrological parameters: a case study of the Modder River catchment of South Africa. Her findings were that it is necessary to develop groundwater sustainability models using Artificial Intelligence for groundwater monitoring to make informed decisions for improved groundwater management.

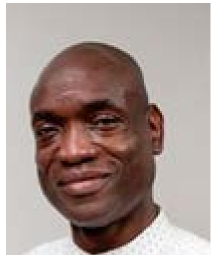
LLEWELLYN VAN WYK

Llewellyn van Wyk is a Part-time Lecturer at the University of Johannesburg in the Department of Mechanical Engineering Sciences. He now resides in Auckland, New Zealand, where he also supervisors post-graduate students at a master and doctoral level. He holds a Bachelor of Architecture degree and a master's in science (cum laude). He retired from the Council for Scientific and Industrial Research's Smart Places Unit in 2019 as a Principal Researcher.

Llewellyn is a researcher, guest lecturer and designer with extensive international experience. He is a leading scholar of 21st century green building and green infrastructure design discourses and innovative building technology.

PROF JEFFREY MAHACHI

Prof Jeffrey Mahachi, Head of Civil Engineering at the University of Johannesburg, is also a Director at the SMaCT Research Centre. He is a registered professional engineer with a PhD in Civil Engineering and an MSc in Structural Engineering. His executive experience includes roles at the National Home Builders Registration Council and as a Research Engineer at the CSIR. His research focuses on disruptive construction technologies and structural risks. As Board Chair of Agrément South Africa, he oversees the certification of non-conventional construction technologies. Jeffrey's leadership and expertise drive positive change in Civil Engineering and The Built Environment.



PROFESSOR WINSTON SHAKANTU

Professor Winston Shakantu is a Professor of Construction Management at Nelson Mandela University. He has been inducted into the SACPCMP as a Professional Construction Manager and the Chartered Institute of Building as a Corporate Member, and a Chartered Construction Manager. His research interest and work is on new developments in construction management such as information, communication and innovative technology, building information modelling and Construction Automation and Digitalisation. He has supervised research projects for Honours, Master's and PhD students. He has supervised 23 PhD candidates successfully and has published over 200 papers.

RENESH THAKOORDEEN

As the Project Lead for the CSIR Energy Storage Testbed since joining in 2021, Renesh Thakoordeen plays a pivotal role in advancing sustainable energy solutions. Situated within the Energy Centre, he leads initiatives at the forefront of energy storage testing, research and innovation. Renesh is dedicated to driving the development and implementation of environmentally conscious practices within the field. With a focus on collaborative efforts and effective project management, he is committed to contributing to a greener and more resilient future. Through the CSIR Energy Storage Testbed, Renesh strives to make significant and lasting impacts in the realm of sustainable energy systems.

DR JULIUS KOMBA

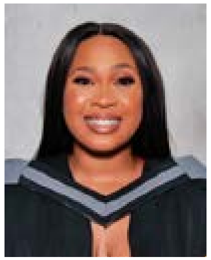
Dr Julius Komba holds a Bachelor of Civil Engineering, a Bachelor of Engineering Honours (Transportation Engineering), a Master of Transportation Engineering, and a PhD (Civil Engineering), all from the University of Pretoria. He is currently a Senior Lecturer at the University of Pretoria, Department of Civil Engineering. He lectures undergraduate and postgraduate courses and conducts research in the field of transport infrastructure engineering. Prior to joining the University of Pretoria, he worked with the Council for Scientific and Industrial Research (CSIR) for over 13 years. He has been involved in several research projects focusing on long-term pavement performance monitoring, forensic investigation into the causes of premature failures of pavements, road pavement design, construction and maintenance, evaluation of road construction materials, technical audits of road works, and climate-resilient roads. He is currently an editorial board member of the American ASTM Journal of Testing and Evaluation, serves on the organising committee of the South African Annual Transport Conference (SATC) and is a technical reviewer for several international journals and conferences.

BENOÎT LE ROY

Benoît Le Roy is an environmental alchemist with forty years of water engineering experience and is the CEO and co-founder of the South African Water Chamber established to represent the private water infrastructure sector to collaborate with and assist government to implement the national water and sanitation master plans; he is also a founding director of Nexus Water Alchemy and Water Ledger South Africa, both incorporated South African companies at the leading edge of the nexus of water digitisation. This will not only be key in reindustrialising the water sector, but it will also provide a myriad of skilled jobs and the opportunity to again export water related products and expertise globally.

WANDILE SIHLOBO

Wandile Sihlobo, an agricultural economist by training, is Chief Economist of the Agricultural Business Chamber of South Africa (Agbiz). Sihlobo was appointed as a member of President Cyril Ramaphosa's Presidential Economic Advisory Council in 2019 after serving on the Presidential Expert Advisory Panel on Land Reform and Agriculture between 2018 and 2019. Sihlobo is also a member of the Council of Statistics of South Africa (Stats SA). He is a Commissioner at the International Trade Commission of South Africa (ITAC). Sihlobo is a columnist for Business Day and Farmers Weekly magazine. He is a member of the Agricultural Economics Association of South Africa (AEASA). Sihlobo is an author of "Finding Common Ground: Land, Equity and Agriculture" published by Pan Macmillan in March 2020. He is also a contributor to the book "Recession, Recovery and Reform" published by Jacana in August 2020. Sihlobo holds a Master of Science degree in Agricultural Economics from Stellenbosch University.



KHENSANI NKATINGI

Khensani Nkatingi is a motivated and results-driven Sustainability Consultant with a profound passion for driving positive environmental and social change. With a solid academic foundation and practical experience in sustainable development, Khensani brings a unique blend of expertise to her role. Holding a PgDip in Sustainable Development from Stellenbosch University, she stands at the forefront of innovative solutions that bridge the gap between business objectives and sustainable practices.

JOHAN O'CONNELL

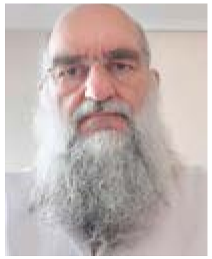
Johan O'Connell is currently a Senior Researcher at the CSIR, Smart Mobility. Obtained a MSc in Organic Chemistry from the University of Port Elizabeth in 1988. He joined the transportation industry in 1992 when he joined Petrocol, a manufacturer of emulsions and modified binders. Experience includes design and application of asphalt and seals, managing a binder laboratory and researching new binder applications and specifications. Experience includes product manufacture, application and evaluation. He specializes in binder rheology and premature failure troubleshooting. He has published more than 40 papers with regards to the bitumen, asphalt and seals industry.

DR RYNETH MBHELE

Ryneth Mbhele is a Research Group Leader (RGL) at the Council for Scientific and Industrial Research (CSIR) leading a team that focuses on Water and Wastewater Infrastructure management. Throughout her career, Ryneth has been instrumental in advancing water and wastewater infrastructure management practices. She has successfully led numerous projects that have resulted in significant improvements in water supply and sanitation systems across various sectors. Her expertise lies in developing innovative solutions for sustainable water resource management, including the implementation of smart technologies for wastewater treatment.

CHRIS CAMPBELL

Over his 40-year career in engineering, Chris Campbell has worked in various capacities in a number of successful consulting engineering companies, spent several years at Transnet Freight Rail and has held executive positions at Aveng Infraset, both locally and internationally. His institutional involvement includes past Gauteng Branch Chair (SABTACO); past Vice President of the South African Institution of Civil Engineering (SAICE); past President of the Engineering Council of South Africa (ECSA); past Vice President of The World Federation of Engineering Organisations (WFEO). Currently he is a Board Member of Business Unity South Africa (BUSA). Chris, a registered Professional Engineer, holds a National Higher Diploma (T4) in Civil Engineering; a BSc. Civil Engineering degree (Summa Cum Laude).



ANTONY COOPER

Antony K Cooper is a Principal Researcher at the CSIR and an Extraordinary Lecturer at the University of Pretoria. He holds a PhD and is a Registered Professional GISc Practitioner (PGP). With over 38 years of multi-disciplinary experience, his recent activities cover geographical information science theory and applications, standards, urban futures, the circular economy, spatial data infrastructures, volunteered geographical information, crime science, terminology and ethics. Antony has published extensively and held leadership positions in ISO/TC 211, Geographic information/Geomatics, the International Cartographic Association, CODATA and South Africa's Committee for Spatial Information.

DR MARTIN B MGANGIRA

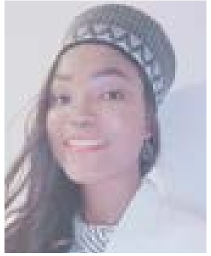
DR Martin B Mgangira is a principal researcher in the Transport Infrastructure Engineering Impact Area at the Council for Scientific and Industrial Research (CSIR). He holds a BSc in Civil Engineering from Polytechnic University of New York, MSc in Engineering from Columbia University, NY, a doctorate from Ruhr University-Bochum, Germany and is registered Professional Engineer, and a Member of SAICE. Current activities and research interests include microstructural characterisation of geomaterials, performance prediction and behaviour of unbound granular materials and their stabilised derivatives, forensic investigation of roadway pavement failures, and engineering education.

MELUSI SIMELANE

Melusi Simelane is a dedicated and accomplished engineer with a passion for enhancing transportation infrastructure in South Africa. He holds a Bachelor of Engineering in Civil Engineering and is currently immersed in postgraduate studies, specializing in Transportation Engineering. He is a member of the Pavement Design and Construction research group, operating within the Smart Mobility cluster at the Council for Scientific and Industrial Research (CSIR). Melusi's professional journey has been marked by a range of impactful projects across various domains, including road investigations, road infrastructure management, road materials testing, road infrastructure life cycle cost analysis, pavement design, and construction. Recently, he has turned his attention to sustainable practices, researching the use of environmentally friendly materials in pavement design. One of Melusi's key research interests is in Intelligent Pavement Analysis, where he employs machine learning algorithms to create cutting-edge, cost-effective solutions. His goal is to develop technologies that can revolutionize the transportation industry. Driven by a vision to elevate the road infrastructure in South Africa, Melusi aspires to leave a lasting positive mark on the transportation sector, recognizing its indispensable role in both the nation's economy and the everyday lives of its citizens.

DR KAREN SURRIDGE

Dr Karen Surridge was awarded her PhD in 2007 by the University of Pretoria and during 2007-2009 she was a postdoctoral Fellow of the Claude Leon Foundation. Her academic career was paralleled by establishing a consulting company specialising in environmental analyses, environmental impact assessments (EIA's), laboratory setup and establishment and consulting to, among others, large energy, environmental consulting and metal industries in South Africa. It offered environmental compliance services in mega industries like steel, energy and mining with scarce expertise in soil amelioration for crude oil contaminated soils, for example and other highly specialised skills related to microbial aspects of environmental impact and restoration.

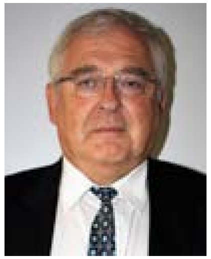


REFILOE MOKOENA

Refiloe Mokoena is a Senior Researcher in the Pavement Design and Construction research group at the Council for Scientific and Industrial Research (CSIR). Her area of focus is on sustainable road construction materials, particularly providing climate resilient road infrastructure for South Africa. She is an advocate for sustainable transport infrastructure and is currently the chairperson for a Climate Change Working Group at the Sustainable Roads Forum in South Africa. She holds a Bachelor of Science in Civil Engineering and a Master of Engineering degree in Civil Engineering from the University of the Witwatersrand.

CATHERINE LARKIN APR CMILT

Catherine is a communication and marketing professional, specialising in Logistics, Transport and Supply Chain. She does a lot of work for membership-based associations in logistics, transport and supply chain. She is the only consultant in the country who currently does work for the 5 leading transport associations in South Africa. She also served as judge in the Women in Transport Awards hosted by the Transport Evolution Africa Forum & Expo in 2018, as well as the Africa Rail Awards, hosted by Terrrapin in 2019. An accredited public relations professional (APR) and a Chartered Member of the CILT (CMILT, Catherine believes that lifelong education and learning is the key to success, as is mobility – hence her passion for transport and logistics! Catherine has developed a high-level and extensive network in this sector and loves connecting people and sharing opportunities. Her company, CVLC Communication, is a corporate public relations, communication, marketing and events consultancy. Established 19 years ago, Catherine has succeeded in positioning the company as a professional organisation, developing an extensive network and strong reputation in logistics, transport, supply chain and warehousing.



MR DAVID NICHOLLS

Mr David Nicholls is highly respected in the nuclear industry and regarded as a non-compromising leader who gets things done. He holds a BSc (Hons) in Mechanical Engineering (2-1) from the Royal Naval Engineering College, Manadon. He was responsible for the nuclear new build programme and overseeing the Koeberg power station until his retirement in December 2018. While at the utility he revitalised the Pebble Bed Modular Reactor (PBMR), an area in which South Africa was a world leader. He had worked his way up through the ranks at Eskom, working in its nuclear engineering department in the early 1980s before being appointed as Technical Support Manager at Koeberg in the early 1990s. He headed up the PBMR project. He was later appointed Chief Nuclear Officer at Eskom, and has experience managing Koeberg, which is the lowest cost provider of electricity to the grid. With 33 years of experience at Eskom, Dave Nicholls is no stranger to the Nuclear industry. Previously Chief Nuclear Officer at Eskom, accountable for all Eskom's nuclear activities, including the operation of the Koeberg Nuclear Power Station.

MARK ALEXANDER

Mark Alexander is Emeritus Professor of Civil Engineering and a Senior Research Scholar in the University of Cape Town. He teaches and researches in cement and concrete materials engineering, with experience in fundamental and applied research relating to design and construction. He is part of the leadership of CoMSIRU at UCT, where work is being done on problems of marine concrete durability, amongst others. Professor Alexander has published extensively both in South Africa and abroad; he is a National Research Foundation (NRF) rated researcher (NRF-B). Professor Alexander is a Past President of RILEM, an international organisation concerned with research in materials and structures, and President of the Concrete Society of Southern Africa for the period 2018–2020. He acts as a specialist consultant on concrete materials and related problems.

VISHAAL LUTCHMAN

Vishaal Lutchman is currently the Managing Director: Transport at Zutari. He leads a highly skilled team of engineering and advisory professionals providing solutions for clients in South Africa, selected African geographies and the Middle East. Previously, he was the Chief Executive Officer of the South African Institution of Civil Engineering (SAICE). He led the advancement of engineering practitioners in addition to advocacy and oversight of the engineering profession capacity. Prior to joining SAICE he was Director in Transportation and Infrastructure at WSP | Parsons Brinckerhoff in the management, design and implementation of the firm's freight logistics projects in the maritime, aviation and rail sectors. He was also the Deputy Chief Engineer at Transnet overseeing the parastatal's capital projects and port infrastructure development. Vishaal has been focussing on integrating organisational strategy, operations and technical capacity with future-fit leadership for the development of African solutions by Africans.

GEORGES MTURI

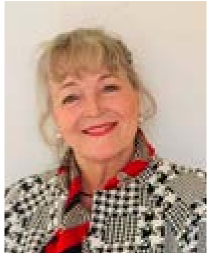
Georges Mturi is a consultant at Road Materials Consulting (Pty) Ltd.. He has served as a Principal Research Scientist, Acting Research Group Leader, and Laboratory Manager for the Road Materials Testing research group, in the Transport Infrastructure Engineering Impact Area (former Built Environment department and thereafter, Smart Mobility Cluster) at the Council for Scientific and Industrial Research (CSIR) in South Africa. He currently consults as part of multi-disciplinary research project teams involving the sustainable use of waste and alternative material for road construction, innovative road technologies, advanced road material characterisation and forensic investigations of road failures across the African continent.

HITEN PARMAR

Hiten stands as a lead expert and renowned thought leader extending over 19+ years in profession. He serves as liaison for multiple sector related forums within the region as well as internationally on advancing the electric mobility ecosystem. His broad-based professional expertise is encompassed with a Master's Degree in Electrical Engineering and Honours in Business Administration, and is mission driven on contributing to technological advancements within the industry globally along envisioning a world with sustainable, and equitable mobility and energy systems under The Electric Mission.

PRIAASH RAMADEEN

Coder at heart, innovator at mind, Priaash tells stories driven by data. An electronic engineer by trade, Priaash spent the first ten years of his career in research, development and technology, on projects ranging from military and defence to security in the fight against rhino poaching. His strong belief that entrepreneurship is the path towards creating value and impact for the world led him to found The Awareness Company in 2018, with the mission to create a sustainable, safe and efficient planet using data, AI and storytelling.



JILL WHYTE

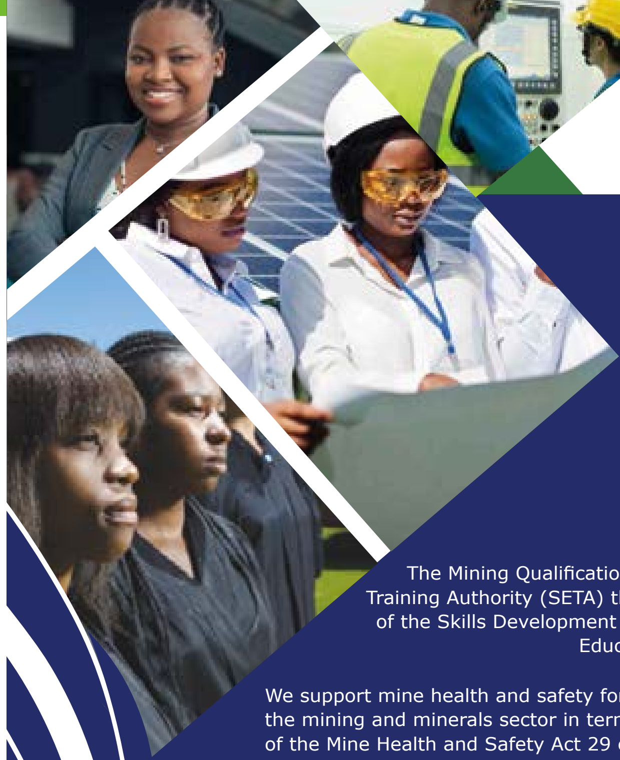
Born in Limpopo grew up on a cattle farm in Limpopo and farms in the then, Rhodesia. Schooling : several schools in SA and UK until standard 3.
1964- 1070 In standard 4 went to St Andrews School for girls in Bedford View where matriculated. 1971/2 Rhodes university : Studied English and Fine art, 1973 Burnam Business College : Business course ,1974 Worked Lindsay Smithers Advertising Agency learning the "business side" of advertising, 1975 UK Charles Barker (film making) and Mervyn Hughes (Advertising Management). Homesick returned to SA and met husband Alan Whyte, married in 1977. Got involved in farm business and ran Avocado Packhouse for 10 years. 1977 First introduction to macadamia nuts and fell in love with them!! Was involved in "start-up" of Katope Exports an avocado exporting business and attended all Board meeting to take minutes. Together with Rodney Green initiated the startup of the 1st privately owned macadamia nut processing business Green Farms Nut Company in 1990. Subsequently started Green Farms Nut Company (Levubu) factory, with partners and later started up, Tzamac a Factory in Tzaneen, also with partners, and in 2007 Coastal Macadamia Factory, with local partners.

NOZONKE DUMANI

Nozonke Dumani is a Senior Researcher at the Council for Scientific and Industrial Research (CSIR) and has over 9 years of experience in the concrete and cement industry, specializing in research, development and innovation of sustainable building and construction materials. She has expertise in life cycle assessment, life cycle management methodology, circular economy principles, embodied carbon, carbon footprinting and the development of standards. She holds a Bachelor of Science and Master of Science degrees in Chemical Engineering from the University of Cape Town.

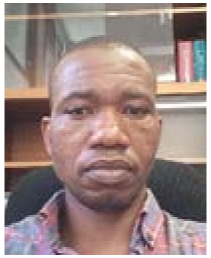
THAPELO PHIRI

Thapelo Phiri is a Founder at Ag Beyond Sustainability, a company focusing on promoting and facilitating the transition to sustainable and regenerative agriculture with a focus on small holder farmers in Africa. He is an advisory board member at HealthGrow Investment Holdings which is a high-performance investment consortium, he possesses over a decade of expertise in frugal innovation and social innovation, with a strong focus on projects focusing on (ESG) Environmental, Social, and Governance and (SDG) Sustainable Development Goals. Phiri has developed a cutting edge, potent and high quality organic liquid fertilizer from chicken manure that has earned him recognition from reputable institutions such as Scientific American, Google, British Council among others. He is often invited to take part at COP events since COP26 Glasgow with his focus mainly on agriculture and food systems and he is a prominent member of a cohort of thought leaders who concentrate on the concept of a "Just Transition in Agriculture" focusing on Africa. Phiri is a multi-award winning innovator and entrepreneur who has won various awards globally.



MANDLA DLAMINI

I am Mandla, a Senior Research Engineer at the Council for Scientific and Industrial Research (CSIR) in South Africa. My expertise centres around construction materials such as geopolymer cement and concrete, with a strong emphasis on sustainability. I am actively involved in piloting and commercializing innovative cement and concrete products, always with a focus on sustainable development. At CSIR, I lead and collaborate on projects that advance the field of material science, particularly in developing eco-friendly construction materials. My commitment to sustainable practices in the construction industry underpins my work, making me a dedicated professional in the realm of construction materials research and development.



DR GERARD LETEBA

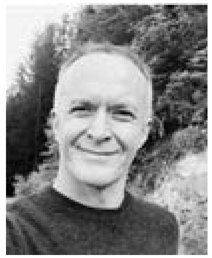
Dr Gerard Leteba is a materials scientist with a focus on the design and engineering of Pt-based high-entropy alloy (HEA) nanoparticles (NPs) and heterogeneous catalysts using wet-chemistry approaches. He uses mostly scanning transmission electron microscopy (STEM) for detailed characterization of the atomic structure of a wide range of materials systems. Characterizing the structure of materials down to the atomic scale allows a much greater understanding of their properties, particularly for use in fuel cell devices. He is particularly interested in determining the surface structure of disordered and ordered (intermetallic) HEA NPs to understand catalytic properties. Gerard has a particular interest in the three-dimensional imaging of nanomaterials, determining the 3D structure and elemental distribution within HEA NPs.

DR JOE MAPIRAVANA

Dr Joe is a seasoned materials engineering specialist with 40 years' experience in research, development, and innovation of metallurgical and process engineering technologies for gold recovery, mineral beneficiation, and manufacturing of metal castings (foundry), refractories, building and construction materials, ceramics, glasses, and composites. He has extensive production management and technical marketing experience that was gained through extensive in-plant exposure to manufacturing facilities and research establishments in Africa, Europe, and Asia. Dr Joe joined the CSIR in 2008 from the SIRDC where he was the inaugural Director of the Metallurgical Research Institute that he founded. Dr Joe has served on several industrial Boards of Directors providing technical leadership to technical and marketing Board committees. He is currently Principal Researcher leading the CSIR Construction Materials Research Group which currently focuses on commercialization of its portfolio of green cements and binders for concrete.

EMMANUEL MARUME

Cofounder and Director at Farmbuzz Agriculture solutions. Emmanuel is also an award winning Agronomist who is passionate about smart farming and precision farming.



STEPHEN LAMB

ANDREW LORD

ABOUT THE AUTHORS:

Stephen Lamb and Andrew Lord are designers and environmental activists who have worked in the sustainable construction, design, art, engineering and architectural sectors for the last 22 years. Their work focuses on the research, development and use of sustainable, alternative, robust, low-cement building materials and restorative, resource efficient, low-tech, socially inclusive building systems. Emphasis is placed on maximizing opportunities for local, gender-neutral job creation, skills development and training, the creation of low-tech building systems, carbon sequestration in the built environment and the restoration of natural eco-systems. Stephen and Andrew have received several acclaimed awards for their work and have presented their work both locally and internationally. These include being invited to build the entrance pavilions for the Shanghai Biennale in China (2012) the Seventeenth session of the Conference of the Parties (COP 17) in Durban, South Africa (2011) and the Cape Town Climate Smart Campaign Pavilion at the FIFA World Cup (2010). During this time they also focused on leading the design and construction of the Table Mountain – Hoerikwaggo Hiking Trail, the design and building of innovative vertical food security systems in informal settlements with the building of the Gege Creche in Langa and the Green Shack at the Design Indaba, Cape Town International Conference Centre.

In 2014 Stephen and Andrew collaborated with Khoi-San Activist Mr !Xoma Ayob and co-designed and built the first "Light House" in Hangberg, Cape Town.Following the success of this project, they were recruited into the South African Government in 2015 and lead the research and development of the Light House Program, an Expanded Public Works Program funded by the South African National Government. The program explored and developed regenerative building technologies and construction methods using alternative bio-based aggregates and binders.

Prior to co-founding nonCrete with Andrew Lord in 2018, Stephen studied at ETH Zurich with the Chair of Sustainable Construction in D-BAUG as an invited visiting student. During this time Stephen and Andrew co-authored the academic paper: "Invasive alien plants as an alternative resource for concrete production – multi-scale optimization including carbon compensation, cleared land and saved water runoff in South Africa", published in the scientific journal "Resources, Conservation & Recycling" Stephen was invited to present his work to the 6th International LafargeHolcim Forum for Sustainable Construction "Re-materializing Construction" in Cairo in 2019 and later that year to The 3rd International Conference on National Urban Policy (United Nations Habitat) in Nairobi. Stephen accepted a full-time position at the Block Research Group (part of the Department of Innovation and Technology in Architecture at ETH Zurich) as research associate for two years (2019 – 2021). During this time Stephen and Andrew were invited to present their work at the Venice Architectural Biennale (2021) in partnership with the Block Research Group, ETH Zurich.

They established nonCrete (pty) Ltd. In 2021. Their current work focuses on researching, developing and implementing the use of low-carbon building materials, bespoke material mix-designs and appropriate design practices through local and international collaborations within the private, academic and government sectors.

Digital Transformation for sustainability

As an architect by training and now a full-time researcher in the built environment, I focus on defining best practices, developing norms and standards, exploring innovative technologies, and evaluating their benefits. My goal is to support national development through research, science, and technology.

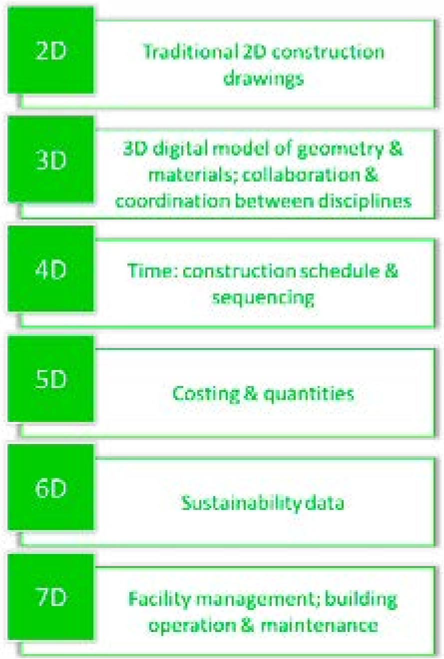
Given that buildings contribute a significant percentage of greenhouse gas emissions and South Africa's commitment to achieve a net zero carbon status by 2050, sustainability in the built environment is a natural research focus. Sustainability in the context of the built environment in South Africa has matured since the 2000s, and the conversation has evolved from passive design and energy efficiency to the extended consideration of embodied carbon and digital transformation.

When first faced with the concept of the digital transformation of the built environment, I considered it to be defined by CAD design and 3-dimensional computer models. Building information modelling (BIM) has been available and used to varying degrees in the South African design industry for many years. However, when exploring BIM beyond three dimensions, its potential to support sustainability becomes evident.

BIM is primarily about information, not buildings – in fact, the currently preferred term is building information management because it is hinged on the management of information pertaining to a building design, construction, and operation. At its core, it is a process for creating and managing digital information about buildings and infrastructure, allowing architects, engineers, construction professionals and property owners to create a virtual model of a building project that contains all the information about its design, construction, and operation.

This information can include everything from the physical geometry of the building, details about materials, systems, and equipment, to project scheduling, cost estimation, and environmental performance. These different types of information are known as dimensions of BIM. The information itself exists in any building project; however, the coordinated management and presentation of the information in a standardised system that survives the construction phase in a useful format is the defining value of BIM.

The different dimensions of BIM refer to different levels of detail and data that can be included in a building information model. The first seven dimensions of information are depicted in Figure 1. There are further dimensions (8 to 10) that relate to safety during construction, Lean construction and construction industrialisation.



Seven Dimensions of Building Information

The sixth dimension – sustainability - is the golden thread that is woven through all the stages of the building lifecycle. This provides an information model that includes data on sustainability and the environmental impact of materials and building performance.

Building information modelling can play an important role by facilitating the integration of sustainable design principles and practices throughout the building lifecycle. A good building information model allows the building owner or custodian to easily access design and material information, facilitating maintenance and the correct operation of the asset beyond the construction phase. The retention of design information after construction provides an essential reference for the operation of the building, ensuring efficient operation and the longevity of the building. Linking life cycle assessment (LCA) data of materials to building elements enables the evaluation of the environmental impact of a building, from construction to demolition, and supports the selection of design strategies and materials that reduce the overall environmental impact of buildings.

In the design stage, sustainability data and building performance can be modelled to predict how the building should perform. Currently, the practice of measuring and monitoring sustainability indicators post-design - such as construction waste, actual energy and water consumption, indoor environment quality, and the frequency of maintenance, repairs, and replacement of elements - is limited but holds enormous potential to improve the sustainability and environmental impact of buildings. Measured building performance data can be used to benchmark, evaluate, predict, and respond to building performance. From a research perspective, this data can be used to develop evidence-based guidelines to improve the safety, resilience and appropriateness of buildings for the occupants, owners and the environment. In a context that is constantly changing due to the impact of factors such as climate change, pandemics, changing socioeconomic conditions, and advances in technology, best-practice guidelines must be continuously reviewed based on data.

Digitally monitoring and managing building information can be extended to the neighbourhood level to ensure efficient and effective service delivery, and predictive models can help mitigate risks associated with natural disasters, such as floods. Access to this information can also contribute to empowering community members to make informed decisions about their own built environment and to participate more fully in the planning and design process. This is a social sustainability aspect that BIM can offer.

There is an observed shift in focus in the built environment to embodied carbon and carbon credits, taxes, and trading. In this regard, the sector is in its infancy, but the change is evidenced in industry tools, such as the inclusion of embodied carbon calculations in the IFC EDGE tool and the GBCSA Net Zero Certification. There is a growing demand for manufacturers to provide LCA data for their products, which is supported by eco-label schemes that verify manufacturers' claims, such as Agrément SA's recently developed ecoASA standards. The inclusion of such data within the building information model supports the quantification of sustainability and the drive for net-zero carbon.

Until now, the management of building data has been primarily confined to each discipline. The key to sustainable information management is in standardising practices and protocols to enable the smooth exchange and uninterrupted access to information related to a particular building. In South Africa, this streamlining of information is being guided by the ISO 19650, which was recently adopted as a South African National Standard. This, along with the emerging interest in embodied carbon data, sets up the built environment industry for rapid growth in terms BIM uptake progressively along the dimensions, towards sustainability.

Further research and development are needed to support the industry along this pathway and to overcome barriers, such as access to devices, software and data. Industry uptake can be supported through knowledge sharing and demonstration across a wide range of building types, including public and private projects of various sizes.

Based on the maxim: 'if you cannot measure it, you cannot improve it', it can be concluded that the digital transformation of the built environment is defined by the coordinated collection, management and analysis of data to inform a sustainable future for generations to come.

Dr Coralie van Reenen, CSIR

Green Visionaries: Innovations and Leadership Fuels Environmental Consciousness

Given that cement is the third most utilized material following sand and water and its manufacture contributes an estimated 6% of global anthropogenic carbon dioxide emissions, there is a need to consider recyclability, life cycle environmental impact, and economic feasibility. Materials science takes front stage in this volume with research and industry investigating technologies which can reduce its negative impacts.

Amongst contemporary challenges faced by concrete, is the durability of the material in infrastructure. Geopolymers represent a valuable addition to the expanding array of cementitious materials, which serve as primary inputs in concrete production. UCT joins hands with the CSIR to build on international research in this field, testing mineral acid resistance in both static and dynamic conditions, for - amongst others - sewer applications.

Dumani and Mapiravana report on their cradle-to-gate environmental life cycle assessment of limestone calcined clay cement (LC3), which shows it to be a very promising alternative to Ordinary Portland Cement. In other work, in quantifying the environmental impacts of a sustainable concrete mix for a block paving system, researchers find that replacing cement with fly ash, beyond 35%, as stipulated in the national cement specification for common cements, presents a significant opportunity to reduce environmental impacts without (necessarily) compromising strength.

Innovation reusing waste materials and circularity is the theme of much research in materials science. The implementation of the dry modification method with polyolefin plastic waste in South Africa shows promise for addressing the plastic waste crisis, enhancing road construction materials, and contributing to sustainability goals. The chapter presents ongoing research, finding that further research and collaboration are needed to refine the approach, establish standards, and monitor the long-term performance of these novel materials. "nonCrete" lay claim to alignment of their lightweight structural floor system with the circular economy principles, by making use of biomass as a sand and aggregate replacement.

Materials science also features in a short piece on energy, setting out some of the challenges and opportunities in the application of platinum-based high-entropy alloy nanocatalysts for green energy production and storage.

Amidst ongoing loadshedding, the Department of Mineral, Resources and Energy have published an Integrated Resource Plan (IRP) for public comment, which has been met with widespread interest and criticism. On the basis of over three decades' experience in nuclear energy, Nicholls critically reviews a perception that nuclear energy is only suitable for base load, making the case for using molten salt for heat storage.

The South African Institution of Civil Engineering (SAICE) explains its recommitment to fostering infrastructure, after its recent Infrastructure Report Card spawned a number of proactive proposals aimed at bridging between government and professional bodies. As the largest professional body in Africa, representing engineers, consultants, policy makers, and organisations involved in the energy sector, South African Energy Efficiency Confederation (SAEEC) sets the goal of advancing the cause of energy and resource efficiency, combating

Editor
Peta de Jager

Read more

Toyota South Africa Motors Drives Conservation: Championing Wild Dog Preservation

Amidst the African wilderness, a spirited and endangered predator roams the expansive landscapes. The African wild dog, also known as the 'painted wolf', reigns as a symbol of tenacity and adaptability in a world where survival is arduous.

Over the past two years, Toyota South Africa Motors has supported conservation efforts for the African wild dogs in Waterberg through its partnership with the Waterberg Wild Dog Initiative (WWDI). The partnership has provided the WWDI team with tools and resources to increase its monitoring of the packs which provides the data needed to better understand the population and the threats they face.

The endangered African wild dog population in the Waterberg freely ranges across a rugged, mountainous landscape. The capability and durability of the Toyota Hilux 2.4L double-cab, provided to the WWDI team by Toyota South Africa Motors, means the team can reach the packs throughout their ranges, enhancing their ability to monitor the packs year-round and rapidly respond to urgent situations.

Enabled by the support of Toyota South Africa Motors, the free-ranging African wild dog population in the Waterberg has grown from only 14 known African wild dogs in one pack to 39 dogs, encompassing two packs and two dispersal groups. One of the packs, the TOOG Area Pack, has seen a 100% survival rate in their 2021 and 2022 litters of pups, providing the best opportunity for pups to be raised to adulthood. African wild dogs have dispersed from their natal packs on three occasions in the last year, signalling that natural processes are being conserved alongside population growth.

Since the beginning of the partnership between TSAM & WWDI, the conservation impact of the Waterberg wild dogs has expanded, as well as continent-wide African wild dog conservation projects that establish new African wild dog packs into formerly protected areas. These translocations have been enabled by the data collected by the WWDI through its partnership with Toyota South African Motors.

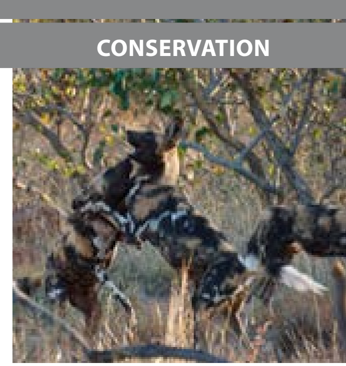
The successes have not been without challenges. In the last year, 4 African wild dogs have been lost to snares, a road collision, and a fence line, highlighting a need for further efforts to mitigate these threats.

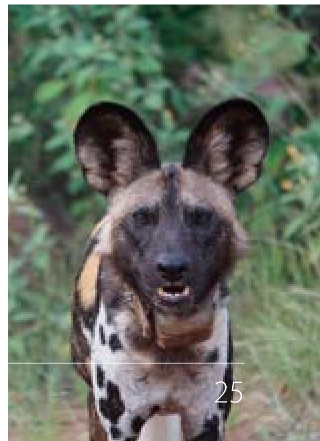
Overall, the continued conservation of the Waterberg wild dog population over the last two years is a testament to the strong partnership of Toyota South African Motors and the WWDI. Toyota South African Motors' support has empowered more effective population monitoring, supplying the data needed to make well-informed management decisions, help with identifying the population's threats, and formulate long-term, sustainable solutions. Together, the Waterberg Wild Dog Initiative and Toyota South Africa Motors are leading the way in African wild dog conservation in the Waterberg.

For more information, please visit:
www.waterbergwilddogs.org.za

TOYOTA

WATERBERG WILD DOG INITIATIVE





Socio-economic KPIs need to be included in corporate plans and shareholder compacts to progress the sustainability of infrastructure agencies and society alike

Vishaal Lutchman

This article serves to take advantage of an opportunity created by the failures of state-owned companies and government agencies responsible for the provision and maintenance of infrastructure in South Africa. The ability of many State-Owned Companies (SOCs) and public sector agencies to deliver on their mandates sustainably may no longer be the case. Whilst some may believe in restoring such entities to the way they were, there remains an alternative, which is to reinvent these entities. Some have referred to long-awaited structural reforms which lean towards regulatory, institutional and or policy changes.

Some background to why SOCs are necessary in developing economies such as South Africa may shape our thinking in how we plan reforms going forward. SOCs are state-owned and often the major shareholder. They are hybrid businesses that are not fully public, private, or non-profit. In all cases, the SOC must act in the public interest and in doing so remain accountable and transparent to the public. As governments are the majority owners of such entities, the temptations remain to exert political authority and such severe exertions cause the SOC to deviate from its mandate to act in the interests of politics. Such dissonance often comes because of governments that grow apart from constituents or if there are significant changes in the markets that need executive interventions. The same does not apply to agencies that provide goods and services to society.

I think we can agree that South Africa has seen a significant increase in the politicisation of agencies and SOCs which has resulted in the neglect of the social mandate amongst other KPIs. This neglect has seen many SOCs fail in their ability to deliver on their shareholder compacts and so too deny that they need to be transparent and renege on their accountability to the public. Much seems to happen behind closed doors. The resulting crises create unintended consequences as we see with the sabotage of the ESKOM plant, Transnet's rail system, SAA's airline business, and Prasa's rail system to mention a few.

Although implementing these reforms may take some time, there remain immediate opportunities to make a direct and positive impact on the country's needs. Should we restore such agencies to their former selves, I argue that even when the agencies were duly established with staff, and resources implementing following a robust mandate, they have made little impact on issues like redress and inequality. I will acknowledge that the failures have significantly deteriorated social sustainability in South Africa. This article articulates that three main strategic contributions could help improve infrastructure provision thereby enabling a sustainable growth trajectory. However, we cannot afford to waste time in granting South African's opportunities to better their lives.

This article supports the notion that three attributes can create a much-needed collaborative network namely, effective organisational strategy, leadership that is motivated by ESG and the sustainability pillars, and technical astuteness. It postulates if these three attributes are appreciated by society, interested and affected parties, shareholders and business partners - it is possible to reform an effective infrastructure ecosystem. If not, society will continue to struggle with ongoing legal challenges, perpetuated criminality, loss of life, and carelessness including undoing any progress made with respect to social and racial cohesion. We are already seeing glimpses of anarchy with the design and implementation of mafias soon to become legitimate economic actors.

Infrastructure agencies operate at national, provincial, and municipal tiers of government.

Corruption and maleficence have deliberately resulted in the removal of important capability, subversion of governance processes, inadequate planning, and lack of financial controls, leading to loss of revenue, high working capital, depletion of capital reserves and reduction in their ability to raise additional capital. The crisis in such entities gives rise to the creation of costly alternative solutions exacerbating unsustainability.

Moving coal by road, diesel supply for energy, water tankers to water and the list may go on. Such solution providers will seek to maintain such a status quo.

As long as there is willingness and ability to change the status quo, there is hope that we can improve the situation. In my opinion, leadership must be effective. The current leadership of many infrastructure agencies have broadly been ineffective

THOUGHT LEADERSHIP

in leading change towards progressing sustainable communities. SOCs' existing leadership can improve by focusing on previous KPIs in a new way. A starting point could be the shareholders allowing boards and CEOs to run their businesses without political interference. Until then, it is anticipated that there will not be any significant changes. All agencies need to find the right leadership, technical and operational skills which may be limited but are still available in the country. If the skills are removed to make way for corruption projects, it will make it difficult for the skills to return. However, in my opinion, there are skilled individuals in the country, and many that want to see these agencies succeed and offer support. This applies to civil engineers that still choose to remain in South Africa despite being in demand in significantly more sustainable geographies.

Agencies complain about the shortage of skilled workers, while they continue to reject talented individuals. Trust in government is at its lowest in recent times and dissuades the attraction of talented skills as employment in such entities seems to be unsustainable. Great talent is attracted to great leadership which typically provides effective support systems and processes, career growth, professionalism in the workplace, ethics, and integrity to name a few attributes. Perhaps a misunderstanding, convenient or otherwise, the majority of South Africans want the public sector to transform towards a higher level of performance and will support such initiatives within the context of pragmatism, meritocracy and most importantly honesty. Effective leadership has the propensity to draw and keep the talent needed to implement strategy. Such leadership requires that shareholder mandates remain pure to what is needed to operate. In addition, boards need to perform and avoid the temptation to manifest influence in operations. Effective boards should enable the executive to stay focussed on organisational KPIs.

As we rebuild and transform the public sector in the country, there exists an opportunity to revise how we structure the key performance indicators of such agencies. For example, there remain reparations that have been ignored or left at a policy level thinking redress would happen, which sadly has not been the case. This applies to access to quality education, wage inequality, unemployment, poverty, diminishing sanitation and the provision of potable water on tap, the provision of reliable and consistent power, non-standard common user facilities, affordable transport systems, and safe and reliable solutions to disaster responses due to changes in climate and associated weather patterns.

Other KPIs must be on clear and definitive training and development of suppliers to allow for growth and entrepreneurship, bringing back research and development to enable the transformation towards a digital economy. Overall KPIs must track the impact of the decisions on the cost of doing business needed to save time have a customer focus, and most importantly strive to reduce the cost of doing business and improve competitiveness. The result would be a public sector ecosystem that can be inclusive and a resilient place to live, play and work.

Hence the urgency is real that socio-economic KPIs are included in public sector agencies that provide infrastructure to enable, keep and protect their integrity whilst empowering them to be allowed to function freely whilst ensuring accountability. The arrogant stranglehold on public sector agencies must stop so that they may be allowed to resume their role to uplift society as is expected. To date, many SOCs for example are no longer a going concern relying on national austerity measures that are not sustainable, yet executives are paid substantial bonuses, effectively meaning that taxpayers are rewarding executives for non-performance in the public sector and continue to do so, whilst the shareholder argues that they have done very well. It is clear that we are setting precedents of below-par performance and justifying the acceptability of such a state of affairs.

I have argued how effective leadership, revised organisational strategies, and attracted skills will bring about the transformation needed to stabilise the infrastructure ecosystem after one could focus on enhancements brought about by R&D and further training. The thinking around sustainable communities supported by a transformed approach (KPIs) can be done in a relatively short brief time and will bring a renewed sense of hope, whilst we seek to amend regulations to deal with systemic shortcomings in the medium term. The positive energy will surely give a greater level of confidence in knowing that hope is no longer a false promise.

Swiss government backs the extension of an NCPC-SA led industrial parks greening programme

Lesego Hlalethwa

The global drive to achieve carbon neutral industries, mitigate climate change and reverse environmental impacts make a strong business case for industrial parks to transition to greener and eco-friendly spaces. The sustainability of these spaces can advance South Africa's reindustrialisation while fostering economic growth and investment attraction.

Supported by collaborative work between the Department of Trade, Industry and Competition (the dtic), the United Nations Industrial Development Organization (UNIDO) with funding from the Swiss State Secretariat for Economic Affairs (SECO), the National Cleaner Production Centre South Africa (NCPC-SA) implemented the first phase of the Global Eco-Industrial Parks Programme (GEIPP) in South Africa.

The GEIPP Phase I launched on Dec 2020 in three pilot parks: Phuthaditjhaba, Ekandustria, and East London Industrial Development Zone (ELIDZ). In this phase, the NCPC-SA and UNIDO conducted capacity-building workshops, Resource Efficient and Cleaner Production (RECP) assessments, park benchmarking, and knowledge-sharing forums that have since assisted the park managers with identifying decarbonisation and cost-saving opportunities.

Opportunities identified through the GEIPP interventions

The identified opportunities enable the parks' transition to eco-industrial parks by evaluating their performance against international EIP framework measures. The performance benchmark scoring considers the park's economic, social, environmental, and management performances. In practice, managing resources such as water, energy and enhanced circularity and synergies within the parks, plays a critical role in improving their performance.

In 2020, the ELIDZ was the highest-performing industrial park, achieving a score of 80% against the performance benchmarks and improved to 82% in 2022. Phuthaditjhaba Industrial Park scored 31% in 2020 but improved to 43% in 2022. The park managers highlighted that they had identified significant opportunities through the programme.

Among these, were promoting circular economy synergies between tenant companies, deploying renewable energy sources to improve energy security, and setting up internal wastewater treatment plants to help attract investment to the parks while benefiting the surrounding communities.

In addition to advancing the work that kicked off in phase I of the GEIPP, phase II will expand to additional parks, facilitate gender mainstreaming, explore green projects implementation funding options and ramp up capacity building.

Industrial parks and companies interested in learning more about the programme can contact the NCPC-SA at ncpc@csir.co.za.

About the Global Eco-Industrial Parks Programme

The GEIPP is implemented by UNIDO in seven countries through funding from SECO and executed by local NCPC's in participating countries.

The programme seeks to assist industrial parks in achieving enhanced environmental, economic, and social performance through collaboration and resource management, rendering the parks more competitive and sustainable. The programme also enhances the work of the dtic's Industrial Parks Revitalisation Programme (IPRP) while supporting the National Development Plan (NDP) 2030, which aims to eliminate poverty and reduce inequality by 2030.


GREEN BUILDING

Transforming the built environment for people and planet to thrive

GBC SA
Green Building Council South Africa

gbcsa.org.za

1080 certifications since 2009

15.8M square meters certified

THIS EQUATES TO APPROXIMATELY

2 250 Rugby fields of space certified

1 575 Million kWh/annum will be saved

1 890 Million kg CO_2/annum will be saved

1 460 Million Litres of potable drinking water will be saved annually

472 800 Cars off the roads every year in terms of kg CO_2 equivalent

109 445 Households worth of annual energy will be saved

2 000 170 Daily drinking water needs for this many people every year

GREEN BUILDING

A "nonCrete" lightweight structural floor system

Stephen Lamb and Andrew Lord, nonCrete

Next to water, concrete is the most consumed substance on our planet. The building industry is responsible for 50% of global resource consumption, over 35% of waste generated worldwide and over 40% of human-caused CO_2 equivalent emissions each year.

The global population is expected to increase by 2.1 billion people over the next 30 years, and it is simply not possible to continue building the way we do today if we want to reduce greenhouse gas emissions, slow the depletion of natural resources and minimise waste production.

With nearly three quarters of a typical building's embodied energy being attributed to its structural mass, a sustainable future of the building industry ultimately requires a drastic shift in how structural systems of buildings are designed, fabricated, and constructed.

It is estimated that over 200 billion square metres (more than 2 trillion square feet) of floor area are to be constructed within the next three decades, mostly in urban areas where medium high-rises of 10 to 30 stories are a common typology. On average, 40% of the mass of these buildings is found in their reinforced concrete floor slabs.

Conventionally cast flooring systems are highly inefficient in their use of materials. They are highly reliant on the tensile strength of steel and do not optimise the inherent compressive strength of concrete. Traditional concrete floor slabs working in bending typically consist of a solid section of concrete reinforced with large amounts of steel.

In contrast, light-weight unreinforced funicular floors offer significant reductions in both steel and cement. Compared to conventional reinforced concrete floor slabs, the proposed floor system has an arched profile that distributes the internal forces predominantly in compression only, with the outwards thrusts being controlled by either a buttress-wall system or steel tension ties.

The separation of material (concrete floor in compression and steel ties in tension) maximises the effectiveness of each material, which consequently reduces the overall amount of material required, and enables a clean disassembly to improve recyclability at end-of-life.

The reduced stresses within the floor system also enables the use of relatively weaker concrete that incorporates recycled or natural "waste" material as aggregate.

In this instance, water-thirsty invasive alien plants (IAP) in South Africa are mechanically chipped and used as a substitute to conventional sand and stone aggregate. When mixed with bespoke low-cement "nonCrete" binders, a slurry is produced which mimics the physical material properties of conventional concrete. The "nonCrete" material produced is half the weight of conventional concrete (1 250 kg's/m3) and has superior fire-ratings when compared to conventional bricks.

In addition to achieving a lighter and a more sustainable concrete using biomass as aggregate, the clearing of these IAP's has the potential to sequestrated carbon in the built environment at scale (879 kg of CO_2/m3), re-establish water security, restore biodiversity and create jobs in impoverished communities.

Current "nonCrete" funicular flooring systems are cast from low-medium strength biomass concrete mixes - one with stiffeners, and one with both stiffeners and infill. The results from the serviceability and ultimate load testing to date has demonstrated their sufficient structural performance (tested in accordance to European Building Standards), surpassing the chosen serviceability and ultimate state criteria.

Introducing the funicular floor system and a low-cement bio-based "nonCrete" could therefore result in significant reductions to the total volume of concrete and steel for the entire building and therefore have a significant impact on the embodied carbon-dioxide emissions of newly constructed buildings worldwide.

Safe, dignified and sustainable housing option in South Africa

South Africa is a water scarce country and many of the country's water resources are already fully allocated. Moreover, access to water is unequal, with the poorest communities suffering the most. Consequently, providing sustainable, secure and equitable access to water is a major government priority.

Within this context, twenty-two Strategic Water Source Areas (SWSAs) have been identified and strategies to "secure" these areas are being developed ; one of the strategies being to deal with alien invasive vegetation, that consume 1,450 to 2,450 million m3 of surface runoff water each year (approximately 3-5% of South Africa's available water resources) .

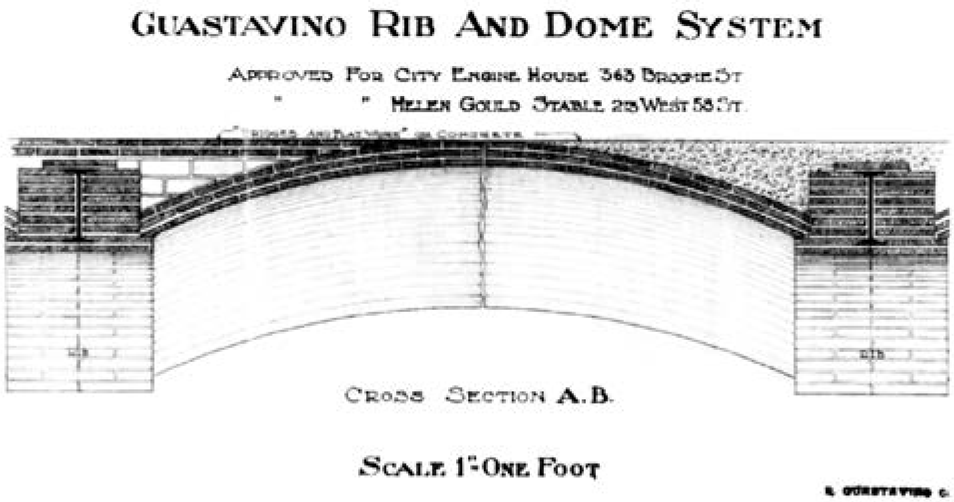
The lack of safe and dignified housing is a similarly major difficulty facing the country, with a shortfall of about 3.7 million homes. In this context developing affordable and sustainable housing solutions remains a pressing goal.

Through a people-centred design and construction approach, this nonCrete material-mix design and construction system aims to create local, low-tech, labour intensive, gender-neutral jobs for clearing of invasive alien plants and construction.

Light weight funicular floors

Floors and roof slabs contribute the largest ratios to the embodied carbon of a building's structure (Huberman et al. 2015). Further, reducing self-weight of floors can have a positive feedback on the other components of a building frame: vertical elements, foundations, and horizontal bracing systems can all be optimised with reduced floor dead loads. Minimising the self-weight and choosing low-carbon materials for floor systems should hence be a priority in sustainable building design.

Within the context of floor system optimisation, funicular floors are a promising stream of research [Liew, Rippmann, Hawkins, Ranaudo]. Their application



Guastavino rib and dome system, New York, 1902. Guastavino/Collins Collection, Drawings and archives, Avery Library, Columbia University.

has successful historic precedents - e.g. the thin masonry tile vaults applied by Mediterranean artisans, exported to the USA by the Guastavino's in the early 20th century. After falling in disuse due to standardised concrete slab construction, compression-dominant funicular floors seem ready for a revival, thanks to their structural efficiency, and ecological potential.

Modern references for funicular floor systems in the larger African context have been shown [Davis SUDU, Block Africa], but have up to now not known wider adoption. Current research can further the wider implementation of funicular floors, by demonstrating simple construction methods, as well as structural performance at medium to large spans of 3 meter – 8 metres.

different strategies shown in Guastavino's patent: the construction of lightweight stiffening walls and the addition of stabilised fill. This allows the system to resist asymmetric live loading and permits thin stiffening elements that are stabilised by the compacted fill.

The shells are stiffened against varying live loads by a series of ribs, in the spanning direction. The ribs allow a floor to be supported at the topside by transmitting the loads to the vault, as well as stiffening the structure, the latter of which is important for resisting asymmetric loading.

The shallow span/rise ratio makes the funicular curve relatively insensitive to changes in material densities. Due to the fill weight causing an uneven distribution of permanent loads, the funicular cannot

Hand-mixing and casting of a 5-meter unreinforced "nonCrete" funicular floor. Re-usable timber formwork is used in the casting of the floor. Undertaken in partnership with the Block Research Group, ETH Zurich 2022.

In current design, fabrication and testing of thin, vaulted, unreinforced "nonCrete" floors, the use of locally developed, scalable and low-skill construction designs are sought out. Structural innovation can be realised in a de-mechanised, low-tech context with limited resources, in a labour-intensive manner.

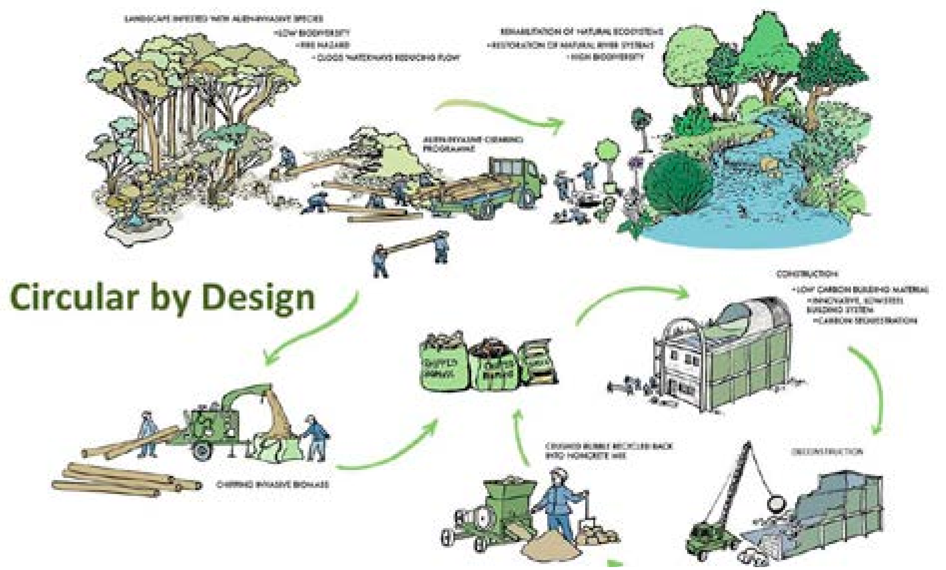
For simple and economic construction, the floors were designed as singly-curved shells. The central surface of the shell follows the funicular curve under permanent loads. Structural depth is added using two

be approximated precisely by either a parabola or a single circle, hence the exact funicular profile is followed during construction.

Circular by design

The design and construction of the funicular floor also aligns with the circular economy principles of regenerating nature, circulating products and materials at their highest value and eliminating waste and pollution. This is achieved in the following ways:

Doing more with less: The asymmetrical load testing of 12.8 kPa on a un-reinforced 5-meter span "nonCrete" funicular floor after 16 hours of uninterrupted loading - thereby exceeding European Building Code requirements. Undertaken in partnership with the Block Research Group, ETH Zurich – 2022



GREEN BUILDING

- The creation of a "nonCrete" material, using the bio-waste generated from invasive plant clearing, circulates products and materials (mostly invasive biomass) at a considerably higher value.
- Clearing invading alien plants restores natural ecosystems, which reduces the threat of large-scale disaster events caused by alien invasive infestation (e.g. flooding, landslides, fire) and increased water run- off in catchment systems.
- Optimising and enabling low-tech, labour-intensive job creation and training opportunities for local communities in the construction sector and minimising the reliance of third-party services providers
- Customised, context specific material-mix designs, and optimised geometry-based design further reduces construction waste and the associated pollution, in particular the use of cement and steel.
- Through a people-centred design and construction approach, nonCrete material-mix designs and construction systems create local, low-tech, labour intensive, gender-neutral jobs.
- Custom-designed Life-Cycle Assessment tools (LCA's) are used to highlight, measure and improve carbon sequestration opportunities.

Building people, building infrastructure

The design and construction methodology of nonCrete places a specific emphasis on the active participation of beneficiary communities as well as people-centred design practices.

The innovation therefore is not merely material-based, but social as well – one which focuses on nurturing and circulating local construction related skills and practice, with a view to stimulating the development of localised construction-based economies.

nonCrete works in partnership with (amongst others) the CSIR, The University of Stellenbosch, Agrement South Africa, The World Wide Fund for Nature (WWF) South Africa, the Block Research Group and the Chair of Sustainable Construction, ETH Zurich.

References:

- Linde, L., Nilsson Lewis, A. and Sanchez, F. (2022). Towards a sustainable global construction and buildings value chain. Policy brief. Leadership Group for Industry Transition, Stockholm.
- Göswein, Verena, et al. "Invasive alien plants as an alternative resource for concrete production–multi-scale optimization including carbon compensation, cleared land and saved water runoff in South Africa." Resources, Conservation and Recycling 167 (2021): 105361.
- Beyond Bending II, Sustainable affordable housing for South Africa, Venice, Italy, 2021
- De Wolf, Catherine, Michael Ramage, and John Ochsendorf. "Low carbon vaulted masonry structures." Journal of the International Association for Shell and Spatial Structures 57.4 (2016): 275-284.
- De Wolf, Catherine Elvire Lieve. Low carbon pathways for structural design: embodied life cycle impacts of building structures. Diss. Massachusetts Institute of Technology, 2017.
- Huberman, N., et al. "Optimizing structural roof form for life-cycle energy efficiency." Energy and Buildings 104 (2015): 336-349.
- Ochsendorf, John. "Guastavino Masonry Shells." STRUCTURE 26 (2014).
- Guastavino/Collins Collection. Drawings and archives. Avery Library, Columbia University
- Liew, Andrew, et al. "Design, fabrication and testing of a prototype, thin-vaulted, unreinforced concrete floor." Engineering Structures 137 (2017): 323-335.
- Rippmann, Matthias, et al. "Design, fabrication and testing of discrete 3D sand-printed floor prototypes." Materials Today Communications 15 (2018): 254-259.
- Hawkins, William John, et al. Thin-shell concrete floors for sustainable buildings. Diss. University of Cambridge, 2020.
- Ranaudo, Francesco, Tom Van Mele, and Philippe Block. "A low-carbon, funicular concrete floor system: design and engineering of the HiLo floors." System 2012.2016 (2010): 2016-2018.
- Davis, Lara, and Philippe Block. "Earthen Masonry Vaulting: Mexican and Catalan Techniques." SUDU. Vol. 1. Ruby Press, 2015. 95-125.
- Block, Philippe, et al. "Tile vaulted systems for low-cost construction in Africa." ATDF journal 7.1/2 (2010): 4-13.

Prior iterations of a modular zero-carbon roof and flooring system and associated applied research include:

- 1. HiLo - Research & innovation unit for NEST, Dübendorf, Switzerland, 2011-2021: This research demonstrated the structure for an unreinforced concrete floor consisting of a thin funicular vault stiffened by a series of spandrel walls on its extrados. A first version of this innovation is built in the NEST HiLo project, realized in 2021 on the Empa campus in Dübendorf, Switzerland.
- 2. SUDU - Sustainable Urban Dwelling Unit, Addis Ababa, Ethiopia, 2010: This research demonstrated a series of key prototypes and the development, design, and construction of double-story, sustainable, low-cost urban dwelling units in Ethiopia. The SUDU project uses rammed earth technology to construct the first level of the building and demonstrates the vaulted roofing technique.
- 3. Beyond Bending II - Sustainable affordable housing for South Africa, Venice Architectural Biennale, Italy, 2021: This exhibit presented innovative material and construction methods of clearing and chipping biomass of water-thirsty invading alien plants (IAP's) as a substitute for sand and stone as aggregate, a more sustainable alternative to conventional concrete, a bio-concrete, was be produced, ensuring water security, restoring natural ecosystems and creating labour intensive jobs in impoverished communities. The proposed structural system as a viable alternative construction method for housing demonstrates how structurally-informed geometry can significantly reduce resource consumption and enable the use of local and more sustainable yet structurally adequate building material.
- 4. Mapungubwe National Park Interpretive Centre, South Africa, 2009: The Mapungubwe Interpretive Centre in South Africa uses novel design and construction techniques to allow local materials and labour to be used in production. Traditional tile vaulting, using locally made, pressed soil-cement tiles, allows the complex shapes to be built by newly trained workers without extensive formwork. A hands-on programme of design and construction suggests a new way to jointly manage architecture and development programs. This merging of novel structural geometry with traditional materials and craft has resulted in a new interpretation centre for a trans-frontier national park in South Africa.

HiLo - Research & innovation unit for NEST, Dübendorf, Switzerland, 2011-2021: This research demonstrated the structure for an unreinforced concrete floor consisting of a thin funicular vault stiffened by a series of spandrel walls on its extrados. A first version of this innovation is built in the NEST HiLo project, realized in 2021 on the Empa campus in Dübendorf, Switzerland.

GREEN BUILDING

Cradle-to-gate environmental life cycle assessment of limestone calcined clay cement (LC3)

Nozonke Dumani, CSIR and
Joe Mapiravana, CSIR

The manufacturing of cement contributes to approximately 5-7% of global anthropogenic carbon dioxide emissions, necessitating the need for reducing the environmental impact. Limestone Calcined Clay Cement (LC³) has emerged as a promising alternative to ordinary Portland cement (OPC), leveraging widely available resources like clay, limestone and gypsum to partially replace the carbon intensive Portland clinker. One ton of Portland cement is associated with about one (1) ton of CO_2. This study aimed to assess and compare the CO_2 emissions of theoretical binary and LC³ cement types against 100% Ordinary Portland Cement (OPC). Considered were: OPC with 30% calcined clay replacement, and LC³, composed of 50% clinker, 30% calcined clay, 15% limestone, and 5% gypsum.

The study, limited to a cradle-to-gate analysis, utilised the life cycle assessment software tool SimaPro 8.1 with the Ecoinvent Database version 3. The life cycle inventory dataset for each material was compiled, and the ReCiPe midpoint (H) method was employed to generate and report the results in CO_2 equivalents.

The results indicated that LC³ exhibited significantly lower CO_2 emissions compared to both OPC and binary OPC with 30% calcined clay replacement. This research demonstrates LC³'s potential as a highly impactful alternative supplementary cementitious material (SCM), particularly in reducing CO_2 emissions in the cement industry and acquiring significant carbon credits and/or reducing carbon tax where applicable.

Keywords: Calcined clay, CO2 emissions, life cycle assessment, limestone calcined clay cement, ordinary Portland cement, supplementary cementitious materials

1. Introduction

Globally, the cement industry faces significant pressure to mitigate and minimize carbon dioxide (CO_2) emissions. Cement manufacturing is responsible for emitting 780 – 1000 kg of CO_2 for every ton of cement produced, contributing to approximately 5-7% of the world's anthropogenic CO_2 emissions (Suryawanshi et al., 2015; Krajči et al., 2015). In response to growing global climate change concerns, the cement industry is actively exploring strategies to minimize its environmental impact and align with international goals outlined in the Paris Agreement (UNFCC, 2023). This agreement, which has been signed by 194 countries emphasizes the urgent need to strengthen measures aimed at limiting the global temperature rise to below 2°C above pre-industrial levels and to pursue further efforts to keep the increase below 1.5°C (UNFCC, 2023). For the cement industry, available mitigation strategies include increasing energy efficiency, utilising of alternative fuels, partially replacing clinker with supplementary cementitious materials (SCMs) to reduce the carbon footprint of the cement, and implementing carbon capture and storage solutions (UNEP, 2019).

The use of SCMs in cements is already a global practice, standardised, for instance, by prEN 197-1:2018 in Europe, and ASTM C 595:2019 in the United States (Rodrigues et al., 2022). The most used SCMs are fly ash (FA), ground granulated blast furnace slag (GGBFS) and, to a lesser extent, silica fume (SF). However, geographical constraints and limited supplies of these SCMs (as depicted in Figure 1.1) pose challenges due to the growing demand for cement.

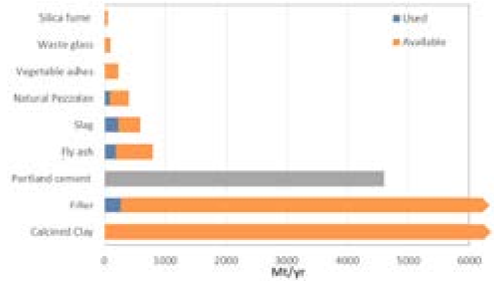


Figure 1.1: Use and estimated availability of possible supplementary cementitious materials and fillers globally in comparison to the amount of cement produced (UN Environment, 2018)

Currently, the South African cement sector produces approximately 13 million tons of cement annually, with an installed capacity to manufacture over 20 million tons per year. The market is projected to grow at a Compound Annual Growth Rate (CAGR) of 2.5% between 2023 and 2028, reaching a value of around 15.5 million tons, driven by increasing urbanisation and infrastructural development (Expert Market Research, 2023). However, in South Africa, fly ash is localised in Mpumalanga, while GGBFS and silica fume are localised to smelters in Gauteng and the North West provinces. Thus, there is a need to find alternative SCMs from local sources that are abundantly and ubiquitously available (Antoni et al., 2012).

Calcined clays have been used as an alternative SCM (Wild et al., 1996; Si-Ahmed et al., 2012). Kaolinitic clays, used to produce calcined clays, are abundantly and ubiquitously available. The deposits of kaolinitic clays are dispersed across various regions in South Africa, including Makana in Eastern Cape, Hammanskraal outside Pretoria, Zebediela in Limpopo, Potchefstroom, Ndwendwe, Kwazulu Natal, Cullinan, and Bronkhorstspruit areas in Mpumalanga and Western Cape and across the rest of Africa, as illustrated in Figure 1.2. This widespread availability of kaolinitic clays makes calcined clays an accessible and viable option for green cement production. In their natural form, kaolinitic clays are valuable materials used for ceramics, and as fillers for paper, paint, polymers and related materials (Rashad, 2013; Shan et al., 2016). However, when calcined under the right conditions, kaolinitic clays convert to calcined clays (Sabir et al., 2001; Rashad, 2013; Krajči et al., 2015; Shan et al., 2016).

Figure 1.2: Kaolinitic clay deposits in Africa (Ekosse, 2010)

Calcined clays can be used to produce a broad range of products including cement blends, geopolymer binders, shotcrete, pre-cast products etc. The calcined clay-based cement blends have significantly lower carbon footprints, increased durability and higher strength compared to most other commercially available cements (Sabir et al., 2001; Krajči et al., 2015). The calcined clay-based cement blends can be applied in the same manner as ordinary Portland cement.

Despite its immense potential, using calcined clay as a cement supplementary cementitious material has failed to receive industry-wide use due to its high market price. Traditional production methods involving rotary kilns, flash calciners and multiple hearth furnaces are capital-intensive and operationally complex. However, researchers have developed a cost-effective process for beneficiating South Africa's huge reserves of kaolinitic clays to produce metakaolin (calcined clay) using a patented coal-fired vertical shaft kiln (VSK). The technology has been demonstrated at a semi-industrial scale (Dumani and Mapiravana, 2017).

In recent years, there has been a growing interest in Limestone Calcined Clay Cement (LC^3) as a viable solution to mitigating carbon dioxide (CO_2) emissions in the cement industry (Scrivener et al., 2018; Sharma et al, 2021). LC^3 represents a new category of ternary blended cements, combining Ordinary Portland Cement (OPC) with calcined clay and limestone (Antoni et al., 2012; Joseph et al., 2023). This approach allows for substantial reductions in CO_2 emissions, making LC^3 a promising alternative to ordinary Portland cement (Malacarne et al., 2021; Rodrigues et al., 2022; Huang, et al., 2023; Barbhuiya et al., 2023; Basavaraj et al., 2023). LC^3 cements permit high levels of clinker substitution, above 50%, with a common composition comprising 50% Portland clinker, 30% calcined clay, 15% limestone, and 5% gypsum (Antoni et al., 2012; Bishnoi et al., 2014; Jaskulski et al., 2020). Commonly referred to as LC^3-50 in literature, this blend has been extensively studied, demonstrating mechanical parameters comparable to OPC just after seven days of hydration, provided the clay contains at least 40% kaolin (Alujas Díaz et al., 2015; Avet et al., 2016; Scrivener et al., 2018; Jaskulski et al., 2020; Sharma et al, 2021, Qian et al., 2023). However, LC^3 encompasses various formulations tailored for specific applications and regulatory requirements (Blouch et al., 2023).

The abundance of raw materials needed for LC^3, namely kaolinitic clays and limestone, which are widely available worldwide, coupled with its superior mechanical and durability properties, positions LC^3 as a sustainable alternative to ordinary Portland cement (Scrivener et al., 2018; Jaskulski et al., 2020; Sharma et al., 2021; Musbau, 2021; Zhou et al., 2022). Calcined clay replaces clinker, significantly reducing emissions, while limestone acts as a filler material. Additionally, LC^3's manufacturing process aligns with existing cement industry practices, requiring no specialized equipment or skills (Bishnoi et al., 2014; Emmanuel et al., 2016; Scrivener et al., 2018).

Industrial trials conducted in Cuba and India have successfully demonstrated that LC^3, with only 50% clinker content, performs similarly to Portland cement, which typically contains over 90% clinker (Bishnoi et al., 2014; Vizcaìino-Andreìs et al., 2015; Emmanuel et al., 2016.) LC^3's environmental friendliness, significantly reduces CO_2 emissions compared to OPC, makes it an attractive choice, particularly in regions where other supplementary cementitious materials are not readily available (Malacarne et al., 2021).

Several life cycle assessment (LCA) studies have verified LC^3's positive environmental impact, confirming reductions of up to and above 30% in CO_2 emissions compared to other commercially available cements (Sánchez Berriel et al., 2016; Cancio Díaz et al., 2017; Scrivener et al., 2018; Gettu et al., 2018; Malacarne et al., 2021; Martinez, Junior et al., 2023; Huang, et al., 2023). Junior et al. (2023) conducted a study to assess the environmental impact of six LC^3 blends prepared from metakaolin and limestone filler in ratios of 2:1, 1.5:1, and 1:1, with 45% and 60% replacement of OPC. OPC and Portland composite cement (PCC) were used as reference binders. The results revealed that LC^3 cements exhibited a reduction in energy consumption of up to 28% and total CO_2 emissions of up to 38% compared to commercial OPC-based cements.

Sánchez Berriel et al. (2016) evaluated and compared the economic and environmental impact of producing three types of cement: traditional Portland cement, commercial blended cement with 15% zeolite content (PPC), and LC^3-50. The results showed that using LC^3 led to a reduction in production costs of around 30% and CO_2 emissions by 40%. The feasibility, environmental benefits, and global scalability of LC^3 position it as a promising supplementary cementitious material (SCM) for partial replacement of traditional cement (Zhang et al., 2020; Malacarne et al., 2021; Rodrigues et al., 2022).

The aim of this chapter was to assess and compare the CO_2 emissions of OPC, binary OPC blended with 30% calcined clay and LC^3-50 utilising the calcined clay produced using the VSK technology. The unique aspect of this research lies in the utilisation of calcined clay produced through a vertical shaft kiln technology, contributing novel insights to the existing body of knowledge.

2. Methodology

A life cycle assessment (LCA) study was conducted to investigate the CO_2 emissions associated with the production of three types of cement; namely ordinary Portland cement, Portland calcined clay and limestone calcined clay cement (LC^3). Life Cycle Assessment (LCA) is a comprehensive and systematic methodology based on the international standards ISO 14040-44, used to evaluate the environmental impact of a product or process throughout its entire life cycle, from cradle to grave. The primary objective of LCA is to quantify and assess the resources consumed and emissions released at various stages of the product's life cycle, including raw material extraction and processing, manufacturing, transportation, use, maintenance, reuse, recycling, and final disposal. Figure 2.1 illustrates the generic life cycle stages of a construction product for LCA.

In an LCA study, environmental impacts are assessed by considering factors such as energy, land, water, materials, and other resources, as well as various types of emissions to the air, water, and soil. LCA methodology involves a detailed analysis of inputs and outputs, accounting for all relevant environmental factors. This systematic analysis helps identify potential environmental "hotspots" along the life cycle of the product or process. Moreover, LCA is an iterative process, allowing for continuous refinement and improvement.

LCA studies are structured into four mandatory phases (refer to Figure 2.2):

- Goal and scope definition: This phase involves stating the reasons and intended application of the study, defining system boundaries, specifying the functional unit to be used in the investigation, and clearly listing assumptions and limitations.
- Inventory analysis: This phase encompasses data collection and modelling of the product system under study.
- Impact assessment: In this phase, potential impacts associated with the investigated impact categories are calculated. Optional steps include normalization and weighting of results.
- Interpretation: This phase involves presenting and interpreting the results of the study, considering the initial intended goal and scope. The aim is to draw conclusions and make recommendations based on the findings.

Goal

The purpose of the study was to evaluate and compare the CO_2 emissions of producing three types of cement; namely ordinary Portland cement, calcined clay as a

Figure 2.1: Life cycle stages of construction product (Saint-Gobain, 2017)

GREEN BUILDING

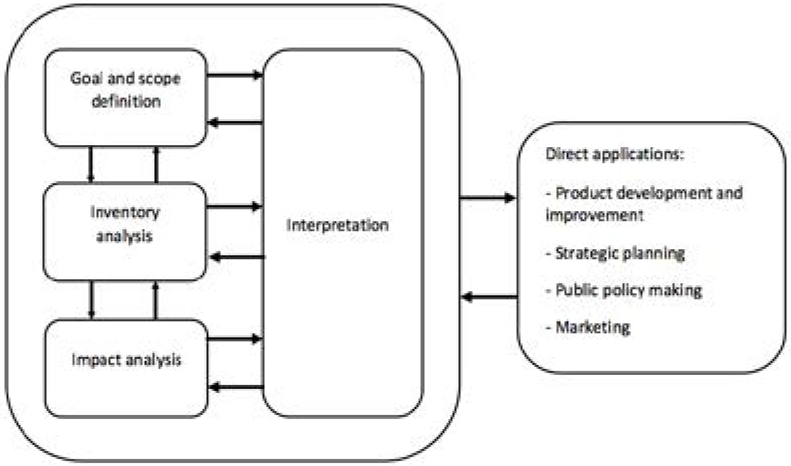


Figure 2.2: Life cycle assessment framework (ISO/SANS:14040,2006)

partial replacement for OPC, and limestone calcined clay cement (LC³). These cements are denoted as OPC, PCC, and LC³, respectively. OPC was also used for the composition of the LC³ cement. The following cements are analysed in this study:

- 100% ordinary Portland cement
- OPC with 30% replacement with calcined clay
- LC³ with a composition of 50% clinker, 30% calcined clay, 15% limestone, and 5% gypsum

Scope

The functional unit of analysis was selected as 1 kg of cement produced. The system boundary defines the scope of the analysis, and in this study, a cradle-to-gate system has been considered, as illustrated in Figure 2.3. This system includes raw material extraction and processing, as well as the transportation of raw materials to the cement production plant, and the actual cement production process, all of which are depicted in Figure 2.4.

Life cycle inventory analysis

The life cycle inventory (LCI) analysis phase involves data collection and modelling. LCI gathers relevant inputs (such as energy and materials) and outputs (such as emissions and wastes) of the product system being studied, which are then scaled to relate to the functional unit. The inventory for all processes in the cradle-to-gate life cycle of the cements was prepared qualitatively first and then quantitatively.

Data sources

The LCA software tool SimaPro 8.1, along with Ecoinvent Database version 3, was utilised to compile the Life Cycle Inventory (LCI) dataset for each material in this study. Table 3.2 provides an overview of the

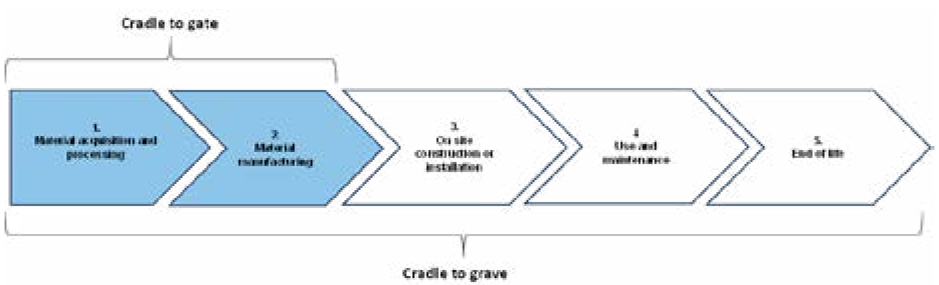
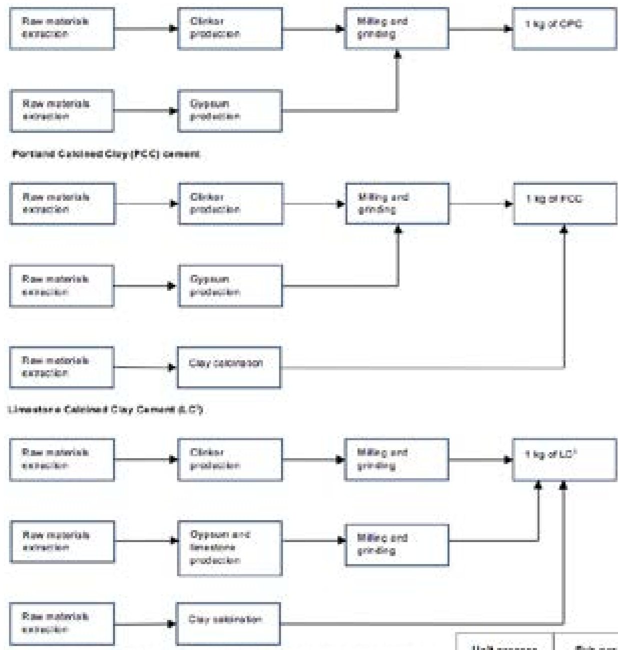


Figure 2.3: Generic life cycle stages of construction product



Caption: Figure 2.4: System boundaries of this study

materials and transportation inventory considered for each material. South African datasets were used whenever they were available. In instances where no South African dataset was available for a specific material, the Rest of the World (RoW) dataset was chosen as a proxy and modified to align with the local context.

Ordinary Portland cement 52.5 N and limestone were sourced from local suppliers and transported to the site. The kaolinitic clay was obtained from a local mining company and transported to a supplier for crushing. The crushed clay was then calcined using a vertical shaft kiln on a semi-industrial scale. Subsequently, a company milled the calcined clay using a ball mill. The milled calcined clay, along with OPC and limestone, was utilized to produce the PCC and LC³ cements on-site.

The energy needed for the complete calcination of the kaolinitic clay was determined through Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). The process took into account a vertical shaft kiln with a 23% fuel efficiency, and the total mass loss during calcination, obtained as 13% based on TGA results. This method aligns with the approach utilised by Pillai et al. 2019 and Malacarne et al. 2021 to calculate energy for complete calcination of clay.

Life cycle impact assessment

In this phase, the potential environmental impacts are calculated based on the inventory. This study considered only climate change, that is, global warming potential. The ReCiPe midpoint (H) methodology, included with the LCA software, was utilized to generate and report the results in CO_2 equivalents.

Unit process	Sub-process	Assumptions	Source
Ordinary Portland cement	Manufacturing	Cement, Portland (RoW) production| Alloc Def, U, used as proxy	Ecoinvent 3 database
	Transporting	Road distance = 74 km Transport = lorry, 16-32t	Ecoinvent 3 database
Calcined Clay	Mining and extraction	Kaolin (RoW) | production | Alloc Def, U used as a proxy dataset kaolin mining and extraction	Ecoinvent 3 database
	Crushing	Limestone, crushed, for mill (RoW) | production | Alloc Def, U used as proxy	Ecoinvent 3 database
	Transporting	Road distance = 62 km Transport = lorry, 16-32t	Ecoinvent 3 database
	Calcining	0.0475 KWh/kg clay Fuel efficiency of the vertical shaft kiln is 23%	TGA and DSC
	Transporting	Road distance = 94 km Transport = lorry, 16-32t	Ecoinvent 3 database
	Milling	Quicklime, milled, loose (RoW) | production | Alloc Def, U used as proxy	Ecoinvent 3 database
	Transporting	Road distance = 79 km Transport = lorry, 16-32t	Ecoinvent 3 database
Limestone	Manufacturing	Limestone, crushed, for mill (RoW) | production | Alloc Def, U used as proxy	Ecoinvent 3 database
	Transporting	Road distance = 60 km Transport = lorry, 16-32t	Ecoinvent 3 database

Table 2.1: Life cycle inventory data sources and assumptions used in the study for the 3 different types of cement.

Results and Discussion

The percentage contributions of total CO_2 emissions arising from different processes and constituents associated with the three types of cement; namely, ordinary Portland cement (OPC), OPC with 30% replacement with calcined clay (PCC), and limestone calcined clay cement (LC^3), are depicted in Figure 3.1. As expected, the results indicate that the clinker production stage emerges as the environmental 'hotspot' in all the cements. OPC has the highest impact, while LC^3 has the least impact due to their highest and lowest clinker contents, respectively. Ordinary Portland cement (CEM I) contains 95-100% clinker and 0-5% minor additional constituents (SANS 50197-1) while LC^3, in this study, contains 50% clinker. Several studies, including those by Huntzinger and Eatmon (2009), Chen et al. (2010), Pillai et al. (2019), and Ige and Olanrewaju (2023), have reported the same findings, highlighting that clinker production is the main contributor to CO_2 emissions in cement.

The analysis also indicates that calcined clay production process significantly contributes to PCC and LC^3 cements. However, the calcination process of clay requires a lower temperature of 600–800 °C (Sabir et al., 2001; Krajči et al., 2015; Shan et al., 2016) compared to 1450 °C for OPC production (Ige and Olanrewaju, 2023), resulting in lower environmental impacts.

The contribution to climate change, expressed in CO_2 equivalents for each of the cements being studied, is represented in Table 3.1. The results indicate that LC^3 has a significantly lower CO_2 impact compared to OPC and PPC, with CO2 emissions from LC^3 measured at 0.668 kg CO_2eq/kg of cement. Similar values have been reported in studies by Cancio Díaz (2017), Gettu et al. (2019), Malacarne et al. (2021), and Junior et al. (2023).

Cement	kg CO_2eq/kg of cement
OPC	1.01
PCC	0.835
LC^3	0.668

Table 3.1: CO2 emissions for each of the cement evaluated in the study.

The comparison of CO_2 emissions for OPC, blended cement PCC, and LC^3 is illustrated in Figure 3.2. OPC exhibits the highest CO_2 emissions, approximately 34% higher than LC^3 cement. These findings align with those reported by Malacarne et al. (2021), who observed reductions of up to 38% in CO_2 emissions compared to OPC, and Sanchez Berriel, who reported up to a 30% reduction in CO_2 emissions.

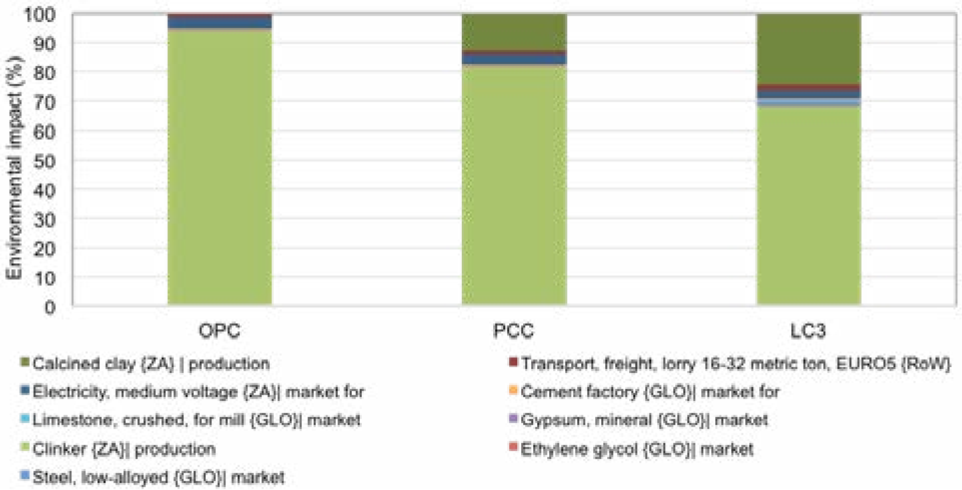


Figure 3.1: Climate change contribution analysis arising from different processes associated with the three types of cement in the study.

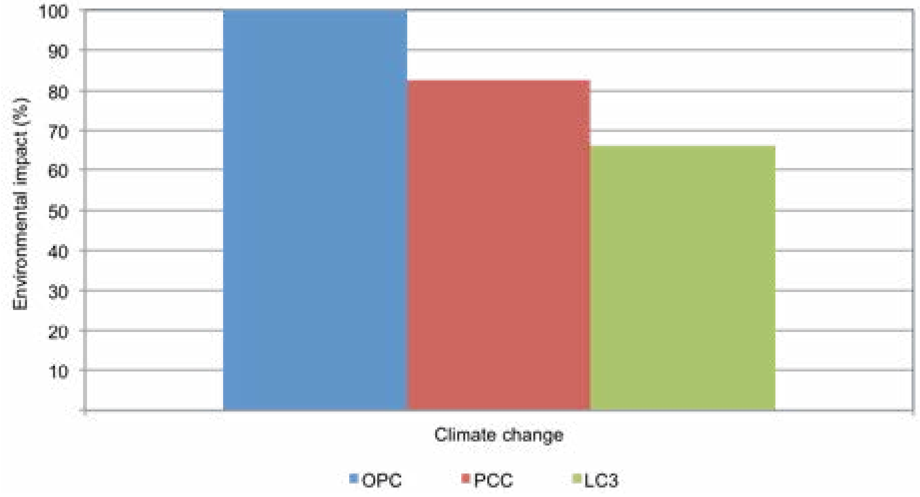


Figure 3.2: Relative CO2 emissions of cement production.

Conclusions

This study quantified and compared the CO_2 emissions associated with the production of ordinary Portland cement (OPC), OPC with 30% calcined replacement, and LC^3, comprising 50% clinker, 30% calcined clay, 15% limestone, and 5% gypsum. The results demonstrated that LC^3 exhibited significantly lower CO_2 emissions in comparison to both OPC and binary OPC with 30% calcined clay replacement. LC^3 displayed a substantial reduction in CO_2 emissions, up to 34% less than OPC and OPC with 30% calcined replacement. These findings emphasize the significant potential of LC^3 as an alternative ordinary Portland cement to meet the increasing demand for cement with a low carbon footprint in the cement industry.

References

- Alujas Díaz, A., Fernández, R., Quintana, R., Scrivener, K.L., and Martirena-Hernández, J.F., 2015, Pozzolanic reactivity of low grade kaolinitic clays: Influence of calcination temperature and impact of calcination products on OPC hydration. Applied Clay Science 108, 94–101.
- Antoni, M., Rossen, J., Martirena, F. and Scrivener, K., 2012, Cement substitution by a combination of metakaolin and limestone. Cement and Concrete Research 42,1579-1589
- Avet, F., Snellings, R., Alujas Díaz, A., Ben Haha, M., and Scrivener, K.L., 2016, Development of a new rapid, relevant and reliable (R3) test method to evaluate the pozzolanic reactivity of calcined kaolinitic clays. Cement and Concrete Research 85, 1–11
- Barbhuiya, S., Nepal, J., and Das, B.B., 2023, Properties, compatibility, environmental benefits and future directions of limestone calcined clay cement (LC^3) concrete: A review. Journal of Building Engineering 79, 107794
- Basavaraj, A.S., Muni, H., Dhandapani, Y., Gettu, R., and Santhanam, M., 2023, Limestone-Calcined Clay (LC2) as a supplementary cementitious material for concrete. RILEM Technical Letters 8, 12-22
- Blouch, N., Rashid, K., Zafar, I., Ltifi, M., and Ju, M., 2023, Prioritization of low-grade kaolinite and mixed clays for performance evaluation of Limestone Calcined Clay Cement (LC^3): Multi-criteria assessment. Applied Clay Science 243, 107080
- Bishnoi S., Maity S., Mallik A., Joseph S. and Krishnan S., 2014, Pilot Scale Manufacture of Limestone Calcined Clay Cement: The Indian Experience. Indian Concrete Journal 88(6), 22-28
- Cancio Díaz, Y., Sánchez Berriel, S., Heierli, U.,

Favier, A.U., Sánchez Machado, I.R., Scrivener, K.L., Martirena Hernández, J.F., and Habert, G., 2017, Limestone calcined clay cement as a low-carbon solution to meet expanding cement demand in emerging economies. Development Engineering 2, 82–91

- Chen, C., Habert, G., and Bouzidi, Y., 2010, Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. Journal of Cleaner Production 18, 478–485
- Dumani, N., and Mapiravana, J., 2017, Production of metakaolin as a partial cement replacement using a vertical shaft kiln. In: The Green Building Handbook South Africa: The Essential Guide 11, 131-140
- Ekosse, G.-I.E., 2010, Kaolin deposits and occurrences in Africa: Geology, mineralogy and utilization. Applied Clay Science 50, 212–236
- Emmanuel, A., Halder, P., Maity, S., and Bishnoi, S., 2016, Second pilot production of limestone calcined clay cement in India: the experience, Indian Concrete Journal 90, 57–64.
- Expert Market Research, 2023, South Africa Cement Market Outlook, Available at: https://www.expertmarketresearch.com/reports/south-africa-cement-market, [accessed: 23 June 2023]
- Gettu, R., Pillai, R.G., Santhanam, M., Rathnarajan, S., Basavaraj ,A.S., Rengaraju, S., and Yuvaraj, D., 2018, Service Life and Life-Cycle Assessment of Reinforced Concrete with Fly ash and Limestone Calcined Clay Cement. Sixth International Conference on Durability of Concrete Structures, University of Leeds, Leeds, West Yorkshire, LS2 9JT, United Kingdom
- Gettu, R., Patel, A., Rathi, V., Prakasan, S., Basavaraj, A. S., Palaniappan, S. Maity, S., 2019, Influence of supplementary cementitious materials on the sustainability parameters of cements and concretes in the Indian context. Materials and Structures 52(10), 1-11
- Huang, G., Zhuge, Y., Benn, B.T., and Liu, Y., 2023, Environmental Assessment of Limestone Calcined Clay Cement in Australia. IOP Conference Series: Materials Science and Engineering 1289, 012082
- Huang, Z., Deng, W., Zhao, X., Zhou, Y., Xing, F., Hou, P., and Chen, C., 2023, Shear design and life cycle assessment of novel limestone calcined clay cement reinforced concrete beams. Structural Concrete 24, 5063–5085
- Huntzinger, D.N., and Eatmon, T.D., 2009, A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. Journal of Cleaner Production 17, 668–675
- Ige, O. E., and Olanrewaju, O.A., 2023, Comparative Life Cycle Assessment of Different Portland Cement Types in South Africa. Clean Technologies 5, 901–920.
- ISO/SANS 14040:2006. Environmental management – Life cycle assessment – Principles and framework. South African National Standard
- ISO/SANS 14044:2006. Environmental management – Life cycle assessment – Requirements and guidelines. South African National Standard
- Jaskulski, R., Jóźwiak-Niedźwiedzka, D., and Yakymechko, Y., 2020, Calcined Clay as Supplementary Cementitious Material. Materials 13, 4734; doi:10.3390/ma13214734
- Joseph, S., Bishnoi, S and Maity, S., 2016, An economic analysis of the production of limestone calcined clay cement in India (Technical paper). The Indian Concrete Journal 90 (9), 1-6
- Junior, E.S.A., de Sales Braga, N.T., and Barata, M.S., 2023, Life cycle assessment to produce LC^3 cements with kaolinitic waste from the Amazon region, Brazil. Case Studies in Construction Materials 18, e01729
- Krajči, L., Mojumdar,S.C., Janotka, I., Puertas, F., Palacios, M. and Kuliffayová , M., 2015, Performance of composites with metakaolin-blended cements. Journal of Thermal Analysis and Calorimetry,119, 851-863
- Malacarne, C.S., da Silva, M.C.R., Danieli, S., Maciel, V.G., and Ana Paula Kirchheim, A.P., 2021, Environmental and technical assessment to support sustainable strategies for limestone calcined clay cement production in Brazil. Construction and Building Materials 310, 125261
- Martinez, D.M., Horvath, A., and Monteiro, P.J.M., 2023, Comparative environmental assessment of limestone calcined clay cements and typical blended cements. Environmental Research Communications 5, 055002
- Musbau, K.D., Kolawole, J.T., Babafemi, A.J., and Olalusi, O.B., 2021, Comparative performance of limestone calcined clay and limestone calcined laterite blended cement concrete. Cleaner Engineering and Technology 4, 100264
- Pillai, R.G., Gettu, R., Santhanam, M, Rengaraju, S., Dhandapani, Y, Rathnarajan, S., and Basavaraj, A.S., 2019, Service life and life cycle assessment of reinforced concrete systems with limestone calcined clay cement (LC^3). Cement and Concrete Research 118, 111–119
- Qian, X., Ruan, Y., Jamil, T., Hu, C., Wang, F., Hu, S., and Liu, Y., 2023, Sustainable cementitious material with ultra-high content partially calcined limestone-calcined clay. Construction and Building Materials 373, 130891
- Rashad, A.M., 2013, Metakaolin as cementitious material: History, scours, production and composition – A comprehensive overview. Construction and Building Materials 41, 303-318
- Rodrigues, A.L.M.V, Mendes, Á.ÁF., Gomes, V., Battagin, A.F., Saade, M.R.M., and Da Silva M.G. 2022, Environmental and Mechanical Evaluation of Blended Cements with High Mineral Admixture Content. Frontiers in Materials 9, 1-11
- Sabir, B.B., Wild, S. and Bai, J., 2001, Metakaolin and calcined clays as pozzolans for concrete: a review. Cement and Concrete Composites 23, 441-454
- Saint-Gobain, 2017, Why and how (Sustainable) buildings can actually save the world. Available at: https://www.linkedin.com/pulse/why-how-sustainable-buildings-can-actually-save-world-camille-fabre/, [accessed: 15 September 2023]
- Sánchez Berriel, S.S., Favier, A., Rosa Domínguez, E., Sánchez Machado, I.R., Heierli, U., Scrivener, K., Martirena Hernández, F., and Habert, G., 2016, Assessing the environmental and economic potential of Limestone Calcined Clay Cement in Cuba. Journal of Cleaner Production 124, 361-369
- SANS 50197-1:2013, Cement Part 1: Composition, specifications and conformity criteria for common cements. South African National Standard
- Scrivener, K., Martirena Hernández, F., and Habert, G., 2016, Assessing the environmental and economic potential of Limestone Calcined Clay Cement in Cuba. Journal of Cleaner Production 124, 361-369
- Scrivener, K., Martirena, F., Bishnoi, S., and Maity, S., 2018, Calcined Clay as Supplementary Cementitious Material (LC^3). Cement and Concrete Research 114, 49–56
- Shan, C.S., Rijuldas, V., and Aiswarya, S., 2016, Effects of metakaolin on various properties of concrete – an overview. International Journal of Advanced Technology in Engineering Science 4(1), 237-245
- Sharma, M., Bishnoi, S., Martirena, F., and Karen Scrivener, K., 2021, Limestone calcined clay cement and concrete: A state-of-the-art review. Cement and Concrete Research 149, 106564
- Si-Ahmed, M., Belakrouf, A., and Kenai, S., 2012, Influence of metakaolin on the performance of mortars and concretes. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering 6 (11), 1010-1013
- Suryawanshi, Y.R., Kadam, A.G., Ghogare, S.S., Ingale, R.G. and Patil, P.L., 2015, Experimental study on compressive strength of concrete by using metakaolin. International Research Journal of Engineering and Technology 2(2), 235-239
- UN Environment, Scrivener, K.L., John, V.M., and Gartner, E.M.,2018, Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. Cement and Concrete Research 114, 2–26.
- UNFCC, 2023, The Paris Agreement, Available at: https://unfccc.int/process-and-meetings/the-paris-agreement, [accessed: 22 September 2023]
- Vizcaîno-Andreìs L.M., Saìnchez-Berriel S., Damas-Carrera S., Peìrez- Hernaìndez A., Scrivener K.L., and Martirena-Gonzaìlez J.F., 2015, Industrial Trial to Produce a Low Clinker, Low Carbon Cement. Materiales de Construcción 65,1-11
- Wild, S., Khatib, J.M., and Jones, A., 1996, Relative strength, pozzolanic activity and cement hydration in superplasticised metakaolin concrete. Cement and Concrete Research 26(10), 1537-1544
- Zhang, D., Jaworska, B., Zhu, H., Dahlquist, K., and Li, V.C., 2020, Engineered Cementitious Composites (ECC) with limestone calcined clay cement (LC^3). Cement and Concrete Composites 114, 103766
- Zhou, Y., Gong, G., Xi, B., Guo, M., Xing, F., and Chen, C., 2022, Sustainable lightweight engineered cementitious composites using limestone calcined clay cement (LC^3). Composites Part B 243, 110183

Performance of geopolymer concrete subjected to mineral acid tests in static and dynamic conditions

Mandla Dlamini & Mark Alexander, University of Cape Town, Engineering and the Built Environment, South Africa; CSIR Smart Places, Pretoria South Africa.

Geopolymer cements are an emerging alternative binder to Portland cements, characterised by an alumino-silicate polymer network nanostructure. These binders are purported to possess numerous beneficial properties such as acid resistance and a relatively low carbon footprint. This study sought to assess the performance of a fly ash-based geopolymer concrete developed at the CSIR, exposed to mineral acids (HCl and H2SO4) under static and dynamic exposure conditions. Portland cement and calcium aluminate cement concretes using calcareous aggregates (dolomite) were used as control specimens, while geopolymer cements were mixed with a range of calcareous and siliceous aggregates. The test results show that the resistance of geopolymer concretes exposed to hydrochloric acid in dynamic and static conditions is significantly higher than Portland cement and calcium aluminate cement concretes, where mass loss was used as a measure. The study also shows that the acid resistance of geopolymers can be further improved by combining them with siliceous aggregates instead of calcareous aggregates. Furthermore, a linear empirical relationship, between basicity (related to the major acidic and basic oxides established via XRF) and the rate of dissolution of concrete in acidic solutions was observed. Basicity was also related to preferential corrosion in concrete mixtures exposed to the dynamic HCl test, and it was found that the difference in the basicity of the paste and aggregate of concrete mixture was useful in determining the type and extent of preferential corrosion.

Keywords: Geopolymers, sulfuric, hydrochloric, acid, resistance.

1. BACKGROUND

The advent of alternative concrete binders such as geopolymers has resulted in the need for the benefits of these materials to be defined and quantified. Amongst the stated benefits of geopolymers is high resistance to acid attack [1] [2]. Acid resistance is a desirable property for concrete structures such as outfall sewers, which are often plagued by a severe type of degradation known as microbially-induced corrosion (MIC). While MIC is known to be more severe in warm climates, the problem has also been reported in cooler countries such as Germany, where a study of the sewer network revealed that MIC was responsible for approximately 40% of all sewer failures [3].

MIC is a highly complex problem wherein the complexity emanates from a large set of variables encountered in the sewer environment, in which the variables include, temperature, effluent flow characteristics, the sewer microbiome, concrete material properties, and concrete corrosion products.

Because MIC is a durability problem, it is useful to describe a material's resistance to MIC in relation to the definition of durability. In the context of durability, resistance to MIC relates to a concrete structure's ability to remain serviceable during its planned life [4]. Thus, in this context, a MIC resistant material need not necessarily be chemically resistant to acids. It is therefore of interest to establish which material properties contribute to MIC resistance.

It is suggested that the MIC resistance properties of a material be categorised into chemical, physical and biological properties (Figure 1-1).

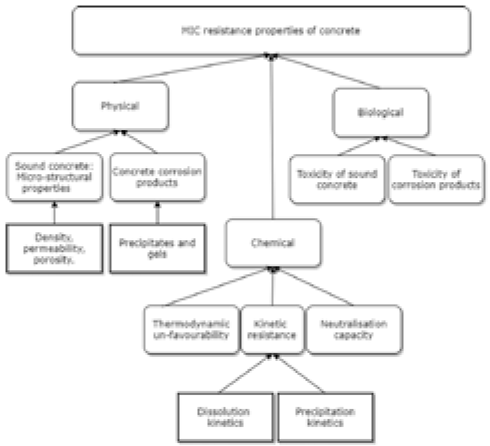


Figure 1-1: Suggested MIC resistance properties of concrete

A significant chemical property related to MIC resistance is the kinetics of the sulfuric acid corrosion reaction. Given that different materials react at different rates with sulfuric acid [5], it is suggested that materials which corrode at slower rates, possess a type of MIC resistance related to the kinetics of the corrosion reaction. At the fundamental chemical level, geopolymers are suggested by researchers to degrade via depolymerisation of aluminosilicate polymers and liberation of silicic acid, replacement of Na and K cations by hydrogen or hydronium ion and dealumination of the geopolymer structure [1].

Furthermore, the capacity of a material to neutralise a specific amount of acid is also an important chemical material property and is dependent on the stoichiometry of the corrosion reaction [5]. For instance, calcium aluminate cements (CAC) have been reported to possess a 40% higher neutralisation capacity than Portland cements [6] [7]. For the range of thermodynamic conditions present in sewers, it is also possible that some components of concrete such as compounds found siliceous aggregate are insoluble in sulfuric acid, thus making them inert due to the unfavourable thermodynamics of the corrosion reaction. Thus, the set of chemical properties of concrete important for understanding MIC performance are, on their own, highly complex.

Researchers have also advanced the notion that materials differ in their receptivity to bacteria and have suggested that some materials possess properties which enable a bacterio-static effect, which kills or stifles the growth of acid producing bacteria [6]. The bacterio-static effect is contentious because is difficult to measure. Studies attempting to measure the differences in corrosion where materials with purported biocidal properties have not yielded statistically significant results in the sewer environment. [8] [9]. Adding more complexity to the bacterio-static effect is that in some binders, the effect emanates not from the binder itself but from its corrosion products. For example, with CAC concretes, the bacterio-static effect is reported to emanate from the toxicity of aluminium ions liberated from gel (AH3) when the surface pH of the concrete drops below 4 [6].

The physical properties of concrete also affect MIC resistance. A dense, impermeable micro-structure is suggested to improve resistance to MIC [8] [10]. Furthermore, insoluble corrosion products are also understood to provide a degree of protection to concrete subjected to MIC. For example, gypsum has been suggested to provide some degree of protection to MIC when Portland cements (PC) concretes are subjected to MIC [11]. This protection is achieved by gypsum coating the corroding surface and providing a physical barrier between the acidic solution and fresh attacks surfaces. Similarly, during the MIC of CAC concretes it has been suggested alumina gel (AH3) provides a physical barrier to corrosion by coating the surface of the concrete [7].

With these forms of resistance identified, it is of interest to see which resistance properties can be measured in accelerated laboratory tests. It is proposed that the mineral acid tests used in this study may be used to assess two specific MIC resistance properties. The first property is related to concrete's chemical stability in acidic solutions, and measures the rate at which concrete constituents are dissolved in acid. This type of resistance to MIC is also applicable to any form of acid based corrosion. Researchers [9] suggest that corrosion process is governed by two distinct sequential steps, dissolution and precipitation, and that these steps often overlap and occur at different rates. Furthermore, it is suggested that the rate if dissolution in acidic solutions is largely controlled by the pH of the solution and not the specific acid species [10].

In terms of the MIC of concrete, dissolution represents the first step in the damage of concrete. Given that concrete is a composite heterogeneous material, a useful rate of dissolution is likely to be an aggregated rate, wherein it accepted that the constituents that make concrete may dissolve at different rates.

A practical problem encountered in the measurement of the rate of dissolution is that the precipitation step of corrosion overlaps ongoing dissolution resulting in the deposition of precipitates at the surface of the corroding concrete specimen [9]. Furthermore, precipitation may, in cases where corrosion occurs in a closed system, cause a repression of the dissolution step by saturating the acidic solution, which in turn results in a higher concentration of dissolved ions and ultimately stalls the dissolution reaction through the common ion effect [6].

To address this problem for Portland cement concretes, Fourie [12] suggested the use of HCl which produces soluble CaCl2 instead of H2SO4 which produces insoluble CaSO4. However, not all HCl corrosion products are immediately insoluble. For instance, the corrosion reaction of HCl and CAC paste produces alumina gel (AH3) as a corrosion product.

Therefore, to negate the stifling effects of precipitating corrosion products to the dissolution reaction, a means by which the corrosion products may be removed from fresh attack surfaces is required. It is suggested here that the dynamic HCl test developed at the University of Cape Town is a test suited to measuring the rate of dissolution for common concrete materials. The test involves immersion concrete in HCl at pH 1 and simultaneously exposes the surface of the rotating cylindrical specimen to brushing. Moreover, it suggested that brushing serves to remove corrosion products forming on the surface of a rotating cylindrical concrete specimen thereby eliminating any protection to sound concrete.

It is also useful to quantify the protective effects of precipitates forming on the surface of concrete. To this end, a static immersion test was used in which concrete specimens were immersed in HCl at pH 1. It is important to note that the primary difference between the dynamic acid test and the static acid test is the brushing, or physical removal of precipitates forming on the surface of the specimen tested in the dynamic acid test. Therefore, by measuring a parameter related to corrosion, such as mass loss over time in each test, the difference in the corrosion rates between the two tests enables a quantification of the protective effects of precipitates formed on the surface of concrete subjected to acid attack.

Thus the two, MIC resisting properties of geopolymer concrete and the control concrete mixes (Portland cement and calcium-aluminate cement concretes) assessed in this study are suggested to be the resistance to dissolution and the physical protection afforded by corrosion products precipitating on the surface of corroding concrete. These two properties were assessed using the dynamic acid test and the static acid test.

2. MATERIALS AND METHODS

2.1 Binders

A fly ash based geopolymer cement developed by the CSIR was the primary subject of testing. Portland cement and calcium aluminate cement were used as control binders because they have been used extensively in sewer concrete infrastructure. Thus, corrosion data from real sewers have been obtained for these two cement types, making them suitable for comparison with geopolymers.

Cement type and origin	Relative density	Loose bulk density (kg/m^3)
CEM I, 52.5 R, Portland cement from PPC	3.1	1260 kg/m^3
Cement Fondu-calcium aluminate cement (Brand: Imerys)	3.3	1370 kg/m^3
Fly ash-based geopolymer cement developed by CSIR Smart Places.	2.5	1020 kg/m^3

Table 2-1: Binders used in concrete mixtures

2.2 Aggregates

Two classes of aggregate were used in the experimental program, namely siliceous and calcareous aggregates. Five types of aggregate in total were collected to for use in the concrete mixes. Four siliceous aggregate types were sourced from AfriSam's quarries located in Gauteng, South Africa. Dolomite, the only calcareous aggregate used, was sourced from Lyttleton quarry in Centurion, Gauteng.

Because this study characterised aggregates and pastes separately, no blending of aggregates from different sources or types was permitted in the mix design of concrete mixtures. Therefore, for the purpose of mix design, both fine (crusher sand) and coarse fractions (stone) from were collected from each quarry.

dynamic acid testing and Table 2-4 for specimens intended for static acid testing.

The mix designs shown below are adaptations of previous mixes prepared for evaluation in the VES [10] [11]. Of significance is that these mixes deliberately had relatively high binder contents (23% by mass) because binder type was a primary concern to studies in the VES.

Specimens prepared for static tests in this study did not include coarse aggregate because the 50 mm mould size used to cast the concrete cubes was limiting. However, the same binder to aggregate ratio was maintained.

Since corrosion occurs on an attack surface in concrete, it follows that comparing acid resistance of mix designs where the mix proportions of competing systems are equivalent by mass, is less suitable than a mix design based on volume because the generally accepted measure of corrosion in sewer pipes is dimensional (mm/yr).

Aggregate	Aggregate type	Source quarry	Relative density
Dolomite	Calcareous	Olifantsfontein	2.86
Ferro-quartz	Siliceous	Ferro (Pretoria)	2.6
Andesite	Siliceous	Eikenhof	2.94
Dolerite	Siliceous	Rooikraal	3.0
Granite	Siliceous	Roodekrans	2.67

Table 2-2: Aggregates used in concrete mixtures

2.3 Concrete mix designs

To enable a meaningful basis for comparison of the concretes considered in this study, the proportions of binder (cement), fine aggregate (crusher sand), and coarse aggregate (stone) were kept constant for the control mixes (PC and CAC) in the proportions provided in Table 2-3 for specimens intended for

Ideally, if competing concrete binder systems are to be compared, the proportions of the binder of competing systems as measured in terms of area across the attack surface should be relatively similar. It follows then, that mix proportions of the competing mix designs should be volumetrically similar. This is especially important

Concrete mix component	Proportion as a percentage of total mass	Mix Ratio (by mass)
CAC/PC	23%	1
Fine aggregate (sand)	33%	1.43
Coarse aggregate (stone)	44%	1.92
Ratio of fine to coarse aggregate by mass	43:57	
Water-cement ratio	0.35	

Table 2-3 : Mix design of control specimens used in dynamic acid tests and mechanical strength testing

Concrete mix component	Proportion as a percentage of total mass	Mix Ratio (by mass)
CAC/PC	23%	1
Fine aggregate (sand)	77 %	3.35
Water-cement ratio	0.37	

Concrete mix design of control specimens used in static acid tests

if there is significant variation in the relative densities of the competing concrete mixes.

Since the relative density of fly ash-based geopolymer concrete is significantly (by 25%) lower than that of PC and CAC, the mass proportion of fly ash based geopolymer was reduced to ensure that the of the volume of the GP binder was approximately equal to the CAC and PC binders in the competing concrete mixes. Thus, the binder mass in the GP specimens was specified to be 75% of the mass used in CAC and PC concrete mixes. The mass proportion of GP binder thus was adjusted to 17% (vs 23%) of the total mix by mass while the coarse and fine fractions of aggregate were adjusted upwards while keeping the coarse/fine aggregate proportions constant.

2.4 Material characterisation

Hardened cement paste and aggregate were separately analysed via X-ray fluorescence (XRF). The purpose of XRF analysis was to determine the elemental composition of the hardened cement pastes and aggregate. Furthermore, XRF analysis software was used to determine the proportions of major oxides in the aggregate and hardened cement paste. Corrosion performance and chemical composition suggested to be strongly related, and chemical elements such as calcium have been reported to influence corrosion behaviour significantly [2] [10]. Furthermore, the hardened cement pastes were assessed using SEM to observe corrosion at the micro and nano scale.

Concrete mix component	Proportion as a percentage of total mass	Mass Mix Ratio (by mass)
Fly ash based geopolymer	17%	1
Fine aggregate (sand)	35.5%	2.1
Coarse aggregate (stone)	47.5%	2.79
Ratio of fine to coarse aggregate by mass	43:57	
Geopolymer liquids to geopolymer solids ratio	0.35	

Table 2-5 : Mix design of geopolymer concrete specimens used in dynamic acid tests and mechanical strength testing

As with the control (CAC and PC) mixes, GP concretes prepared for static tests did not include coarse aggregate because the 50 mm mould size was limiting.

2.5 Static acid test

The process involved in producing the specimens was intended to simulate the industrial process of concrete

Concrete mix component	Proportion as a percentage of total mass	Mass Mix Ratio
Fly ash based geopolymer	17%	1
Fine aggregate (sand)	83 %	4.89
Geopolymer solids to geopolymer liquids ratio	0.37	

Table 2-6: Mix design of geopolymer concrete specimens used in static acid tests

sewer pipe manufacturing. The ordinary concrete and calcium aluminate concrete specimens were steam cured for 4 hours at 80 degrees Celsius until set, there after they were water cured for 28 days. Similarly, geopolymer specimens were cured 80 degrees Celsius in humidity sealed bags, and thereafter cured at ambient temperature in moisture sealed containers. There after the specimens were testing in both static and dynamic acid testing conditions.

Mineral acid attack under static conditions involved placing 50 mm concrete cubes in hydrochloric acid bath. The pH was maintained between 1 and 1.1 by adding concentrated acid into the PVC vessel while measuring the pH using a calibrated pH meter. Furthermore, the acidic solution was fully replaced every 24 hours.

The concrete cube specimens were first placed in water for 4 hours and their saturated surface dry mass was recorded together with their dimensions. Four cubes of the same type are placed into 5 Litres of acid (HCl) solution of pH 1.

Four concrete specimens of each mix design were placed in a container and submerged in 5 litres of pH 1 acid solution. Therefore, the total initial surface area subjected to acid attack for each specimen was 150 cm2, and the total initial surface area of concrete specimens within a bucket containing 5 litres of pH 1 acid was 600 cm2. The ratio of concrete specimen's initial surface area to the volume of pH 1 HCl solution is 0.12 m2/m3 (600cm2/5000cm3).

placed 12 cylindrical concrete specimens contained in a 60-litre vessel. The corroding concrete surface to acidic solution ration used in a similar study was calculated to be 0.16 m2/m3 [12].

Care was taken during mass measurement not to unintentionally abrade the specimens as this test was meant to measure the material removed from the specimen without disturbing any protective precipitates or gels that formed as a result of corrosion. The mass of specimens was recorded every 6-8 hours for the duration of the experiment which ranged from 300 to 800 hours for various mixes. The mass of the specimens was monitored by measuring each specimen's mass individually and then taking the average of at least three readings as the representative reading.

2.6 Dynamic acid test

The most relevant previous work related to this test method was undertaken by Fourie [14] and Motsieloa [9]. Originally developed by Fourie [14] at the University of Cape Town, this test has was intended to simulate the corrosion condition at the effluent line. However, in this study, it is suggested that it is more suited to assessing the kinetic resistance to dissolution of concrete in acidic solutions.

This test involves subjecting concrete specimens to both acid attack and brushing simultaneously. The dynamic HCl test was conducted on all 7 concrete mixes and is typically conducted over 48 hours,

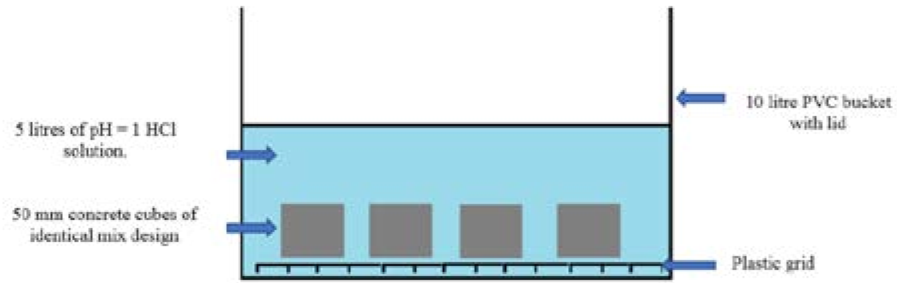


Figure 2-1 : Static test configuration

This experimental arrangement provides a relatively low surface area per unit volume of acid solution. In comparison, Xiao et al (2016) when conducting a sulfuric acid immersion test on concrete specimens,

however clear trends and satisfactory results were achieved for most specimens within 24 hours in this study as well as previous studies [9] [14]. In addition to HCl, three concrete mixes (GP-ferro-quartz, GP-granite

GREEN BUILDING

and GP-andesite) with low calcium content were also subjected to H2SO4 in the dynamic test.

Cored cylindrical concrete specimens (78 mm diameter × 125 mm were pre-saturated with tap water for four hours and the acid tank was filled with 50 ℓ of a hydrochloric or sulfuric acid solution (pH=1).

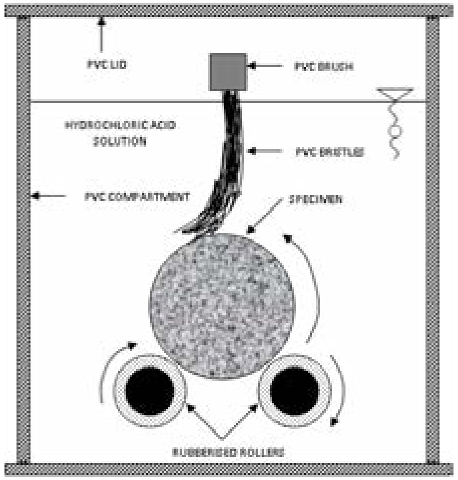


Figure 2-2 : Dynamic HCl/H2SO4 test

Thereafter the cores were immersed in the acid tank and rotated at approximately 16 revolutions per minute over rubberised rollers driven by pulleys connected to an electric motor. A brush with PVC bristles was lowered onto the surface of the specimen to dislodge any loose erodible material forming at the surface of the specimen (Figure 2-2).

Measurements of the mass of the specimen were measured every 2 hours and a pH of between 1.0 and 1.1 was maintained for the duration of the test. The acid solution was renewed daily for tests that were conducted for durations longer than 24 hours.

3. RESULTS

3.1 Static acid test results

Because the corrosion performances of the 7 mixes tested under the static and dynamic acid tests varied significantly, to maintain a reasonable resolution in data, the results are presented two clusters of mixes of the same order of acid resistance. Furthermore, in addition to the mass loss over time graphs, the corrosion performance is also presented in terms of the proportion (%) of mass lost over time. The rationale for providing the corrosion in these two formats is because the rate of mass loss is estimated by linear regression of the specimens mass loss over time, while the proportion (%) of original mass over time gives a better indication of the relative performance of each specimen. This is especially important because mass loss on its own may be misleading if the densities of the concrete mixes differs substantially.

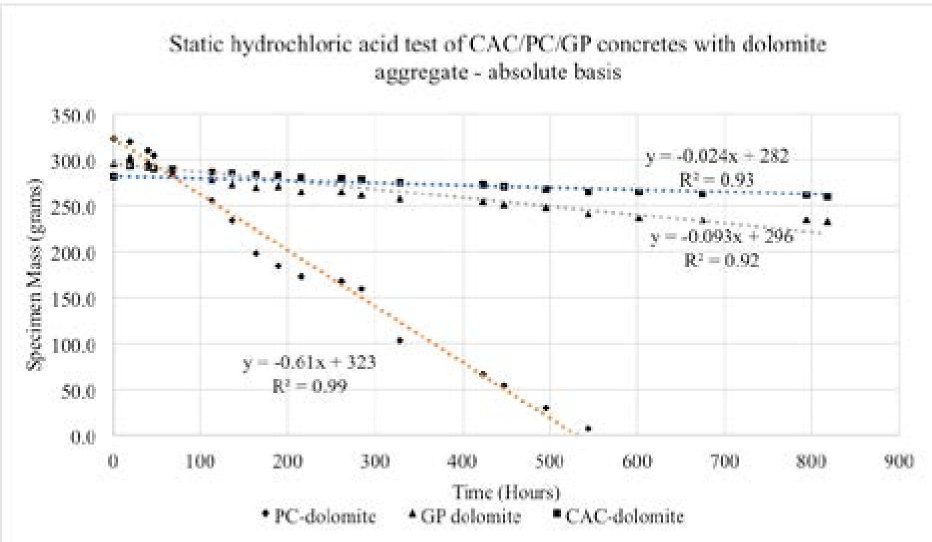


Figure 3-1: Mass loss of CAC/PC/GP concretes with dolomite aggregate in the static hydrochloric acid

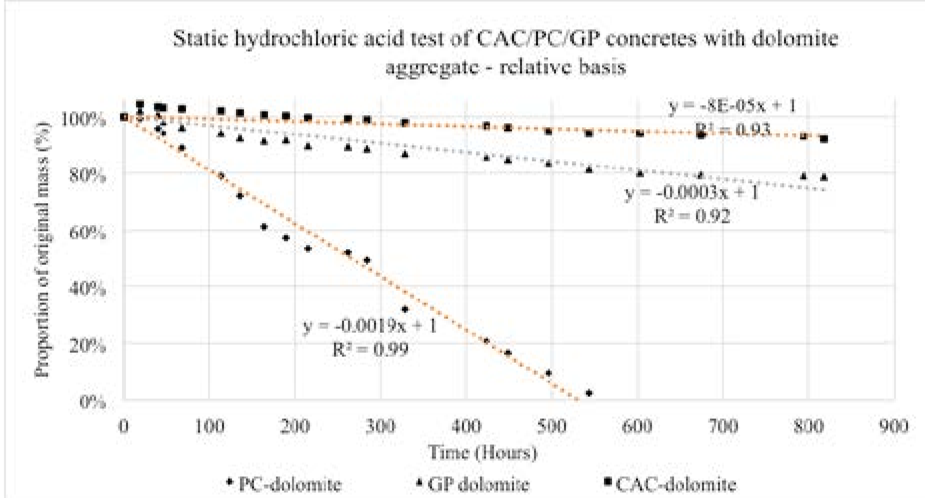


Figure 3-2: Proportion (%) of CAC/PC/GP concretes with dolomite aggregate in the static hydrochloric acid

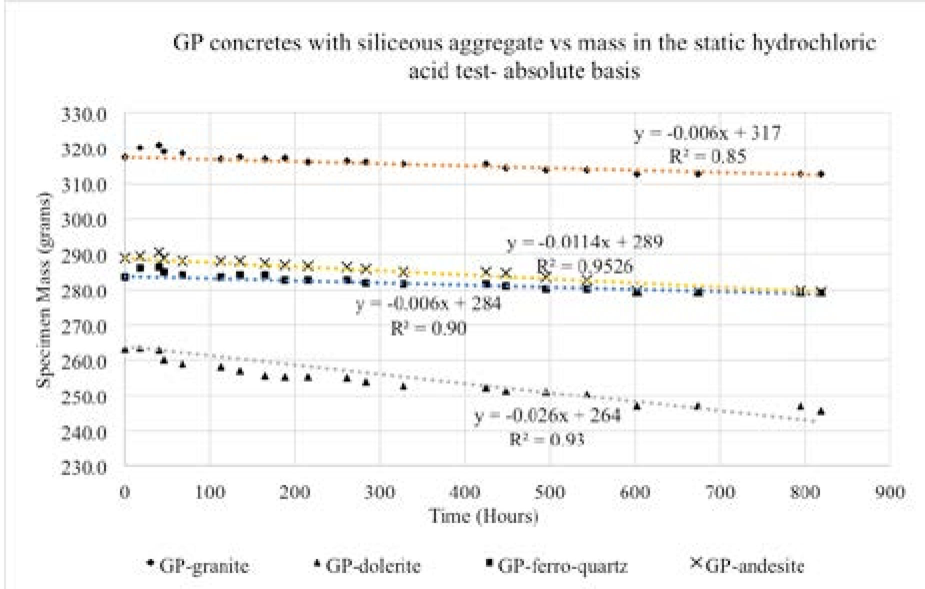


Figure 3-3 : Static hydrochloric acid test of GP concretes with siliceous aggregate

The static test reveals that the CAC-dolomite mix is the most acid resistant mix when immersed in HCl under static conditions. By the 550th hour of immersion, PC-dolomite is completely dissolved whereas CAC-dolomite and GP-dolomite retained 92% and 79% of their original masses, respectively.

The next cluster of result is GP concrete using various siliceous aggregates. These specimens generally had a much lower rate of mass loss over the 800 hour period while immersed in pH 1 HCl, with the most resistant mix, GP-ferro-quartz, retaining more than 98% of its original mass and the least resistant mix, GP-dolerite, retaining 93% of its original mass.

3.2 Dynamic acid tests (HCl)

Results from the dynamic HCl test are also presented in the same clustered fashion as the static acid test results. Because the dynamic HCl test is much more

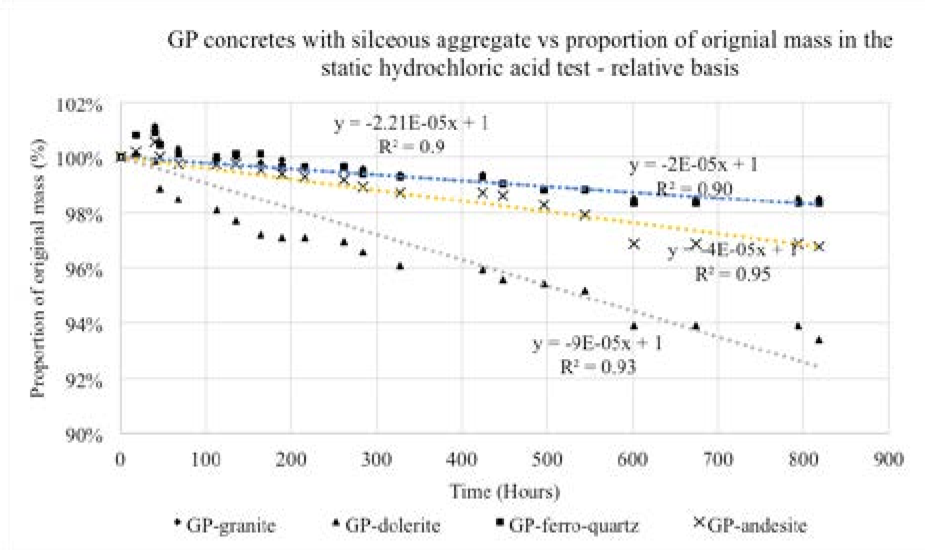


Figure 3-4 : Proportion (%) of CAC/PC/GP concretes with dolomite aggregate in the static hydrochloric acid

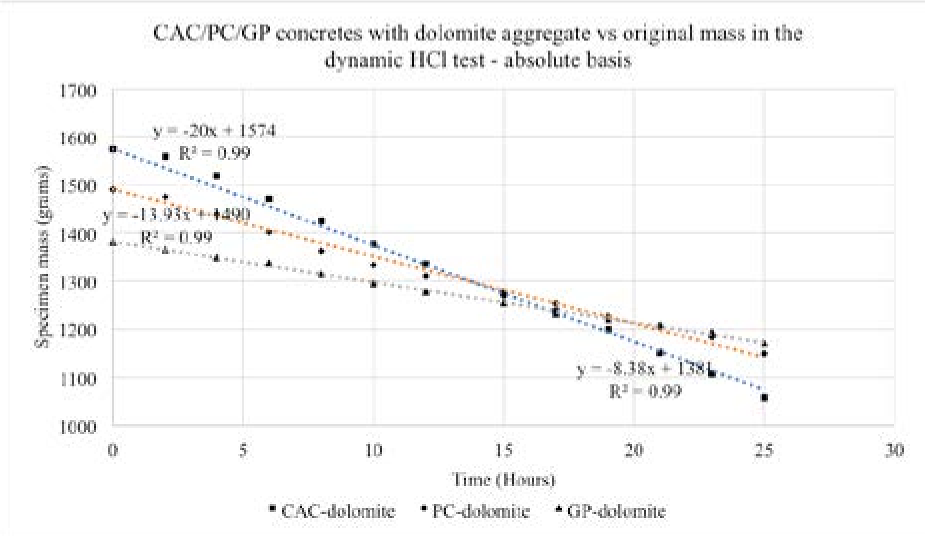


Figure 3-5: Dynamic hydrochloric acid test of CAC/PC/GP concretes with dolomite aggregate vs mass

aggressive, trends in mass loss were established over between 20 and 50 hours of testing.

The first cluster of results compares GP-dolomite, CAC-dolomite and PC-dolomite concrete mixes. Under this test CAC-dolomite is the most severely attacked mix, retaining 67% of its original mass over the 25 hour testing period whereas PC-dolomite and GP-dolomite retained 77.2% and 84.7% of their masses, respectively. A notable difference in the results between the dynamic HCl test and the static HCl test is that the order in performance between the PC-dolomite and CAC-dolomite concrete mixes is reversed.

Geopolymer concretes tested under the dynamic HCl test display high resistance in the dynamic HCl test compared to CAC and PC mixes. GP-ferro-quartz exhibited the lowest rate of mass loss over the test duration retaining 99.72% of its original mass after 48 hours of testing .Figure 3-8 shows that of the set

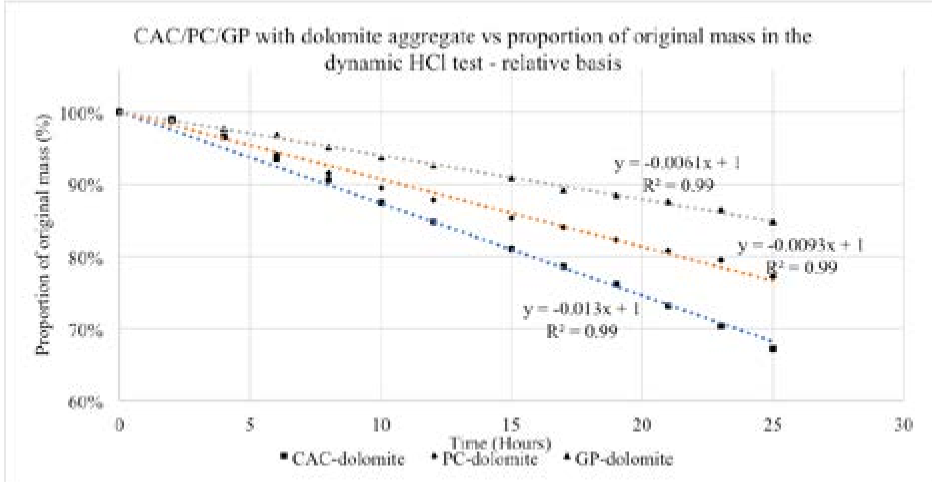


Figure 3-6: Dynamic hydrochloric acid test of CAC/PC/GP concretes with dolomite aggregate vs proportion of original mass

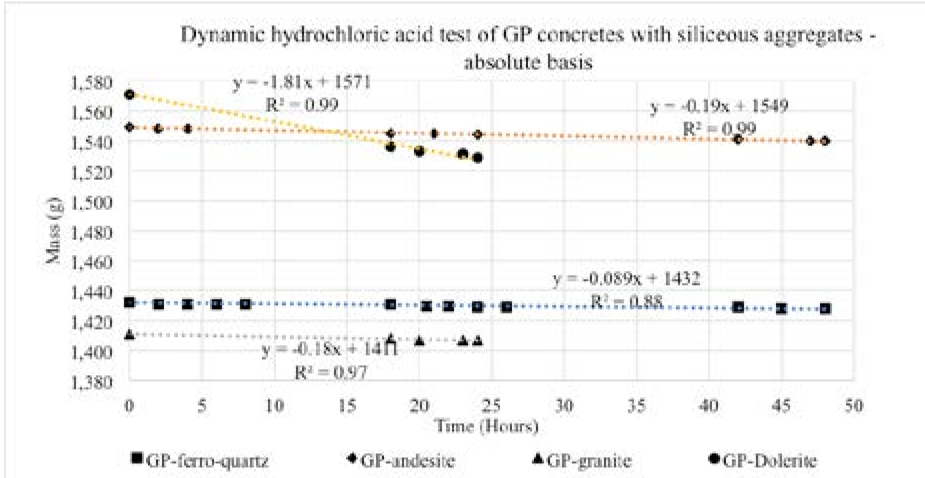


Figure 3-7: Dynamic hydrochloric acid test of GP concretes with siliceous aggregate vs mass

of GP-siliceous aggregate mixes, GP-dolerite was corroding at a substantially faster rate, which indicates a higher acid solubility of dolerite aggregate.

rate of dissolution since work by Gay et al [12] suggests the rate of dissolution is not a function of acid type but of the pH of the solution. Thus, if both these claims

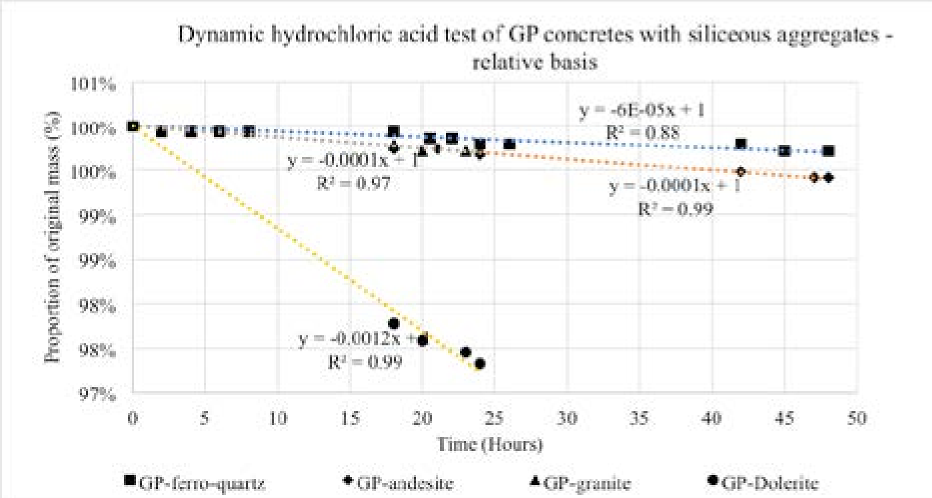


Figure 3-8: Dynamic hydrochloric acid test of GP concretes with siliceous aggregate vs proportion of original mass

3.2 Dynamic acid tests (H2SO4)

The low calcium systems were useful because they enabled a comparison between the corrosion rates in HCl and H2SO4. This test could also be used to test the hypothesis that the dynamic test is an indicator of the are true there should be minimal difference in the corrosion rates of these mixes in HCl and H2SO4 when tested under dynamic conditions.

Figure 3-10 and Figure 3-11 show that the test was conducted over 150 hours compared to the 48

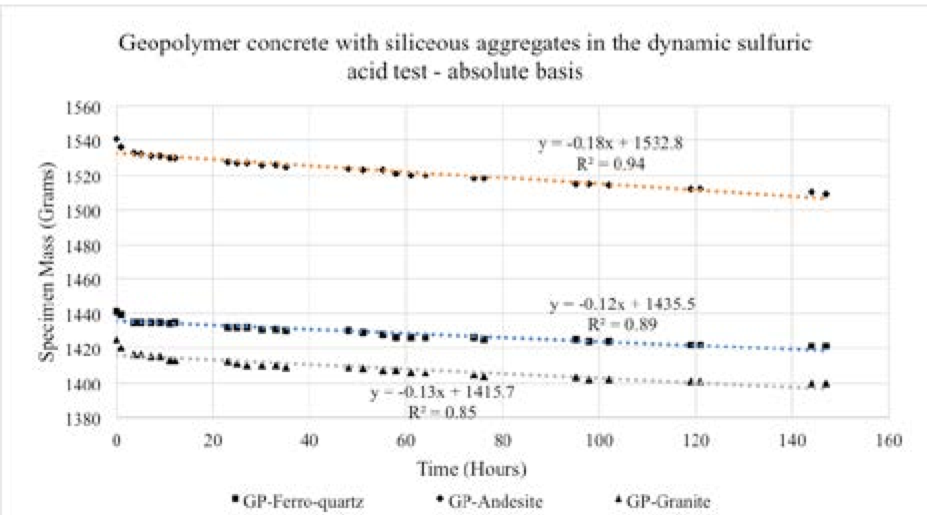


Figure 3-9: Dynamic sulfuric acid test of GP concretes with siliceous aggregate vs mass

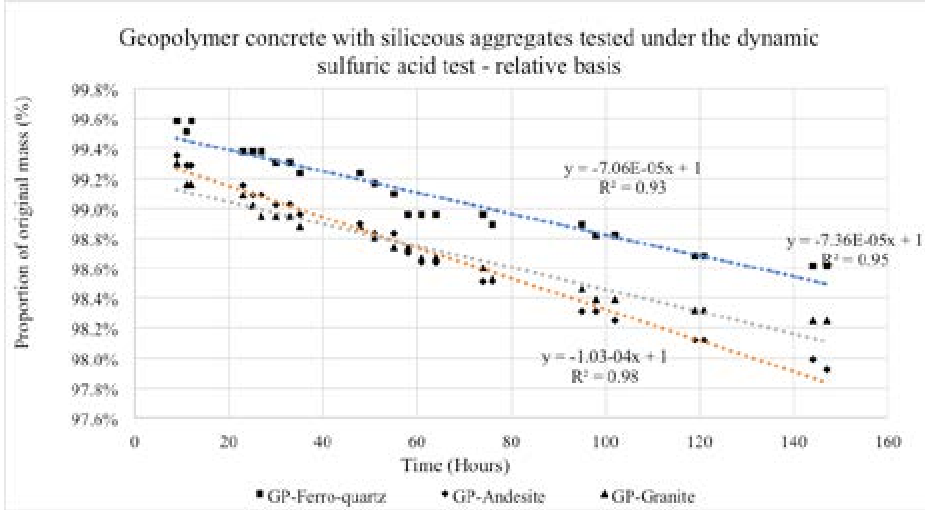
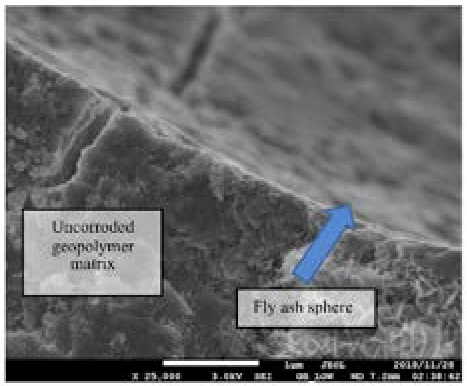


Figure 3-10: Dynamic sulfuric acid test of GP concretes with siliceous aggregate vs proportion of original mass

hour duration used in the dynamic HCl test. This was undertaken to establish whether the corrosion rate would begin to stall after an extended period in the test. This was the experience of Fourie [13] when he tested calcium rich concrete mixes in H2SO4, which resulted in the saturation of the acidic solution with gypsum precipitate and a stalling of the corrosion reaction as a result of the common ion effect. The three GP-siliceous aggregates exhibited a relatively constant rate of corrosion over the duration.

Scanning electron microscopy results

Kriven [13] and Davidovits [14] state that the nano-structure of geopolymers consists of geopolymer micelles which range from 5 nm to 20 nm in size. A characteristic of the geopolymer matrix is that the micelles form nano-channels and pores. Figure 3-11 shows a fracture surface, where the geopolymer micelle matrix is in contact with a fly ash sphere from an un-corroded geopolymer paste specimen. Figure 3-12, Figure 3-13 and Figure 3-14 show effect of HCl on the geopolymer matrix.



3-11: Fly ash sphere in contact with geopolymer micelle matrix

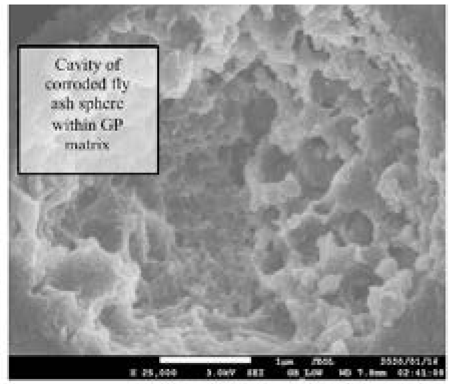


Figure 3-12: HCl Corroded specimen: cavity where FA sphere was embedded. Cavity from which a fly ash sphere was dissolved by acid. The uncorroded shell is likely composed of acid resistant minerals such as Mullite.

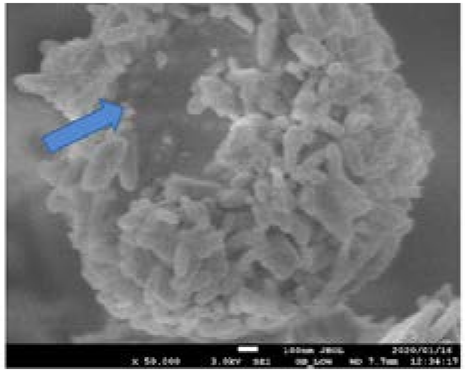


Figure 3-13: Corroded fly ash sphere enveloped by geopolymer matrix after exposure to the dynamic HCl test

Figure 3-12, Figure 3-13, and Figure 3-14 indicate that fly ash spheres are preferentially corroded by hydrochloric and sulfuric acid, this is observation is in line with findings [2] which state that unreacted precursor materials such as fly ash are subject to dissolution under acid attack. Figure 3-13 shows what seems to be a geopolymer matrix shell, which, before corrosion was covering an embedded fly ash sphere. Figure 3-14 shows a partially damaged fly ash sphere, with a circular opening at one end. The damaged sphere is embedded within the geopolymer matrix. This indicates that GP matrices at the micro and nanoscale exhibit preferential corrosion of some microstructures while others are not readily dissolved in HCl.

4. DISCUSSION

4.1 Corrosion rates measured in HCl

Data from the static HCl test and the dynamic HCl test provide us with an indication of the performance of each mix relative to the other 6 mixes tested in this study. If mass loss is used as a measure for corrosion, then is clear that geopolymers present a significant increase in corrosion resistance when compared to CAC and PC binders.

By using linear regression, it was possible to estimate the rate of mass loss per unit area over time for the concrete mixes under both the static and dynamic acid test. The average corrosion rates, obtained via linear regression. for the two mineral acid tests are presented in Table 4-1 and Table 4-2 below:

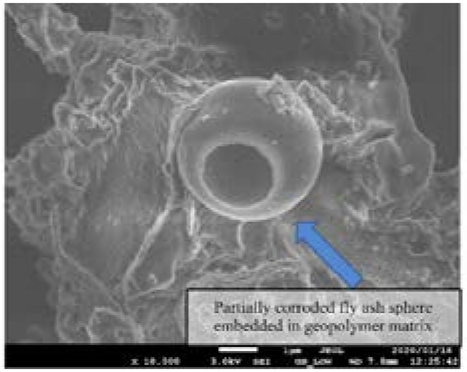


Figure 3-14: Partially corroded fly ash sphere enveloped by geopolymer matrix after exposure to the dynamic sulfuric acid test

Rank in resistance	Concrete mix	Corrosion rate ($mg/cm^2/hr$)
1	GP-ferro-quartz	0.19
2	GP-granite	0.44
3	GP-andesite	0.46
4	GP-dolerite	4.43
5	GP-dolomite	21.1
6	PC-dolomite	34.12
7	CAC-dolomite	52.1

Table 4-1 : Rank in resistance and corrosion rates calculated in the dynamic HCl test

Rank in resistance	Concrete mix	Corrosion rate ($mg/cm^2/hr$)	Abrasion factor
1	GP-ferro-quartz	0.056	3.3
2	GP-granite	0.059	7.5
3	GP-andesite	0.086	5.4
4	GP-dolerite	0.14	32.9
5	CAC-dolomite	0.27	196
6	GP-dolomite	0.54	39.0
7	PC-dolomite	3.85	8.8

Table 4-2 : Rank in resistance and corrosion rates calculated in the static HCl test

Table 4-2 also presents a parameter termed the "abrasion factor". The "abrasion factor", which is equal to the surface corrosion rate in the dynamic acid test divided by the surface corrosion rate in the static test for each concrete type is expressed as:

$$\text{Abrasion Factor} = \frac{\text{Corrosion rate-dynamic HCl test}}{\text{Corrosion rate-static HCl test}}$$

It is suggested that the "abrasion factor" provides a quantifiable measure of the effect of abrasion on concretes in acidic media. Higher values indicate that abrasion in acidic media has a severe effect while lower values indicate a minor effect. This parameter relies on the assumption that the dynamic HCl test nullifies the protective effects of precipitates and gels.

The highest abrasion factor" value was calculated for CAC-dolomite mix (196). This value supports the hypothesis of a protective precipitate or gel forming around the specimen under static conditions. However, it is not effective in the dynamic HCl test where corrosion products are removed by continuous brushing. GP-ferro-quartz displayed the lowest abrasion factor (3.3) indicating that while the conditions in the dynamic test are more severe, the reduction in resistance was much lower than all the other six concrete mixtures. The GP-ferro-quartz result also indicates that geopolymer concretes do not form corrosion products with significant protective properties while undergoing corrosion.

The calculated corrosion rates in both tests do not differ significantly (0.011-0.105 g/cm2/hr), when considered in terms of the range in corrosion rates for the 7 concrete mixes (0.19 – 52.1 g/cm2/hr) in the dynamic HCl test. This finding, though limited to only three mixes is in keeping with two claims. Firstly, that the dynamic acid test provides an indication of the combined rate of dissolution of a concrete specimen and secondly, that the rate of dissolution is primarily dependent on the pH of the acidic solution and not the acid type as suggested by Gay et al [12].

4.2 Reasons for GP corrosion resistance

It is argued that the dynamic HCl test provides an indication of the combined rate of dissolution for a specific concrete mix. The high resistance to dissolution of the geopolymer mixes can be attributed to the high Si and low Ca content of geopolymers [2]. This is in contrast to Portland and calcium aluminate cements which contain a significant proportion of Ca. It is argued here that the chemical composition of concretes is the primary factor to consider where acid resistance is concerned.

4.3 Performance of CAC and PC concretes

The performance disparity of the CAC-dolomite mix between the dynamic and static test may be explained by protection emanating from alumina gel (AH3) forming on the surface of the corroding specimen in the static HCl test, and that the gel does not provide protection in the dynamic HCl test because the continuous brushing removes corrosion products from the surface of a corroding specimen. This explanation is in agreement with the protective mechanisms suggested in previous studies, wherein, alumina gel, the bacterio-static effect and neutralisation capacity are protective mechanisms attributed to CAC concrete [4] [6]. Given that the mineral tests used in this study did not include a bacterial component, and that the stated neutralising capacity of CAC is only 40% higher than Portland cement, it is suggested that the predominant protective mechanism emanates from alumina gel in the CAC concrete mixes.

This finding is also supported by a visual examination of CAC-dolomite specimens taken from the two acid tests. The surface of the cubic CAC-dolomite specimen from the static HCl test *Figure 4-1) displays a relatively smooth surface, with negligible levels of preferential corrosion of the binder or the paste.

Concrete mix	Corrosion rate dynamic HCl test ($mg/cm^2/hr$)	Corrosion rate dynamic H_2SO_4 test ($mg/cm^2/hr$)	Difference in corrosion rate ($mg/cm^2/hr$) between HCl and H_2SO_4
GP-ferro-quartz	0.19	0.295	0.105
GP-granite	0.44	0.328	0.112
GP-andesite	0.46	0.449	0.011

Table 4-3: Difference between calculated corrosion rates in the dynamic acid test (HCl vs H2SO4)

Figure 4-1 : CAC-dolomite specimen taken from the static HCl test after 350 hours

Figure 4-2 : PC-dolomite specimen taken from the static HCl test after 350 hours

Figure 4-3 : CAC-dolomite specimen taken after 48 hours in the dynamic HCl test

In the dynamic HCl test, the paste in the CAC-dolomite specimen(Figure 4-3) is clearly preferentially corroded, creating a rough surface with dolomite aggregate standing proud. This observation supports the idea that the brushing in the dynamic HCl test nullifies the protective effects of the alumina gel (AH3) layer.

Furthermore, if this specimen is compared to the PC-dolomite specimen after the same period of immersion in HCl in the static test, it can be inferred from the high levels of corrosion of the dolomite aggregate in the PC-dolomite specimen (Figure 4-2), that there exists a protective coating on the CAC-dolomite, preventing the dolomite from being dissolved in the acidic solution.

4.4 Relating results from the dynamic HCl test to concrete chemical composition

Concrete is the combination of a cementitious binder (or hardened cement paste), binding a filler material (aggregate) to form a hardened cement paste/aggregate matrix. Therefore, by analysing the chemical properties of the aggregates and the hardened cement paste separately, it may be possible to determine the contribution of each component to acid resistance.

Since corrosion is effectively an acid-base reaction, a parameter, the basicity value, which is ordinarily used to measure the reactivity of slags in Portland cement, was selected for use measuring the ratio of major basic to acidic oxides in hardened cement pastes and aggregates.

X-ray fluorescence (XRF) analysis was used to quantify the elemental proportions of the aggregate and hardened cement paste, from which, the proportion of major oxides present in the hardened cement paste and aggregates were determined.

Thereafter the Basicity value of the hardened cement paste and aggregates were calculable using the formula below.

$$\text{Basicity} = \frac{\text{CaO (\%)} + \text{MgO (\%)}}{\text{SiO}_2\text{ (\%)}}$$

Furthermore, the combined basicity value of a concrete mix was also calculable by multiplying the concrete mix proportions of the HCP and aggregate with their associated basicity values and taking the sum of the two, as expressed by formula (3) below.

$$\text{Basicity}_{\text{concrete specimen}} = (\text{Basicity}_{\text{HCP}} \times \text{binder \%}) + (\text{Basicity}_{\text{Aggregate}} \times \text{aggregate\%})$$

HCP type	CaO (%)	MgO (%)	SiO2 (%)	Basicity
PC	53.7%	2.01%	17.77%	3.138
CAC	32.9%	2.40%	4.06%	8.686
GP	11.6%	0.53%	44.06%	0.276

Table 4-4:Basicity values of hardened cement pastes

Aggregate type	CaO (%)	MgO (%)	SiO2 (%)	Basicity
Dolomite	23%	16%	25%	1.565
Ferro-Quartz	2%	0%	96%	0.026
Dolerite	11%	6%	52%	0.321
Andesite	8%	4%	55%	0.222
Granite	2%	1%	72%	0.029

Table 4-5: Basicity values of aggregates used in the study

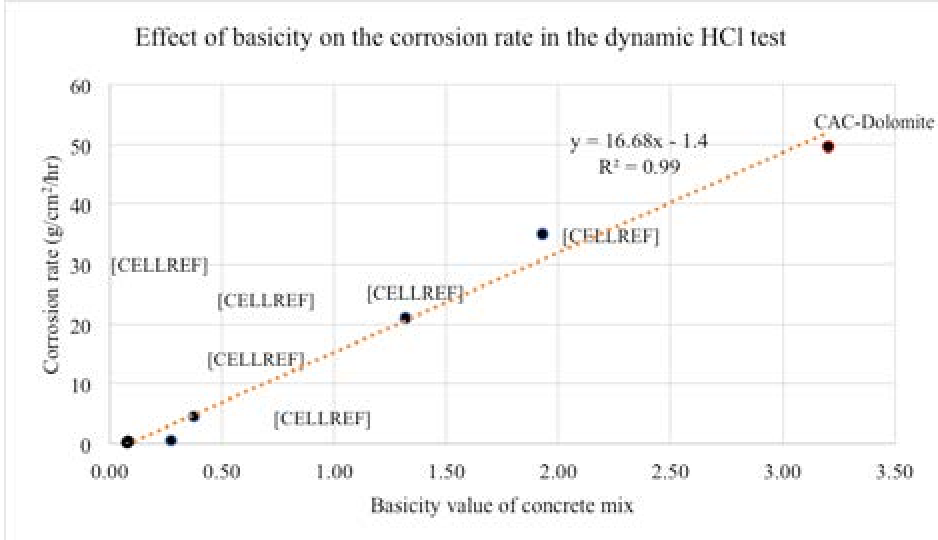


Figure 4-5 : Basicity value of concrete mixes compared to the corrosion rate measured in the dynamic HCl test

Figure 4-4 shows the corrosion rate from the dynamic HCl test of the 7 different mixes compared against the calculated basicity value. The graph shows a strong linear relationship between the basicity value and the corrosion rate measured in the dynamic HCl test.

Since the basicity value is a measure of the ratio of basic oxides to acidic oxides, it could be inferred that higher basicity values are associated with higher corrosion rates. However, since corrosion involves dissolution and precipitation, it is also important to attribute to which phase of the corrosion process the basicity value is related. It is argued that the dynamic HCl test provides an aggregated measure of the rate of dissolution of a concrete mix in HCl. Thus it is

GREEN BUILDING

inferred that the rate of dissolution, measured here in g/cm2/hr is linearly related to the basicity value of the concrete mixes tested in this study. However this relationship will require further study and verification.

4.5 Effect of basicity on aggregate-binder compatibility in concrete mixtures subjected to the dynamic HCl test

While preferential corrosion of the either the paste or binder fraction of concrete in acidic milieu is undesirable, the effects of preferential corrosion of the binder can be more damaging since it results in aggregate fallout and rapid disintegration of concrete. There is a lack of focus in the literature on this specific problem.

In South Africa, calcareous aggregates are prescribed in the concrete mixes used for sewer pipes in order to spread corrosion over both aggregate and paste. With respect to this SANS 677 suggests that the insoluble portion of the selected aggregate in hydrochloric acid should not exceed 25% by mass [15].

It is argued here that preferential corrosion is strongly related to a disparity in the rate of dissolution between the binder and the paste. Therefore, it would be useful if the difference in the rate of dissolution between the binder and the paste were quantifiable. It is further argued that the combined rate of dissolution of a concrete mix is measurable by the dynamic HCl test. Furthermore, given the highly correlated relationship between the basicity of a concrete mix and the corrosion rate shown in Figure 4-4, it is suggested that the extent of preferential corrosion in a concrete mix may be assessed by calculating the difference between basicity values of the paste and aggregate.

$$\text{Basicity differential} = \text{Basicity}_{\text{aggregate}} - \text{Basicity}_{\text{HCP}}$$

A qualitative assessment of this hypothesis was conducted by comparing the surface characteristics of specimens after they were subjected to the dynamic HCl test. The basicity differentials of the seven concrete mixes was calculated using equation (4). The visual appraisal of the corroded concrete specimens conformed to the hypothesis. The specimen with the largest basicity differential was the CAC-dolomite mix, with a basicity differential value of -7.09. The surface of the specimen displayed a clear preferential corrosion of the binder, with stone and sand sized particles protruding from the specimen. PC-dolomite specimen showed preferential corrosion of the binder however to a reduced extent, which was in keeping with its lower basicity differential (-1.53). The smoothest concrete mixes had basicity differentials close to zero (GP-ferro-quartz, GP-granite, GP-andesite). The concrete mixes that displayed preferential corrosion of the aggregate were GP-dolomite and GP-dolerite. The surface characteristics of these two mixes were characterised by cavities in the binder matrix where aggregates were dissolved by HCl. Therefore, it is suggested that the visual assessment of the specimens subjected to the dynamic HCl test are in agreement with the calculated basicity differential value of the seven mixes tested in this study.

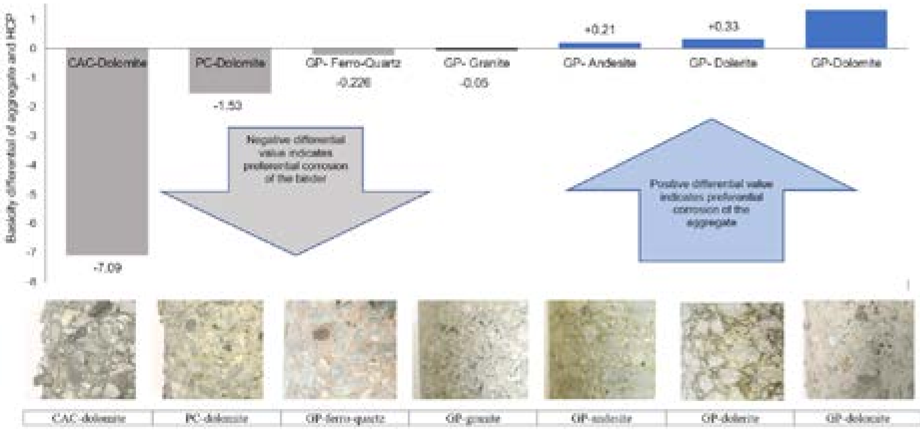


Figure 4-6: Visual examination of surface corrosion in the dynamic HCl test compared to the calculated basicity differential for the concrete mixture.

5. CONCLUSIONS

The performance of geopolymer concrete mixes subjected to mineral acid tests is generally superior to Portland cement and calcium aluminate cements combined with dolomite aggregate.

Results from the static HCl test showed that GP-ferro-quartz concrete, the most acid resistant concrete specimen, provided a 69-fold improvement in resistance when compared to PC-dolomite mixes (control #1) and a 4.72-fold improvement in resistance when compared to CAC-dolomite mixes (control #2).

Results from the dynamic HCl test show that the GP-ferro-quartz mix provided a 180-fold increase in resistance when compared to the PC-dolomite mix and a 275-fold increase when compared to CAC-dolomite mix. The CAC-dolomite mix was found to have the lowest resistance to the erosive-corrosive exposure conditions of the dynamic HCl test. Thus, in terms of the concrete MIC resistance properties identified in this study, it is suggested that the CAC-dolomite mix had poor kinetic resistance to dissolution. However, under the static acid test (static corrosion exposure condition), the CAC-dolomite mix performed better than the PC-dolomite mix and GP-dolomite mix. CAC-dolomite concrete performed inferiorly only to the set of GP-siliceous-aggregate mixes in the static HCl test.

The difference in the performance of CAC-dolomite concrete performance between the static and dynamic test is largely attributed to the formation of alumina gel, an acid corrosion product of CAC hardened paste, which envelopes the concrete specimen and reduces the rate of surface corrosion in the static HCl test. However, under the dynamic HCl test, the gel layer is brushed off the surface of the concrete specimen rendering it ineffective in protecting the concrete specimen from corrosion.

The difference in the rate of corrosion of GP-siliceous aggregate concrete mixes subjected to HCl and H2SO4 under dynamic conditions was minute. This finding reinforces the suggestion that the dynamic acid test provides an indication of the rate of dissolution and that the rate of dissolution is not dependent on acid type [12].

A strongly correlated linear relationship between the basicity value of a concrete mix and the corrosion rate from the dynamic HCl test was established. This empirical relationship warrants further investigation and verification, as it would, in principle provide a means to estimate the dissolution rate of concrete by calculating its basicity.

Basicity was also found to be useful in determining the corrosion compatibility of binder and aggregate types. It was found that the difference between the basicity value of hardened cement paste and the basicity value of the aggregate was useful in determining the type and extent of preferential corrosion of a concrete specimen tested under the dynamic HCl test. For ease of reading, this difference was called the "basicity differential". By visually assessing corroded concrete specimens from the dynamic HCl test, it was possible to determine whether the hardened cement paste or aggregate component was preferentially corroded, and to quantify the severity of preferential corrosion.

REFERENCES

- [1] T. Bakharev, "Resistance of geopolymer materials to acid attack," Cement and concrete research, pp. 658-670, 2005.
- [2] C. Grengg, "Microbially induceced acid corrosion in sewer environments," 2017.
- [3] W. Kaempfer and M. Berndt, "Estimation of service life of concrete pipes in sewers," in 8th confernce of durability and building material components, Vancouver, 1999.
- [4]M. Alexander, A. Bentur and S. Mindess, Durabiliyt of concrete: design and conctruction., London: CRC Press, 2017.
- [5] M. Kiliswa, Composition and microstructure of concrete mixtures subjected to biogenic acid corrosion and their role in corrosion prediction of concrete outfall sewers, University of Cape Town, 2016.
- [6] J. Herrision and F. Saucier, "Use of calcium aluminate cements in H2S biogenic environment," Institute of Concrete Technology, 2015.
- [7] R. Letourneux and K. Scrivener, "The resistance of calcium aluminate cements to acid corrosion in wastewater applications," Lafarge, France, 1999.
- [8] M. G. Alexander and C. Fourie, "Performance of sewer pipe concrete mixtures with Portland and calcium aluminate cements subjected to mineral and biogenic acid attack.," Materials and Structures, vol. 44, pp. 313-330, 2011.
- [9] M. Druga, N. Ukrainczyk, K. Weise and S. Lackner, "Interaction between wastewater microorganisms and geopolymer on cementious materials: Biofilm characteriszation and deterioration characteristic of mortars," International Biodeterioration & Biodegredation, vol. 14.
- [10] N. Motsieloa, Acid resistance of sewer pipe concrete, University of Cape Town, 2012.
- [11] B. Huber, H. Hilbig, J. E. Drewes and E. Muller, "Compartive analysis of biogenic and chemical sulfuric acid attack on hardened cement paste using laser ablation-ICP-MS," Cement and concrete research, vol. 87, no. 87, pp. 14-21, 2016.
- [12] H. Gay, T. Meynet and J. Colombani, "Local study of the corrosion kinetics of hardened Portland cement under acid attack," Cement and concrete research, pp. 36-42, 2016.
- [13] C. Fourie, "Acid resitance of sewer pipe concrete. MSc dissertation.," University of Cape Town, 2007.
- [14] A. Goyns, Design Manual for concrete pipe outfall sewers, Midrand: Concrete Manufacturers Association (CMA), 2013.
- [15] J. Xiao, W. Li and P. Zhu, "Investigation on effect of aggregate on three non-destructive testing peoperties of concrete subjected to sulfuric acid attack," Construction and building materials, pp. 489-496, 2016.
- [16] W. M. Kriven, J. Bell and M. Gordon, "Microstructure and micro-chemistry of folly-reacted geopolymer and geopolymer matrix composites.," Ceramics transactions, pp. 227-250, 2003.
- [17] J. Davidovits, Geopolymer chemistry and applications, Saint Quentin: Geopolymer Institute, 2008.
- [18] South African Bureau of Standars (SABS), "Concrete non-pressure pipes," 2010.

Quantifying the environmental impacts of a sustainable concrete mix for a block paving system

Nozonke Dumani, CSIR, Refiloe Mokoena, CSIR and Martin Mgangira, CSIR

1. Abstract

A sustainable concrete mix design, incorporating industrial by-products: fly ash and recycled plastic pellets, was developed, and optimized through laboratory performance-based testing trials. The primary objective of this investigation was to offer environmentally sustainable alternatives to conventional concrete mixes that can be used for concrete block paving and aligns with circular economy principles and fosters enhanced employment opportunities and poverty reduction.

Following a laboratory investigation to optimise the quantities of fly ash and plastic pellets in the concrete mix, paving blocks were produced in the laboratory using the optimised mix. The blocks were also tested to ensure compliance with performance criteria stipulated in national specifications for concrete block paving. This chapter focuses on the comprehensive life cycle assessment (LCA) conducted to investigate the environmental impacts associated with the production of the optimised concrete mix design in comparison with two reference mixes. All three mixes comprised varying quantities of cement, fly ash as a partial cement replacement, and plastic pellets as a partial substitute for sand. The analysis included concrete with 100% Portland limestone cement, concrete with 50% Portland limestone cement and 50% fly ash, and concrete with 50% Portland limestone cement, 50% fly ash, and plastic pellets.

The study, limited to a cradle-to-gate analysis, utilized the life cycle assessment software tool SimaPro 8.1 with the Ecoinvent Database version 3. The life cycle inventory dataset for each material was compiled, and the CML-IA Baseline World 2000 method was employed to generate and report the results.

The LCA study results demonstrated that adding fly ash as a cement substitution significantly reduced the environmental impacts of concrete mixes. However, the extent of this reduction depended on the type of allocation method used. Under no allocation and economic allocation scenarios, concrete mixes with fly ash exhibited lower environmental impacts than those without fly ash. Conversely, mass allocation scenarios indicated higher environmental impacts for concrete with added fly ash more than 35%. Additionally, it was noted that environmental impacts for fly ash concrete mixes with plastic pellets as a partial substitute for sand were marginally higher than those with fly ash concrete mixes using only sand.

2. Introduction

Concrete is the second most consumed substance on Earth, surpassed only by water, making it the world's most widely used material (Chen et al., 2010). Comprising cement, aggregate, and water, plain concrete's essential constituents include cement, which accounts for approximately 10 to 15% of the concrete volume, serving as the binding component

(ACMP, 2011; Muigai et al., 2013). Aggregate, constituting gravel, sand, crushed stone, and recycled materials, is the primary structural filler, comprising about 65% to 80% of concrete volume (Muigai et al., 2013).

Concrete production significantly contributes to environmental burdens, particularly in carbon dioxide (CO2) emissions (Wang et al., 2017). Ordinary Portland cement (OPC) is a key contributor to these high impacts (Celik et al., 2015; Marinković et al., 2016; Kurad et al., 2017). Studies indicate OPC's responsibility for 74-81% of emissions in typical commercially produced concrete mixes (Flower and Sanjayan, 2007). This production process, highly energy-intensive, contributes 5-7% of global CO2 emissions, with approximately one ton of OPC production leading to roughly one ton of CO2 emissions (Rashad and Zeedan, 2011).

Efforts to reduce concrete's environmental impact involve minimizing OPC use through supplementary cementitious materials (SCMs) like fly ash, ground granulated blast furnace slag (GGBS), and silica fume. In South Africa coal-fired power plants already produced approximately 34.4 million tons of fly ash in 2015 (Reynolds-Cluasen and Singh, 2019). Various studies have demonstrated that incorporating fly ash to partial replace OPC in concrete significantly reduces CO2 emissions and energy consumption (Chen et al., 2010; Van den Heede and De Belie, 2012; Marinković et al., 2016; Wang et al., 2017; Kuda, et al., 2018).

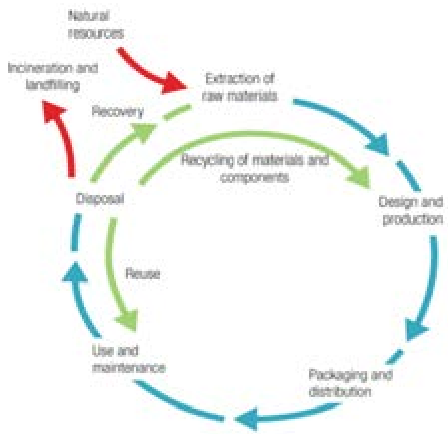


Figure 2.1: A typical product life cycle (UNEP/SETAC Life Cycle Initiative, 2023)

Research on utilising industrial by-products as partial aggregate replacement or partial cement replacement in concrete has been ongoing for many years. Additionally, there has been substantial interest in using recycled waste plastic as a partial substitute for aggregate in the concrete industry. This approach addresses the feasible reuse of plastic, providing a solution to the plastic disposal issue (AbdelMoti and Mustafa, 2019; Sharma and Bansal, 2016; Kumar and Kumar, 2016; Saikia and de Brito, 2012).

Several studies have explored the use of plastic waste as aggregate replacements and demonstrated significant environmental benefits, particularly when combined with supplementary cementitious materials like fly ash (Betita, 2013; Mello et al., 2016; da Silva et al., 2021; Gravina et al., 2021; Ersan et al., 2022; Nikbin et al., 2022; Goyal et al., 2023). In the study by Goyal et al. (2023), the environmental impacts of manufacturing different types of paver blocks were compared. The results indicated that paver blocks with plastic as filler material (PFPB) and conventional concrete paver blocks (CCPB) processes had higher environmental impacts due to the use of cement, unlike paver blocks with plastic as a binder (PBPB). The study concluded that PBPB, manufactured by completely replacing cement, is more environmentally friendly than PFPB and CCPB. Furthermore, Ersan et al. (2022) investigated and compared the environmental impact of conventional lightweight concrete (LWC) and green LWC made by partially replacing coarse natural aggregates with 30% recycled plastic waste and replacing 20% of Portland cement with class F fly ash. The study reported that green LWC had lower environmental impacts than conventional LWC, except for eutrophication.

This chapter aims to explore the environmental impact of incorporating recycled plastic waste as partial replacement of fine aggregate in concrete, particularly when combined with fly ash while maintaining the strength and durability requirements for concrete block paving products.

3. Life cycle assessment methodology

A life cycle assessment (LCA) study was conducted to investigate the environmental impacts associated with the production of different concrete mix designs. Life cycle assessment (LCA) is a systematic approach that quantifies and evaluates the environmental impacts of a product or process throughout its entire life cycle, from the extraction and processing of raw materials, manufacturing, transportation and distribution, to use, maintenance, reuse, recycling, and final disposal (ISO/SANS 14040, 2006 and ISO/SANS 14044, 2006). Figure 2.1 illustrates the generic life cycle stages of a product for LCA.

An LCA takes into account various environmental impact categories in the assessment, including energy, land, water, materials, and other resources, as well as various types of emissions to air, water, and soil. LCA identifies opportunities to improve product performance with the identification of environmental "hotspots' along the product life cycle, thereby revealing potential trade-offs.

The methodology used in this study follows the approach outlined by the International Organization for Standardization (ISO) 14040:2006 and ISO 14044:2006. ISO standards provide general principles, a methodological framework, guidelines, and requirements for performing the LCA of any system and should always be complied with. There are four mandatory stages (see Figure 2.2) in an LCA study, namely:

- Goal and scope definition which states the key objective of the study, defines the system boundaries, functional unit to be used in the investigation, the limitations and assumptions
- Life cycle inventory (LCI) analysis which involves data collection and calculation of an inventory of materials, energy and emissions related to the system being studied
- Life cycle impact assessment (LCIA) which involves analysis of the LCI results to evaluate contributions to environmental impact categories
- Life cycle interpretation which entails evaluation of the LCI and LCIA results in consideration of the initial intended goal and scope in order to reach conclusions and make recommendations.

3.1 Goal and scope definition

3.1.1 Goal

The objective of this study is to assess and compare the environmental impacts associated with different concrete mixes, which incorporate fly ash as a cement partial replacement and plastic pellets as a partial substitution for sand. A description of the materials used in this study the proportion of mix ingredients are provided in Table 2.1 and Table 2.2, respectively.

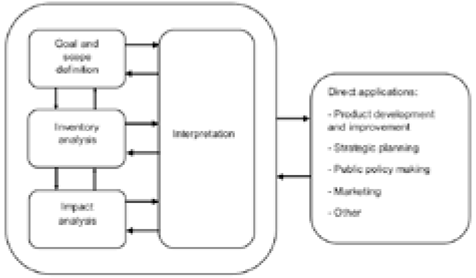


Figure 2.2: Life cycle assessment framework (ISO/SANS 14040, 2006,)

Material	Description
Cement	42.5N Portland limestone cement
Fly Ash	Class F fly ash
Fine aggregates (Sand)	Crusher dust
Fine aggregates (Plastic pellets)	Pelletized recycled milk carton plastic
Coarse aggregates (Stones)	Meta-quartzite crushed aggregate

Table 2.1: Materials description used in this study

Three different concrete mixtures are analysed in this LCA study and are as follows:

- Mix 1: Concrete with 100% Portland limestone cement (control mixture)
- Mix 2: Concrete with 50% Portland limestone cement and 50% fly ash
- Mix 3: Concrete with 50% Portland limestone cement, 50% fly ash, plastic pellets as partial substitution for sand

3.1.2 Scope

The functional unit of the study was chosen as one cubic meter (1 m3) of concrete. The system boundary of the study was limited to cradle-to-gate analysis as shown in Figure 2.3. This will cover the environmental impacts resulting from the extraction, processing and

Mix	Water/binder	Cement	Fly ash	Water	Stone	Sand	Plastic pellets	Compressive strength (MPa)
Mix 1	0.36	583	-	210	1062	546	-	53
Mix 2	0.35	286	286	200	963	568	-	38
Mix 3	0.35	286	286	200	963	549	10	36

Table 2.2: Mix proportions of concrete mixtures (kg/m3) and compressive strength at 28 days (MPa)

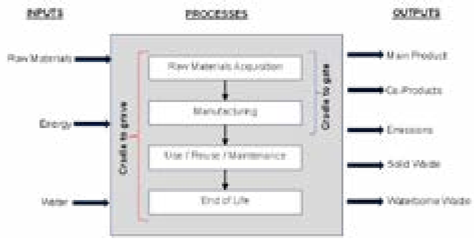


Figure 2.3: System boundaries (Environmental Protection Agency (EPA), 1993)

production of raw materials required to produce the concrete mixes, transportation of raw materials to the concrete plant and concrete production at the plant as shown in Figure 2.4.

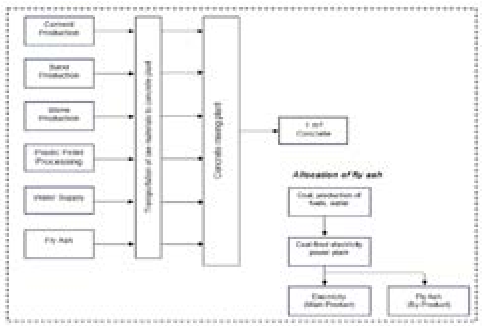


Figure 2.4: System boundary of concrete in the study

3.2 Life cycle inventory analysis

The life cycle inventory (LCI) phase of the study involves the data collection and calculation procedures. The inventory analysis gathers relevant inputs (e.g. energy, materials) and outputs (e.g. emissions and wastes) of the product system being studied, which is then scaled to relate to the functional unit. The inventory was prepared first qualitatively, then quantitatively for all the processes involved in the cradle-to-gate life cycle of the concrete mix designs. This is a very critical step as the data quality determines the success of the study. It is very important in the inventory phase to collect data from high quality resources.

3.2.1 Data sources

The LCA software tool SimaPro 8.1 with Ecoinvent database 3 was used to compile LCI dataset for each material of this study. Table 3.2 presents the inventory of the materials and transportation considered for each material. South African datasets were used whenever available in this study. In cases where no South African dataset was available for a particular material, the Rest of the World (RoW) dataset was selected as a proxy and adapted to suit the local context. For plastic pellets, only the energy used for shredding the plastic with a granulator and the energy used in the extrusion process, which pelletizes the plastic, were taken into account (refer to Table 3.2) (Mello et al., 2016).

(Tap on button to see table 3)

Table 3

3.2.2 Allocation methodology

When collecting the inventory data, attention must be given to allocation. In processes yielding multiple products, environmental impacts must be distributed among the different end products. Allocation can be done either on a mass basis or an economic basis. Traditionally, fly ash was viewed as a waste product from coal-fired power plants. However, it is now recognized as a useful by-product, carrying a portion of the environmental burden of electricity production in coal-fired power plants. Therefore, for this study, three allocation scenarios were considered: no allocation, mass allocation, and economic allocation.

3.2.2.1 No allocation scenario

In this scenario, no allocation was applied, fly ash was considered as waste and only the environmental impact from transport was included.

3.2.2.2 Mass allocation scenario

In this scenario, the environmental impacts of electricity production in the coal-fired power plant were allocated between fly ash (by-product) and electricity (main product) based on Equation (1). The mass allocation coefficient Cm can be calculated as the mass ratio between the main product and by-product (Chen et al., 2010):

$$C_m = \frac{m_{by-product}}{m_{main\ product} + m_{by-product}} \quad \text{.......... Equation (1)}$$

where $m_{by-product}$ is fly ash mass and $m_{main\ product}$ is electricity mass.

Mass quantities were calculated based on LCI data from Ecoinvent Database 3. In the database, a South African dataset for electricity production from hard coal is available (Treyer and Bauer, 2016). To produce 1 kWh of electricity, 0.475 kg of hard coal is consumed, generating 0.0811 kg of hard coal ash. According to Siddique (2010), the ashes collected from pulverised coal-fired furnaces consist of fly ash and bottom ash, with fly ash constituting a major component ranging from 70-90%, while bottom ash accounts for 10-30%. For this study, it was assumed that fly ash constitutes 80% of hard coal ash, with the remaining 20% being bottom ash, resulting in the generation of 0.0645 kg of fly ash and 0.0166 kg of bottom ash.

A mass equivalent of 0.394 kg for electricity was calculated by applying the principle of the conservation of mass, as reported by Chen et al., 2010. Applying the mass allocation coefficient equation, Cm was calculated as 0.141. This means approximately 14.1% of the environmental impact of electricity production was attributed to fly ash production.

3.2.2.3 Economic allocation scenario

In this scenario, environmental impacts of electricity production in the coal-fired power plant were allocated between fly ash and electricity based on Equation (2) which gives the formula for the economic allocation coefficient (Ce) (Chen et al., 2010). The economic allocation coefficient Ce was calculated as follows (Chen et al., 2010):

$$C_e = \frac{(\varepsilon.m)_{by-product}}{(\varepsilon.m)_{main\ product} + (\varepsilon.m)_{by-product}} \quad \text{.......... Equation (2)}$$

where ε is the price per unit of material, $m_{by-product}$ is fly ash mass and $m_{main\ product}$ is electricity mass.

The mass quantities needed to calculate economic coefficient were determined using the same method as described for the calculation of the mass coefficient, Cm. Electricity rates in South Africa vary based on consumption and time of use. For industrial use during the summer season, an on-peak rate of R1.56/kWh was applied in the calculations (Joburg, 2019). The cost of fly ash in South Africa was found to be approximately R80/ton for unclassified fly ash (information obtained via phone call with Ulula Fly Ash). Utilizing the economic allocation coefficient equation, Ce was calculated as 0.0033. This implies that roughly 0.33% of the environmental impact of electricity production was attributed to fly ash production.

3.3 Life cycle impact assessment

In this phase, the potential environmental impacts are calculated based on the inventory. This study considered eight environmental impact categories for the environmental performance assessment, including global warming, acidification, eutrophication, human toxicity, abiotic depletion, abiotic depletion fossil, and photochemical oxidation. The CML-IA Baseline World 2000 method (Sleeswijk et al., 2008) which is included with the LCA software was used to generate and report the results.

3.4 Sensitivity analysis

A sensitivity analysis was conducted to assess the impact of fly ash prices when implementing economic allocation. The cost of fly ash in South Africa was found to be approximately R80/ton for unclassified fly ash and R150/ton for classified fly ash (information obtained via phone call with Ulula Fly Ash). As a result, economic allocation coefficients were calculated as 0.33% and 0.62%, respectively. Additionally, the ReCiPe midpoint hierarchist (H) method was employed for the sensitivity analysis, enabling a comparison of LCA results using these two methods.

4 Results and discussion

4.1 Environmental impacts: No allocation scenario

The environmental impact results of the cradle-to-gate LCA analysis, where no allocation of fly ash is applied, are presented in Table 3.1 and Figure 3.1. As shown in Table 3.1 and Figure 3.1, mix 1 exhibited higher environmental impacts than the concrete

mixes incorporating fly ash (mix 2 and mix 3) in each of the investigated impact categories. It is evident that the inclusion of fly ash in concrete significantly reduces environmental impacts for mix 2 and mix 3. Specifically, mix 2 demonstrated the lowest impact, while mix 1 exhibited the highest across all environmental impact categories.

Table 3.1: Quantification of environmental impact categories when no allocation scenario is applied based on CML-IA baseline.

Impact category	Units	Mix 1	Mix 2	Mix 3
Global warming	kg CO_2 eq	488	253	256
Acidification	kg SO_2 eq	1.33	0.727	0.754
Eutrophication	kg PO_4^{3-} eq	0.221	0.129	0.136
Ozone layer depletion	kg CFC-11 eq	7.27 x 10[illegible]	4.42 x 10[illegible]	4.45 x 10[illegible]
Human Toxicity	kg 1,4-DB eq	36.9	24.5	25.4
Abiotic depletion	kg Sb eq	4.18 x 10[illegible]	3.34 x 10[illegible]	3.34 x 10[illegible]
Abiotic depletion fossil	MJ	1.73 x10[illegible]	1.05 x 10[illegible]	1.09 x 10[illegible]
Photochemical oxidation	kg C_2H_4 eq	0.0502	0.0284	0.0293

However, the results for mix 3, presented in Table 3.1 and Figure 3.1, indicate that incorporating plastic pellets into concrete as a partial substitution for sand does not enhance the environmental performance of concrete. These findings contradict what has been reported in the literature (Betita, 2013; Mello et al., 2016). Previous studies suggested that utilising waste PET/plastic as a partial substitution for sand could significantly improve the environmental performance of concrete, especially when combined with supplementary cementitious materials. This discrepancy was attributed to the high energy demand for shredding and pelletizing the plastic in this study compared to the values reported by Mello et al. (2016). The energy consumption estimates were based on South African company information for granulators and extruders. It's important to note that energy consumption data for shredding and pelletizing the plastic should ideally be obtained directly from the producers of the plastic pellets used in this study.

Additionally, Figure 3.2 illustrates the contribution of each stage to the manufacturing of concrete. According to the results, cement production emerges as the major contributor to the global warming potential in concrete production. This is primarily due to the clinker production stage, which is the most energy-intensive step in cement production. Portland limestone cement (CEM II/A) typically contains 80-94% clinker, 6-20% limestone, and 0-5% minor additional constituents (SANS 50197-1). These findings align with the results reported by Flower and Sanjan (2007), who reported that Ordinary Portland Cement (OPC) was responsible for 74-81% of CO2 emissions from typical commercially produced concrete mixes.

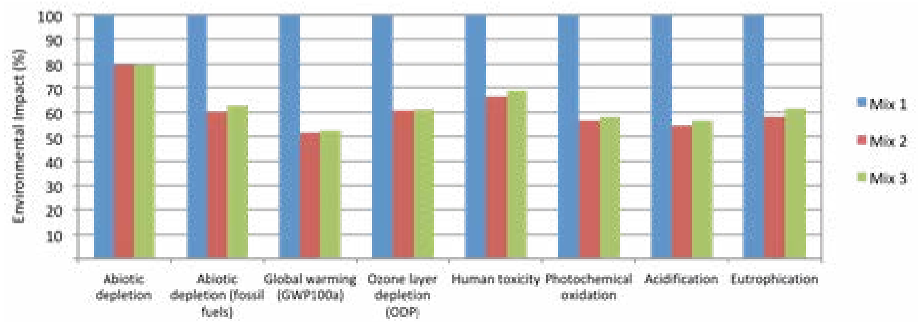


Figure 3.1: Environmental Impact Assessment – no allocation scenario

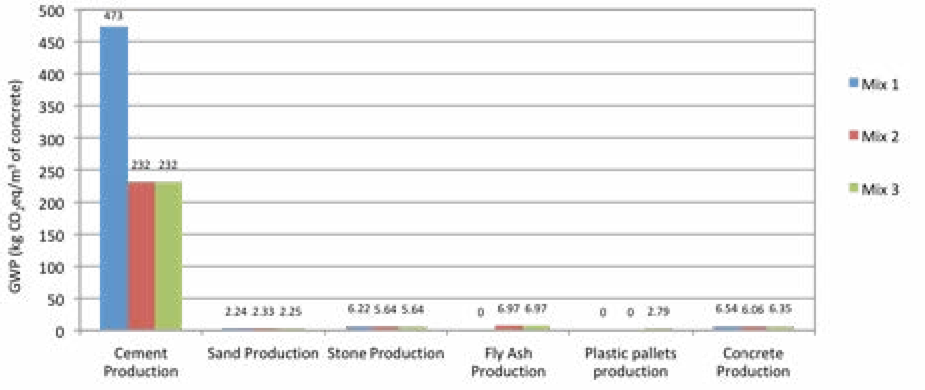


Figure 3.2: Global warming potential for each stage for the production of concrete for no allocation scenario

4.2 Environmental impacts: Economic allocation scenario

The environmental impact indicators, when economic allocation is adopted, are presented in Table 4.2 and Figure 4.3. Unlike the no allocation scenario, economic allocation results differ significantly. The process of electricity production from a coal power plant yields high environmental impacts; thus, even a small allocation coefficient can strongly influence fly ash impact indicators (Marinković et al., 2016).

In the economic allocation scenario, it was observed that mix 2 and mix 3 with fly ash, have lower impacts than mix 1 due to the relatively low price of fly ash in South Africa. Similar findings have been reported in several studies analysing the environmental impacts of concrete with economic allocation of fly ash (Chen et al., 2010; Van den Heede and De Belie, 2012; Marinković et al., 2016; Seto et al., 2017). However, there is a drawback to using economic allocation: the instability of prices, which can lead to significant fluctuations in LCA results (Van den Heede and De Belie, 2012). This is not the case with mass allocation, where the environmental burden of fly ash remains constant over a long period (Van den Heede and De Belie, 2012).

Furthermore, Figure 3.4 illustrates the contribution of each stage to concrete manufacturing when economic allocation is adopted. The results clearly indicate that cement production remains the major contributor to the global warming potential in concrete production, consistent with the findings of the no allocation scenario.

Table 3.2: Environmental impacts when economic allocation scenario is applied based on CML-1A baseline.

Impact category	Units	Mix 1	Mix 2	Mix 3
Global warming	kg CO_2 eq	488	263	266
Acidification	kg SO_2 eq	1.33	0.877	0.905
Eutrophication	kg PO_4^{3-} eq	0.221	0.169	0.176
Ozone layer depletion	kg CFC-11 eq	7.27 x 10[illegible]	3.98 x 10[illegible]	4 x 10[illegible]
Human Toxicity	kg 1,4-DB eq	36.9	29.2	30.1
Abiotic depletion	kg Sb eq	4.18 x 10[illegible]	3.18 x10[illegible]	3.18 x 10[illegible]
Abiotic depletion fossil	MJ	1.73 x10[illegible]	1.21 x 10[illegible]	1.25 x 10[illegible]
Photochemical oxidation	kg C_2H_4 eq	0.0502	0.0333	0.0342

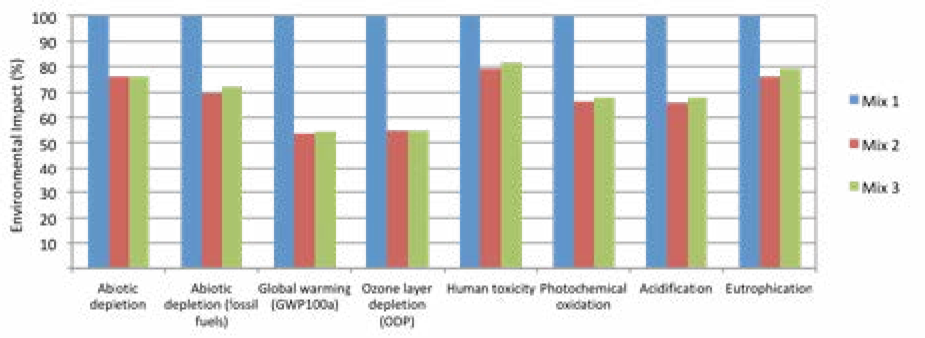


Figure 3.3: Environmental impact assessment – economic allocation scenario

4.3 Environmental impacts: Mass allocation scenario

Finally, when mass allocation was applied, it was observed that mix 2 and mix 3 with fly ash, emerged as the major contributors to the environmental impacts of concrete production, as depicted in Table 3.3 and Figure 3.5. The study revealed that, with mass allocation, all concrete mixes containing fly ash (mix 2 and mix 3) exhibited higher impacts than Portland Limestone Cement (PLC) concrete (mix 1). This was attributed to the relatively large mass of fly ash generated during electricity production, resulting in a substantial mass allocation coefficient. Similar results were obtained by Marinković et al. (2016), who reported that with mass allocation, recycled aggregate concrete (RAC) with fly ash (FA) had significantly higher impacts compared to RAC with no FA.

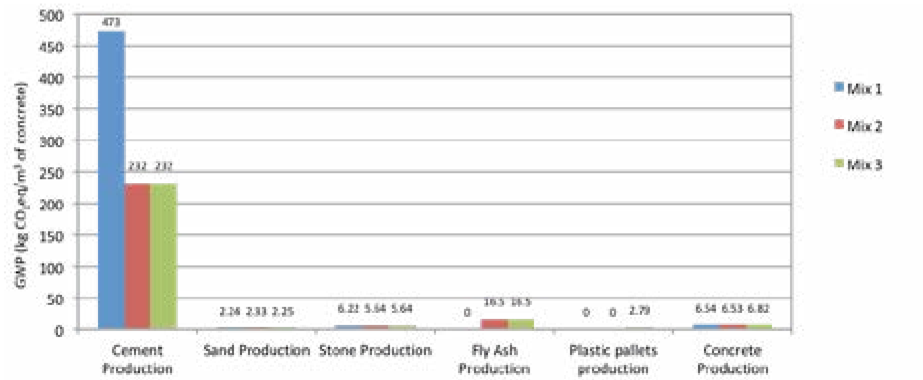


Figure 3.4: Global warming potential for each stage for the production of concrete for economic allocation scenario

Table 3.3: Environmental impacts when mass allocation scenario is applied based on CML-1A baseline.

Impact category	Units	Mix 1	Mix 2	Mix 3
Global warming	kg CO_2 eq	488	965	968
Acidification	kg SO_2 eq	1.33	8.12	8.15
Eutrophication	kg PO_4^{3-} eq	0.221	2.05	2.06
Ozone layer depletion	kg CFC-11 eq	7.27 x 10[illegible]	6.66 x 10[illegible]	6.69 x 10[illegible]
Human Toxicity	kg 1,4-DB eq	36.9	270	270
Abiotic depletion	kg Sb eq	4.18 x 10[illegible]	4.09 x 10[illegible]	4.1 x 10[illegible]
Abiotic depletion fossil	MJ	1.73 x10[illegible]	1.24 x 10[illegible]	1.24 x 10[illegible]
Photochemical oxidation	kg C_2H_4 eq	0.0502	0.277	0.277

As seen in Table 3.3 and Figure 3.5, mass allocation of fly ash imposes significant environmental impacts, which poses a critical issue. The primary purpose of using supplementary cementitious materials like fly ash is to reduce the clinker content in cement, thereby lowering environmental impacts. However, if mass allocation of fly ash is applied, the cement and concrete industries will not benefit from using fly ash. This is due to the increased environmental load of fly ash surpassing that of Portland Limestone Cement (PLC) when mass allocation is adopted.

4.4 Sensitivity analysis

When adopting the economic allocation scenario, one significant drawback is the instability in the price of fly ash, leading to notable fluctuations in LCA results.

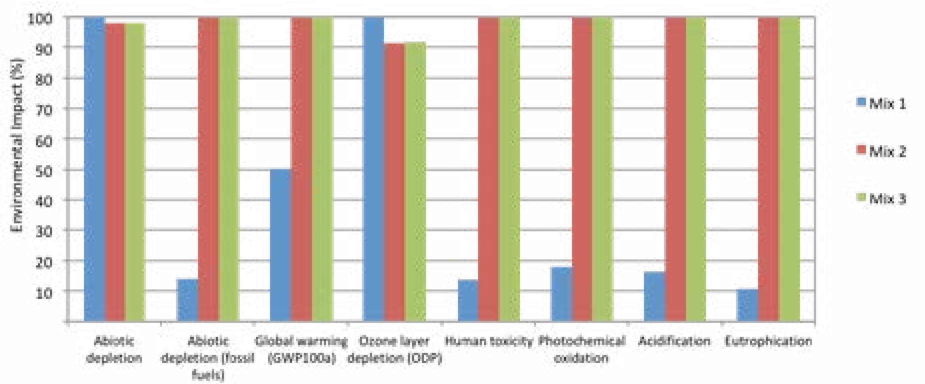


Figure 3.5: Environmental impact assessment – mass allocation scenario

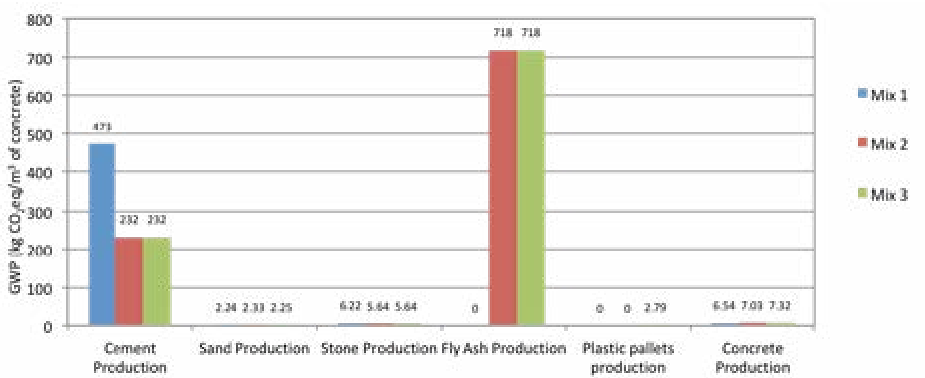


Figure 3.6: Global warming potential for each stage for the production of concrete for mass allocation scenario

Furthermore, Figure 3.6 illustrates the contribution of each stage to concrete manufacturing when mass allocation is adopted. Unlike the scenarios with no allocation and economic allocation, which indicated that cement production is the major contributor to the global warming potential in concrete production, mass allocation results show that fly ash production becomes the primary contributor to the global warming potential in concrete production. This is

A sensitivity analysis was conducted to compare two prices of fly ash: R80/ton and R150/ton, reported as the price range for unclassified and classified fly ash, respectively (information obtained via phone call with Ulula Fly Ash). The economic allocation coefficients were found to be 0.62% and 0.33% for fly ash prices of R150/ton and R80/ton, respectively (refer to Table 3.4). The results showed that in both cases, the environmental impacts attributed to fly

ash were lower. Consequently, all concrete mixtures incorporating fly ash (mix 2 and mix 3) exhibited lower impacts than Portland Limestone Cement (PLC) concrete (mix 1).

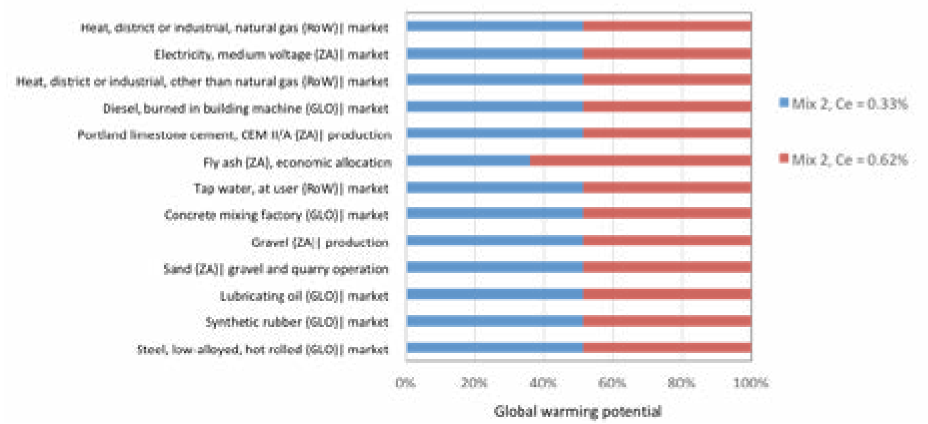


Figure 3.7: Global warming potential contribution analysis of concrete with fly ash (Mix 2) when fly ash price increases from R80/ton to R150/ton and economic allocation coefficients change from 0.33% to 0.62%

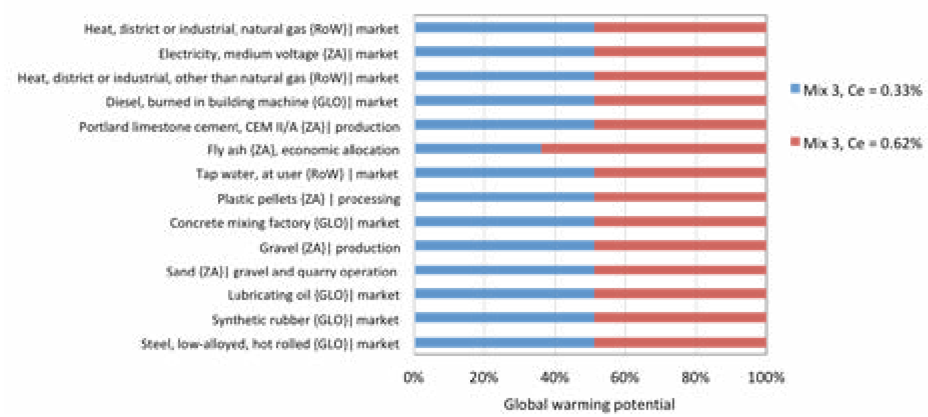


Figure 3.8: Global warming potential contribution analysis of concrete with fly ash and plastic pallets (Mix 3) when fly ash price increases from R80/ton to R150/ton and economic allocation coefficients change from 0.33% to 0.62%

Furthermore, as seen in Figure 3.7 and Figure 3.8, when the economic allocation coefficients change from 0.33% to 0.62%, the contribution of fly ash to the overall impacts increases, while the contributions of other components remain relative the same. However, this increase is not significant enough to outweigh the benefits of using fly ash as a cement replacement.

Furthermore, as indicated in Table 3.5, it was observed that the comparison of CO2 emissions among different types of concrete mixtures was consistent regardless of the evaluation method. Both the ReCiPe midpoint (H) and CML-IA Baseline World 2000 methods yielded the same CO2 equivalents.

5. Concrete laboratory investigation

A laboratory investigation was conducted in three stages to establish (i) the optimum content of fly ash as a cement replacement, (ii) the optimum replacement level of fine aggregate with plastic pellets, and (iii)

Table 3.5: Comparison of the CO_2 emissions results for the concrete with different mix designs using ReCiPe midpoint (H) and CML-IA baseline (World 2000) methods

Type of concrete	Type of allocation	ReCiPe midpoint (H) ($kgCO_2eq/m^3$)	CML-IA baseline (World 2000) ($kgCO_2eq/m^3$)
Mix 1	-	488	488
Mix 2	No allocation	253	253
	Mass allocation	965	965
	Economic allocation	263	263
Mix 3	No allocation	256	256
	Mass allocation	968	968
	Economic allocation	266	266

national specification testing of concrete paving blocks produced from the optimal mix containing fly ash and plastic pellets.

Concrete cubes with varying fly ash contents—0%, 50% and 90%—in place of cement by mass were subjected to compressive strength tests during the initial stage of laboratory testing. All compressive strength tests were conducted as per SANS 5863. It was found that workability and compressive strength decreased as fly ash content increased. An increase in fly ash content was also associated with a decrease in water requirement while maintaining a workable mix in comparison to the reference mix (Mokoena and Mgangira, 2018a). By lowering the amount of water needed for mixing, this can also lessen the impact on the environment. For this round of testing, Mix 1 served as the reference mix, while Mix 2, which contained 50% fly ash was determined to be the most optimal mix with a 28-day compressive strength of 38 MPa given a target strength of 35 MPa, as per SANS 1058:1985, for Class 35 blocks.

The second stage of laboratory testing followed a similar program to substitute the fine aggregate component with plastic pellets at 5%, 15% and 35% replacement levels. The compressive and flexural strengths were observed to decrease as the plastic content increased, with the exception of the mix containing 5% plastic pellets which exhibited a slight increase in flexural strength. During this stage, an optimal level of replacement, while maintaining the compressive strength target of the concrete mix, was determined to be 5% which resulted in Mix 3, which had a compressive strength of 36 MPa (Mokoena, 2018b).

The final stage of laboratory testing was to produce the concrete pavers in the laboratory using Mix 3 to produce a concrete paving product that contains fly ash and plastic pellets as alternative materials with lower associated greenhouse gas emissions compared to conventional concrete ingredients.

The resulting pavers are illustrated in Figure 4.1 and were found to exceed all minimum requirements as per SANS1058:2012. The results for each required category (namely: tensile splitting strength, abrasion resistance and water abrasion) are presented below.

Figure 4.1: Interlocking concrete pavers

4.1 Tensile splitting strength

Tensile splitting strength tests were conducted on 6 interlocking pavers as per SANS 1058:2012. The average tensile strength for the pavers was 2.52 MPa and is 0.5 MPa over the required tensile strength for blocks with a design compressive strength of 30 MPa. All individual results are also above 1.5 MPa as per the standard as illustrated in Figure 4.2.

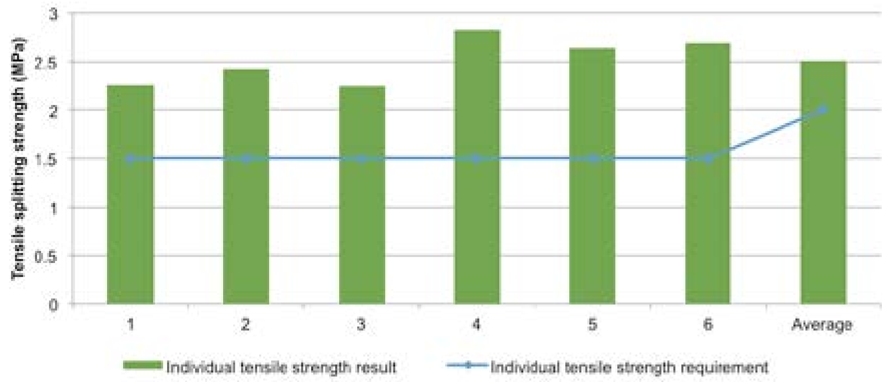


Figure 4.24.1: Comparison of tensile strength results vs individual strength requirement

4.2 Abrasion resistance

Results for abrasion resistance showed no loss and therefore in compliance with the standard. Specifications require a maximum average and individual mass loss of 15g and 20g respectively.

4.3 Water absorption

Water absorption (W_a) tests were conducted on the interlocking pavers as per Equation (3).

$$W_a = \frac{M_2 - M_1}{M_1} x\ 100 \quad \text{.......................Equation (3)}$$

Where M_2 = wet mass of specimen after submersion

M_1 = mass of oven-dried specimen

Water absorption was calculated for a 24-hour period as per the standard and after 96 hours and 120 hours for observation because higher water absorption values were anticipated even after 24 hours. However, as seen in Table 4.1, only a slight increase was observed. The average and individual water absorption of the blocks were below 6.5% and 8.0% respectively (See Figure 4.3). Therefore, the pavers are following the water absorption requirements of the national standard.

6. Conclusion

This study focussed on quantifying the environmental impacts of a sustainable concrete mix for concrete block paving. Following an experimental laboratory program to optimise the fly ash and waste plastic content, concrete paving blocks were produced in the laboratory to assess compliance with performance criteria as per the national specification for concrete blocks (SANS1058:2012).

Duration	Water absorption(W_a)%
After 24 hours	2.95
After 96 hours	3.02
After 120 hours	3.08

Table 4:1: Average water absorption results

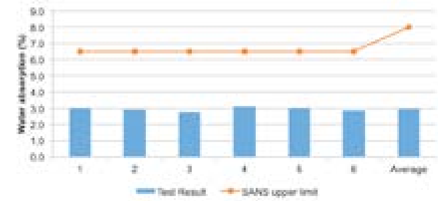


Figure 4.3: Individual and average results for water absorption

The innovative concrete mix was found to produce concrete paving blocks that meet the performance criteria of the specification and presents an opportunity to reduce greenhouse gas emissions and preserve natural resources with the use of alternative materials for road construction. This strategy can also reduce

GREEN BUILDING

material costs without sacrificing relevant performance requirements for concrete paving blocks. Overall, this study aims to contribute towards knowledge generation on sustainable local production of "green" concrete mixes and concrete pavers, particularly for communities near ash sources by also promoting labour intensive construction methods.

Following the laboratory investigation, a detailed assessment of the environmental impacts associated with various concrete mix designs, that were used during the laboratory investigation, using LCA methodology. Results showed that incorporating fly ash in a concrete mix can reduce environmental impacts, contingent on the allocation method. Three scenarios were compared: no allocation, mass allocation, and economic allocation.

Under no allocation, all fly ash concrete mixes exhibited lower impacts than Portland limestone cement concrete. However, mass allocation increased fly ash's environmental load beyond that of Portland limestone cement, while economic allocation reduced it.

Replacing cement with fly ash, beyond 35%, as stipulated in the national cement specification for common cements (SANS 50197-1:2013), presents a significant opportunity to reduce environmental impacts while maintaining structurally sound concrete paving blocks that surpasses minimum specification criteria. Nonetheless, mass allocation results in substantial environmental impacts, potentially discouraging the use of supplementary cementitious materials. Fly ash incorporation reduces environmental impacts under no allocation and economic allocation scenarios. Conversely, substituting fine aggregates with plastic pellets does not significantly reduce concrete's environmental impact, in comparison to the substitution of cement with fly ash. However, the use of plastic pellets as a sand replacement may alleviate the increasing need for sand as a construction material.

7. References

- AbdelMoti, H. M., Mustafa, M. A., 2019, Use of Polypropylene Waste Plastic Pellets as Partial Replacement for Fine Aggregate in Concrete. University of Khartoum Engineering Journal (UofKEJ) 9 (1), 37- 43
- ACMP, 2011, Cementing a sustainable future. [Online available] from: http://www.acmp.co.za/wp-content/uploads/2016/05/ACMP-Sustainability-Report-2008-2010.pdf, [accessed: 11 November 2014]
- Betita, R., 2013, Environmental Impacts of recycled plastic concrete. Climate earth. Online available from: https://www.calcima.org/files/Concrete/EnvironmentalBenefits.pdf, [accessed: 12 March 2020]
- Celik, K., Meral, C., Gursel, A.P., Mehta, P.K., Horvath, A., and Monteiro, P.J.M., 2015, Mechanical properties, durability, and life-cycle assessment of self-consolidating concrete mixtures made with blended Portland cements containing fly ash and limestone powder. Cement & Concrete Composites 56, 59-72
- Chen, C., Habert, G., Bouzidi, Y., Jullien, A., and Ventura., A., 2010, LCA allocation procedure used as incitative method for waste recycling: An application to mineral additions in concrete. Resources, Conservation and Recycling 54, 1231-1240
- Colangelo, F., Forcina, A., Farina, I., and Petrillo, A., 2018, Life cycle assessment (LCA) of different kinds of concrete containing waste for sustainable construction. Buildings 8(70), 1-12
- da Silva, T.R., de Azevedo, A.F.G.,* , Cecchin, D. ,Marvila, M.K., Amran, M., Fediuk, R., Vatin, N. Karelina, M., Klyuev, S., and Szelag, M., 2021, Application of Plastic Wastes in Construction Materials: A Review Using the Concept of Life-Cycle Assessment in the Context of Recent Research for Future Perspectives. Materials 2021, 14, 1-19
- Environmental Protection Agency. 1993. Life Cycle Assessment: Inventory Guidelines and Principles. EPA/600/R-92/245. Office of Research and Development. Cincinnati, Ohio, USA.
- Ersan, Y.C., Gulcimen, S., Imis, T.B., Saygin, O., and & Uzal, N., 2022, Life cycle assessment of lightweight concrete containing recycled plastics and fly ash. European Journal of Environmental and Civil Engineering, 26:7, 2722-2735, DOI:10.1080/19648189.2020.1767216
- Flower, D.J.M. and Sanjayan, J.G., 2007, Greenhouse gas emissions due to concrete manufacture. International Journal of Life Cycle Assessment 12(5), 282-288
- Goyal, H., Kumar, R., Mondal, P., 2023, Life cycle analysis of paver block production using waste plastics: Comparative assessment with concrete paver blocks. Journal of Cleaner Production 402, 1-12
- Gravina, R.J., Xie, T., Bennett, B., Visintin, P., 2021, HDPE and PET as Aggregate Replacement in Concrete: Life-cycle assessment, Material Development and a case study. Journal of Building Engineering 44 (2021), 1-14
- ISO/SANS 14040, 2006, Environmental management – Life cycle assessment – Principles and framework. South African National Standard
- ISO/SANS 14044, 2006, Environmental management – Life cycle assessment –Requirements and guidelines. South African National Standard
- Joburg, 2019, Tariffs 2019/2020. Online available from:
- https://joburg.org.za/documents_/Documents/TARIFFS/Tariffs/big%20%20tariff.pdf, [accessed: 03 March 2020]
- Kurda, R., Silvestre, J.D., de Brito, J., and Ahmed, H., 2017, Effect of incorporation of high volume of recycled concrete aggregates and fly ash on the strength and global warming potential of concrete. Journal of Cleaner Production 166, 485-502
- Kumar, P., and Kumar, G., 2016, Effect of Recycled Plastic Aggregates on Concrete. International Journal of Science and Research (IJSR) 5(6), 912-915
- Kurda, R., Silvestre, J.D., and de Brito, J., 2018, Life cycle assessment of concrete made with high volume of recycled concrete aggregates and fly ash. Resources, Conservation and Recycling 139, 407-417
- Marinković, S., Habert, G., Ignjatović, I., Dragaš, J., Tošić, N., Brumaud, C., 2016, Life cycle analysis of recycled concrete with fly ash as partial cement replacement. Sustainable Built Environment (SBE) Regional Conference Zurich
- Mello, R.Z., Coelho, F.Z., and Calmon, J.L., 2016, LCA of waste PET particles as a partial replacement for sand in self-compacting concrete. SB16 Brazil & Portugal Sustainable Urban Communities towards a Nearly Zero Impact Built Environment
- Miller, S.A., Monteiro, P.J.M., Ostertag, C.P., and Horvath, A., 2016, Concrete mixture proportioning for desired strength and reduced global warming potential. Construction and Building Materials 128, 410-421
- Mokoena, R., and Mgangira, M, 2018a, Laboratory Investigation of Environmentally Sustainable Concrete Paving Blocks. Pavement Materials Characterization., Council for Science and Industrial Research (CSIR), Pretoria
- Mokoena, R, 2018b, PG Report: Block Paving System. CSIR Technical Report, Pretoria
- Muigai, R., Alexander, M.G., and Moyo, P., 2013, Cradle-to-gate environmental; impacts of the concrete industry in South Africa. Journal of the South African Institution of Civil Engineering, 55(2), 2-7
- Nikbin, I.M., Dezhampanah, S., Charkhtab, S., Mehdipour, S., Shahvareh, I, Ebrahimi, M, Pournasir, A, and Pourghorban H., 2022, Life cycle assessment and mechanical properties of high strength steel fiber reinforced concrete containing waste PET bottle. Construction and Building Materials 337, 1-20
- Reynolds-Clausen, K., Singh, N., 2019, South Africa's power producer's revised coal ash strategy and implementation progress. Coal Combustion and Gasification Products 11, 10-17
- Saikia, N., and de Brito, J., 2012, Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Construction and Building Materials 32, 385–401
- SANS 1058:1985. Concrete paving blocks. South African National Standard. South African Bureau of Standards Division. Pretoria, South Africa
- SANS 1058:2012. Concrete paving blocks. South African National Standard. South African Bureau of Standards Division. Pretoria, South Africa
- SANS 50197-1:2013, Cement Part 1: Composition, specifications and conformity criteria for common cements. South African National Standard
- Seto, K.E., Churchhill., C.J., and Panesar, D.K., 2017, Influence of fly ash allocation approaches on the life cycle assessment of cement-based materials. Journal of Cleaner Production 157, 65-75
- Siddique, R., 2010, Utilisation of coal combustion by-products in sustainable construction materials. Resources, Conservation and Recycling 54, 1060-1066
- Sleeswijk, A.W., van Oers, L.F.C.M., Guinée, J.B., Struijs, J., and Huijbregts, M.A.J., 2008. Normalization in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. Science of the Total Environment 390(1), 227-240.
- Sharma, R., and Bansal, P.P., 2016, Use of different forms of waste plastic in concrete – a review. Journal of Cleaner Production 112, 473-482
- Treyer, K., and Bauer, C., 2016, Life cycle inventories of electricity generation and power supply in version 3 of the ecoinvent database – Part I: electricity generation. International Journal of Life Cycle Assessment 21, 1236-1254
- UNEP/SETAC Life Cycle Initiative, 2023, What is Life Cycle Thinking? Online available from: https://www.lifecycleinitiative.org/activities/what-is-life-cycle-thinking/, [accessed: 20 September 2023]
- Van de Heede, P and De Belie, N., 2012, Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations. Cement and Concrete Composites 34, 431-442
- Wang, J., Wang, Y., Sun, Y., Tingley, D.D., and Zhang, Y., 2017, Life cycle sustainability assessment of fly ash concrete structures. Renewable and Sustainable Energy Reviews 80, 1162-1174

INFRASTRUCTURE

The circular economy, human settlements and municipal government

Antony K Cooper, Tinus Kruger,
Linda K Godfrey & Mark Napier

The linear economy is where resources (including energy and space) move through the economy in one direction, from being harvested, collected or mined, through refining and processing to create products and services, to uses and consumption, until being discarded. This creates value only while available resources are entering at one end and the waste exiting at the other does not foul up anything, or even everything.

The circular economy goes beyond just repeated recycling of end-of-life materials. It aims at rethinking how the economy functions: designing out waste and pollution in the first place, keeping resources, materials and products in use for as long as possible (through reuse, refurbishing, repurposing, recycling, etc) and regenerating natural systems to improve ecosystem services (such as trapping carbon and pollutants) and renew natural capital.

A human settlement is essentially any collection of buildings, from hamlets and villages to cities and megalopolises. Human settlements are diverse, comprising mixes of housing (informal and formal), retail, wholesale, commercial, manufacturing, social services, recreation, urban farming, and parks and other green and blue spaces. Circularity can occur at many levels within human settlements, within homesteads, neighbourhoods, suburbs, towns and cities, and between human settlements.

This chapter considers the current resources within human settlements for circularity, the expected trends, the potential resource constraints for future growth of circularity, key economic and socio-economic gains and losses associated with the linear economy, and opportunities for the circular economy in human settlements.

Note that this paper follows on from the book, The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, edited by Linda Godfrey and published by the CSIR in 2021, particularly the chapter, Creating resilient, inclusive, thriving human settlements through a more circular economy [Cooper et al 2021].

1. Human Settlements: Current development path

1.1 Brief overview

The linear economy is where resources (including energy and space) move through the economy in one direction, from being harvested, collected or mined, through being refined and processed to create products and services, to being used and consumed, until being discarded or thrown away. The linear economy creates value only while there are available resources entering at one end and the waste exiting at the other does not foul up anything, or even everything. Unfortunately, many of the resources required for the linear economy are non-renewable (finite) and are running out or becoming uneconomical to obtain. At the other end of the line, waste disposal is becoming more difficult, with landfills filling up, everything becoming polluted, and the climate being changed by greenhouse gases. A key problem with breaking out of the linear economy is that there are

too many incentives for not doing so, such as not having to pay for the pollution and other environmental and social damage caused by one's processes, products and waste [Cooper 2022; Cooper et al 2021; Godfrey 2021b; UNEP 2022].

The circular economy aims at changing this by rethinking how the economy functions: designing out waste and pollution in the first place, keeping resources, materials and products in use for as long as possible (through reuse, refurbishing, repurposing, recycling, etc) and regenerating natural systems to improve ecosystem services (such as trapping carbon and pollutants) and to renew natural capital. While the label circular economy might be recent, many of the actions considered to be circular have been practiced for a long time, such as recycling [Godfrey 2021b]. Godfrey [2021b] provides an overview of the circular economy in general, and within human settlements (or the built environment) specifically [Cooper et al 2021].

The charity, Tearfund [Gower & Schröder 2016], identified some obstacles to the circular economy in low and middle-income countries: mispricing of externalities and resources (eg: dirty energy is often subsidised), no access to credit, information failures (including limited access to intellectual property), coordination problems, and poor design incentives (planned obsolescence, products difficult to repair, and toxic materials).

A human settlement is essentially any collection of buildings, from hamlets and villages to cities and megalopolises. They are diverse, comprising mixes of housing (informal and formal), retail, wholesale, commercial, manufacturing, social services, recreation, urban farming, and parks and other green and blue spaces, and are used for many purposes [Cooper et al 2021; Petzer et al 2020]. There are many linkages (or networks) within and between human settlements for distributing goods, services, energy and people, such as roads, railways, water courses, pipelines, cables and other networks. These linkages consume energy, water and other resources, while increasing pollution, carbon emissions and waste [Cooper et al 2021].

About two-thirds of South Africans already live in urban areas [Statista 2021], but often with inappropriate spatial planning due to Apartheid and modernism, with sprawl, low densities, monofunctional neighbourhoods and informality [CSIR & DHS 2019]. Key problems with South African human settlements are that many municipalities do not provide adequate amenities,

services and public spaces, and conduct inadequate maintenance [AGSA 2023]. Further, they are perceived to be energy- and carbon-intensive, and to produce inefficiencies and excess waste [SEA 2020]. Additional research is needed to explore these assumptions in South Africa, though the Auditor-General of South Africa has found that there is "defective management and delivery of wastewater and solid waste services at 60% of the municipalities" [AGSA 2022].

Nominally, the earlier circularity happens, the better, but we would suggest the opportunities are likely to be limited with fewer resources available close to the source. There might be unexpected costs and lost opportunities. Closing resource loops (resource use and reuse) within a municipality can facilitate managing the loop, with only one municipality being responsible for the whole loop [Williams 2021]. The more wide-ranging the circular economy, the greater the logistical complexity and energy demand: fuel, electricity, human effort, etc – but the greater the opportunities for reuse, repurposing, renovating, recycling, etc.

1.2 Linear and circular economies

Unfortunately, "Circularity is in reverse: our 2020 report communicated that the global economy is 8.6% circular, while our 2018 edition reported 9.1%. Alongside our widening Circularity Gap, the world is heating up" [Circle Economy 2021]. Since then, various events have caused a world-wide energy crisis with shortages and high energy prices, particularly for natural gas, causing an increase in the use of coal [IEA 2022].

The waste and pollution of the linear economy cause about 16% of all deaths worldwide (over 44 000 in South Africa annually) and about 275m disability-adjusted life years (DALY), and squanders 6.2% of global output through welfare losses – yet deaths and DALYs from cadmium, chromium, endocrine disruptors, mercury, pharmaceutical wastes, plastics and radionuclides have not been determined [Landrigan 2018, GAHP 2019]. Air pollution kills about one million people annually in Africa, through strokes, heart disease and lung diseases. Reducing waste and pollution can also boost economic growth [Landrigan 2018, GAHP 2019]. In 2019, over 90% of the global population lived where $PM_{2.5}$ concentrations exceed the 2005 Global Air Quality Guidelines (AQGs) of the World Health Organisation (WHO) – based on better research and data, WHO has made many AQGs more stringent, without yet accounting for exposures to multiple types of pollution [WHO 2021].

The circular economy should decouple growth from exploiting resources (particularly water and dirty energy), to being derived from growing knowledge and productivity, which should help reduce conflicts over resources. The circular economy is about managing resources and development risks sustainably; and discovering and exploiting possibilities for creating jobs and flourishing activities [Nahman et al 2021]. This aligns with the solidarity economy (or social and solidarity economy) where social profitability (eg: cooperatives, fair trade, ethical purchasing, gifting, local currencies, and self-help organisations) should take priority over financial profitability [RIPESS 2023]. Further, circularity aligns with the environmental, social, and governance (ESG) criteria often used for investing [Feyertag & Bowie 2021].

It is claimed the circular economy will improve economic growth and employment and slash pollution, but the focus has been on high-income countries, while lower-income countries are becoming less resource efficient [Gower & Schröder 2016]. However, "the costs of implementing social risk mitigation activities in emerging markets are around 2% of project costs" – but the costs of not doing so are 2 to 4 times greater [Feyertag & Bowie 2021]. The most successful activities are community meetings, stakeholder mapping and grievance resolution mechanisms, then training and operational monitoring, and social impact assessments [Feyertag & Bowie 2021]. Circularity alone is insufficient to justify a project or intervention: it needs to be useful as well.

1.3 Overview of current resources within human settlements

"As places of concentrated economic activity, cultural diversity, learning, innovation and creativity, cities can enable a country to build a dynamic competitive advantage and allow its people to advance socially and economically. They are also critical for achieving national environmental objectives" [CoGTA 2016].

Due to loadshedding (rolling blackouts), oil prices, and rail and harbour constraints on exports, real GDP growth is now forecast to be 0.3% for 2023 and 1.0% for 2024, both lower than previous forecasts [SARB 2023]. The infrastructure development and maintenance grants from national government to municipalities were R 35.45 bn in 2020-21, of which 93% was spent, but this declined to R 33.31 bn in 2021-22, yet only 91% was spent [AGSA 2023].

Of the 257 municipalities, 78 received qualified audits with findings for 2021-22 (vs 83 in 2020-21), 6 adverse audits (vs 4 in 2020-21), 15 disclaimed audits with findings (vs 26 in 2020-21) and 16 had outstanding audits (vs 3 in 2020-21) – and 21 of these municipalities were under administration or intervention during 2022 [AGSA 2022]. Over a quarter of municipalities are in such poor financial positions it is unlikely they can function as going concerns soon – they owe too much already, and their revenue does not cover expenditure. Then, 47% of municipalities owed more than they had available, so they raided the following year's budget to pay for current expenditure [AGSA 2021, 2022].

Key problems are municipal debts not paid (R 41.2 bn was written off in 2020/1 alone); incorrect billing; not knowing what is owed; poor budgeting practices; not paying creditors (including small businesses), with creditor days increasing from 139 to 240 days over five years; ineffective supply chain and financial management; and not disciplining irresponsible municipal officials [AGSA 2022]. Municipalities owe Eskom over R 36 bn and water boards over R 14 bn [AGSA 2023]. Thus, much municipal income must be spent on interest and penalties (R 1.2 bn during 2020/1 alone) – yet over the five financial years to 2020/1, R 14.1 bn went on fruitless and wasteful expenditure, but municipalities do not report all irregular expenditure [AGSA 2021, 2022, 2023].

Municipal reporting on performance is even worse: "But most telling is municipalities' inability to plan for, and report on, their performance" [AGSA 2022]. Many municipalities do not really know what they are doing to deliver services, making it difficult for them to improve service delivery: "In our assessment, the senior management of only 11% of municipalities was fully effective" [AGSA 2022]. There is also inadequate oversight by municipal councillors and instability amongst the political and administrative leadership [AGSA 2022], with the President stating at a recent meeting of Mayors, "I am told that more than 300 councillors have been killed in the past few years by virtue of being councillors" [Ramaphosa 2022].

Further, 40% of municipalities have indicators and targets that are useless [AGSA 2022], such as the target being holding meetings on a topic rather than being outputs or outcomes for the topic. As the AGSA [2022] points out, this hampers effectively managing the municipality and makes it difficult for anyone (councillors, community members, other government entities, etc) to monitor how well any municipality functions.

Many municipalities have poor and out-dated asset registers, so they cannot account for all their assets and might lose the documentation for operating and maintaining them [AGSA 2022]. Thus, assets could become inoperable prematurely; or could be stolen, lost or abandoned accidentally, without the municipality realising it. Such assets could be duplicated or replaced unnecessarily; abandoned assets could become hazards or pollution sources, as the contents leach out; records might not be kept of dangerous materials stores; or maintenance might be inappropriate, as the asset register does not keep track of when and what is required.

The Integrated Urban Development Framework (IUDF) aims for a sustainable urban growth model of compact, connected and coordinated cities and towns [CoGTA 2016]. The IUDF calls for urban areas to transition to "resource-efficient infrastructure systems, which provide for both universal access and more inclusive economic growth" [CoGTA 2016]. A review for National Treasury [2018] identified the following as key underlying issues for the IUDF's. Unsurprisingly, some are typical of problems with the linear economy.

- The over-emphasis on housing megaprojects most often on the peripheries of urban areas, that then trap the poor (because of the resulting transport costs and the lack of jobs) and exacerbate urban sprawl. The review proposes that housing projects should rather "stimulate infill, densification, conversion and refurbishment" and improve existing backyard dwellings and informal settlements, such as through upgrades and better services, including ensuring that settlements conform to regulations, particularly for health and safety [National Treasury 2018].
- The focus on the supply of subsidies creates housing dependency and distorts the market. It would be better to focus on the demand for middle-income households, and subsidised rents

and small-scale rental housing for lower income households [National Treasury 2018]. Encouraging housing supply by the private sector could, according to supply-demand modelling, reduce unmet demand and informality significantly [Napier et al 2022].
- Different modes of public transport are not integrated into comprehensive networks across the urban areas and there is the legacy of hub-and-spoke public transport, inappropriate technology choices and separated funding streams. Rather, there should be integrated, multi-modal public transport networks across urban areas, which are polycentric [National Treasury 2018].
- Municipal funding is constrained, increasing the risks with capital expenditure because of covering recurring costs to maintain and operate the infrastructure. Thus, new ways are needed for increasing municipal revenues and for more flexible grants from central government [National Treasury 2018].

In 2018, the total expenditure in South Africa on construction and related activities was over R430 billion, but the sector has been struggling, shedding 142 000 jobs in the first quarter of 2019. However, public sector expenditure on construction for residential buildings was only R 1 910m in 2018 and R 712m in 2020, and for other buildings was R 16 812m in 2018 and R 8 406m in 2020. The key problem has been the decline in spending on infrastructure, due to the poor local economy and the threats of expropriation of land and buildings without compensation [Potgieter et al 2020; Napier et al 2022]. There is still much demand for housing in urban areas: even with significant improvement of housing delivery, in Gauteng alone there is likely to be unmet demand of over 600 000 housing units in 2030 [Napier et al 2022].

Cities need to attract the people, businesses and diverse economic activities to make them competitive and boost incomes. Sustainability is integral to a resilient built environment [WEF 2021]. Urban economies often mirror their national economies and the global economy. Challenges of the linear urban economy include [EMF 2017, WEF 2021, Potgieter et al 2020]:
- Limited holistic planning and management.
- Limited awareness of circular economy opportunities and relevant vocational training.
- Increasing consumption of resources due to increasing urban populations and increasing wealth.
- Existing buildings are seldom refurbished, remodelled, recycled or deconstructed and they often produce significant emissions during operations and when demolished. This increases unnecessarily the demand for land and buildings, and for building materials, particularly cement, building sand, aggregates, metals and bitumen. These materials are often expensive because of shortages and transport costs, which can lead to illegal mining, particularly for river sand.
- Many buildings have poor energy efficiency and waste containment.
- Increasing demands and pressures on constrained government resources (particularly funding) and urban infrastructure.
- Structural waste and environmental impacts causing economic losses (such as materials lost to landfills and incineration) and health problems.
- Unfortunately, disposing waste to landfills is often so cheap that it discourages reuse, recycling or recovery at source, though many waste pickers recover materials from landfills.
- Many resources are idle, such as motor vehicles spending much of their time parked and offices being vacant for more than half the week (made worse by the lockdowns due to the COVID-19 pandemic).
- Traffic congestion, wasting time and fuel [EMF 2017, WEF 2021, Potgieter et al 2020].

Of about 875 Mt of materials extracted annually in South Africa, about 170 Mt are exported, about 221 Mt are extractive wastes (with limited recycling potential) and about 105 Mt are wastes that could be reused or recycled [Von Blottnitz et al 2022]. The material flows in South Africa's economy are dominated by export-oriented extractives; energy is dominated by fossil fuels (mainly domestic coal and imported oil); the rate of domestic stock building of infrastructure is low; there are pockets of significant circularity with much informal activity, but overall recycling is only 2%; and while bio-based flows are about 17% of domestic extraction, there are concerns about the sustainability of ecological cycling [Von Blottnitz et al 2022].

The circular economy goes beyond just repeated recycling of end-of-life materials. For example, the Demolition Depot in New York City trades in fixtures, fitments and building materials recovered from buildings that have been demolished or altered, or after businesses have closed. Many of these decorative and functional artifacts are finely crafted original examples from iconic architectural styles of the past that are attractive and can be reused in different contexts [Demolition Depot 2022].

While South African households do not recycle much, South Africa has a relatively high rate of recycling due to waste pickers, who collect, sort and distribute recyclable and reusable waste. It is estimated that informal reclaimers collect about 1 445 567 tons annually, about three-quarters of all waste collected in South Africa for recycling [Godfrey 2021a]. These waste pickers recover from landfill sites, dump sites, kerbsides (including from waste bins) and directly from businesses and sell on to brokers and recycling businesses. Integrating the informal waste sector into the formal sector needs to maintain the dignity of the pickers and to create value to be sustainable [Potgieter et al 2020]. The waste pickers help prevent waste accumulation, lower costs for governments and businesses, and provide livelihoods. However, they probably need support to organise and improve their working conditions [Gower & Schröder 2016].

Urban Surfer aims to integrate the work of informal waste reclaimers. Urban Surfer claims there are over 140 000 informal reclaimers who recycle 80-90% of the plastic and paper packaging waste recycled in South Africa. They aim to support those doing the recycling and for example, track reclaimers who volunteer to show where they collect waste and how far and wide, they range [Urban Surfer 2022].

1.4 Expected trends in human settlements

South Africa's population is still growing at ~1.01% (though the rate is declining [Stats SA 2021b]) and there is much migration from rural to urban areas, including circular labour migration: migrants who do not consider the urban area to be their home, even though they have lived there for many years. Their rural "landscape of home remains central to migrants' cultural identity, belonging and well-being" [Njwambe et al 2019]. Over 2016-2021, Stats SA [2021a] estimates the total inter-provincial migration at 3 625 800, with most migration (56%) being to Gauteng (1 564 861 people) and the Western Cape (470 657). Stats SA does not estimate the rural-urban migration trends, but migration to Gauteng and the Western Cape is likely to be into urban areas. It is important to realise that both the rich and the poor migrate to urban areas, though for different reasons.

Migration can be voluntary (mainly due to pull factors), or involuntary due to unfavourable conditions, or forced due to environmental or socio-political conditions: refugees, asylum seekers and internally displaced persons [WEF 2017]. The World Economic Forum (WEF) lists various push and pull causes of migration, both internal and across borders. Particularly relevant to migration to urban areas and the current linear economy in South Africa are the economic pull factors of perceived job opportunities and wealth prospects, and primarily for the better educated, the specialised education of universities and colleges and industrial innovation creating demand for scarce skills. Further pull factors are perceived freedom (such as from authoritarian tribal authorities), better social and recreational services and amenities, and family reunification – though this can be in the other direction as well, as people return to rural areas to retire (investing in the interim to upgrade their family's dwellings) or because they are dying of AIDS [WEF 2017; Nwambe et al 2019]. A key push factor from rural areas is probably safety and security, particularly for commercial farmers and their staff. This is likely exacerbated by the complexities of modern farming, poor rural infrastructure (hampering getting produce to markets) and political instability due to poverty and the threats of expropriation without compensation.

The impacts on the urban areas can be both positive and negative [WEF 2017]. On the positive side, growing urban populations should provide larger markets, more labour (though with surpluses and hence downward pressure on wages and employment), increase tolerance through the growth and integration of multi-ethnic and multi-cultural societies, and access to new services and thinking brought in by immigrants and migrants. Politically, growing urban populations are likely to push for more-inclusive policy making and integrated development, because of greater awareness due to the diversity of opinions they encounter [WEF 2017].

Many who migrate to urban areas remit value back home, be it through money transfers or investments in housing and farming equipment. These can have positive impacts, such as providing additional money to circulate in the rural economy. But they can have negative impacts in rural areas, such as encouraging others to migrate due to the urban wealth displayed or by creating entitlement and discouraging their beneficiaries from working productively in the rural areas. In urban areas, if such remittances are substantial, they could reduce the wealth available to support local consumption in those urban areas, potentially reducing available jobs and increasing risks for those making retail-oriented investments in those urban areas [WEF 2017].

The key impact of growing urban populations is increasing demand for urban services and social infrastructure, exacerbating the parlous state of many municipalities. These include housing, schools, clinics, hospitals, community centres, shops, recreation facilities and the road and rail networks to access them. Further, there is a need to improve social inclusion and integrate community development. However, these are limited by the availability and affordability of suitable land and housing units, and the risks of inappropriately distributing the population, which can create congestion on roads and in pedestrian spaces, consume more resources and redirect scarce public funds [WEF 2017]. Between 1990 and 2020 in Gauteng alone, the urban land use (excluding smallholdings) grew from 1 309.1 km2 to 2 145.5 km2, over 11% of the province [Ballard et al 2021].

Cape Town is a major destination for migrants, receiving 125 528 between 2011 and 2016, being over 3% of its population in 2016 [Stats SA 2021a]. Key pull factors are that Cape Town provides better access to basic services and more economic opportunities, and to reconnect with family and friends who migrated previously. The challenges are housing (notoriously expensive in and around Cape Town), education, unemployment (23% for Cape Town), congested roads, metro rail system failures and integration and social cohesion (that is, preventing xenophobia). The municipality expects community and political leaders to set the tone for how residents respond, as some escalate volatile situations with their language and attitudes [WEF 2017].

These trends all increase consumption of resources and demands and pressures on urban infrastructure and government resources. Without an holistic approach to urban management, this results in economic losses due to structural waste and negative environmental impacts [EMF 2017].

Some indicators of spatial transformation in neighbourhoods facilitating the circular economy include the degree to which residents can access various freedoms, rights and benefits, particularly to enhance their quality of life and well-being. These include the density of neighbourhoods being sufficient to enable efficient service delivery, while houses themselves are not overcrowded; accessibility of job opportunities and public facilities and services, such as through affordable public transport; and walkability of a neighbourhood, where residents can walk safely to a range of facilities, services, activities and job opportunities [Petzer et al 2020].

There are many different models or paradigms for urban design and planning, possibly indicating that none is perfect. A recent term aligning with circularity is the 15-minute city [Moreno 2016; Moreno et al 2021], with the intention that most people can meet most of their needs within a 15-minute walk or bicycle ride from their home (about 1 to 5 km). The concept in various forms has been proposed before, such as the isobenefit urbanism of D'Acci [2013]; the Leadership in Energy and Environmental Design for Neighbourhood Development (LEED-ND), launched in 2009 [US Green Building Council 2022]; New Urbanism and its many variations from the 1980s [CNU 2015]; car-free movements; and Jacobs' [1961] focus on active sidewalk life.

The 15-minute city is a flexible concept based on inclusive, mixed-use neighbourhoods with work opportunities and core services and amenities: education, healthcare, retail (particularly for fresh fruit and vegetables), green and other public spaces (including urban farms), digital connectivity, co-working spaces, public transport, cycle lanes, broad sidewalks, and active street life. The 15-minute city should reclaim the space dominated by motor vehicles and reduce vehicle pollution by reducing their need. These are also called complete neighbourhoods and they should be convenient and improve health, wellbeing and community cohesion and sustainability – and facilitate circularity. However, the community should not be isolated and confined to their neighbourhood. While some boundaries can be hard, such as rivers or highways, neighbourhood boundaries should be fluid [C40 2020, 2021b, 2021c; Moreno et al 2021; Chamberlain 2022; Weng et al 2019].

The 15-minute city also correlates with the guidelines of the Red Book for laying out human settlements in South Africa, such as compactness, and walkable neighbourhoods with a variety of housing choices and quality public transport [Van Niekerk et al 2015; CSIR & DHS 2019]. Essentially, the 15-minute city is a return to the mixed-use walkable neighbourhoods, towns and villages from before motor vehicles, but with much more available for residents. It should also support the principles of crime prevention through environmental design (CPTED): surveillance and visibility (with more pedestrians as eyes on the street), territoriality (as inhabitants take a sense of ownership as they are not isolated from the neighbourhood by their cars) and image and aesthetics (as people are more actively involved in their environment) [Kruger et al 2016].

1.5 Potential resource constraints for future growth

The IUDF recommends that urban areas be planned and managed well to benefit from productivity and growth and provide sustainable quality of life for all. This includes investing in integrated, inclusive and multi-functional social and economic development; reducing pollution, GHG emissions and noise; transporting goods and services efficiently; investing appropriately in land and property to provide municipal income for further investments; fostering entrepreneurialism and innovation; being stable, safe, just and tolerant; and enabling people to walk, cycle and use public transport in safety to access economic opportunities, social services, recreation and other needs [CoGTA 2016].

Waste management and waste disposal sites are critical constraints. It is estimated that in developing markets, solid waste collection and management can use up to half a municipality's budget [EMF 2017]. Some South African municipalities are running out of space in their landfills and suitable places to site new ones. The further away landfill sites are, the more expensive it is to transport waste to them (yet much waste gets shipped around the world!). Thus, it should be more economical to recycle or otherwise reuse waste, rather than throw the waste away. Unfortunately, landfills are still considered the cheapest way of disposing of waste because of the lack of appropriate costs for the polluters. It can take five years to get a licence for a new landfill site and then a further year to build it, to ensure containment of the hazardous waste, etc [Githathu 2019]. There can be a significant correlation between changes in GDP and the increase in the size of a landfill site (such as Robinson Deep in Johannesburg) – but increasing the stringency of restrictions on movement (specifically for the COVID-19 pandemic) increases the sizes of landfills, despite the drop in GDP [van Zyl & Celik 2021].

Landfill sites can generate much methane as organic wastes decompose, but these gases are being harvested at some landfills to generate energy. However, if not managed properly, the methane can ignite, creating fire hazards and producing toxic fumes and an overpowering stench. Such fires can burn for many days and be difficult to control because of the dangerous conditions, thus taxing the limited resources of fire services. An example is the massive Ghazipur landfill in Delhi, India, which exceeded its capacity a decade ago, but is still being used. It catches fire occasionally, such as in March 2022 [Verma 2022]. Further hazards are illegal landfills and open dumping.

Some construction materials are becoming expensive due to shortages and the cost of transport, such as building sand and bitumen. The principles of the circular economy can alleviate this, by mixing certain wastes into concrete and asphalt, including furnace slag and crumb rubber. Because of the shortages, there is much illegal mining of sand and aggregates around the world, including in South Africa. The industry body representing legal miners feels the government and police are not taking illegal mining seriously. As well as damaging the environment (such as taking sand from rivers and wetlands), illegal mining causes pollution problems, leaves large and unrehabilitated pits causing safety risks for humans and animals, and threatens the viability of legal miners [O'Reilly 2021].

There is a limit to the availability of land, particularly for new or greenfield developments. Further, new developments should be sited appropriately, such as having residential areas close to employment opportunities and social services, and industrial areas close to resources and transport. As discussed above, urban areas already cover over 11% of Gauteng and there are suitable sites for brownfield developments, such as industrial areas that have lost tenants [Mthuli 2022].

Poor environmental conditions due to the linear economy impact on human health, which can undermine the competitiveness of a city and cause a brain drain (which is happening in China, for example), depriving a city of the skilled people who can help the transition to a circular economy [EMF 2017]. Replacing hard surfaces with green spaces and water-permeable surfaces can help combat urban heat islands, stabilise hills to prevent landslides, and improve liveability [UCCRN 2018].

With various other organisations, the Ellen MacArthur Foundation has developed toolkits for assessing circularity and implementing circularity [EMF 2021, 2022c]. These include:

1. **Circulytics,** a toolkit for measuring circular economy performance, is aimed at private companies and other organisations. It covers 11 themes that are enablers (such as strategy, planning, innovation, people, skills and external engagement) and outcomes, such as products and materials (and waste), services, asset procurement and consumption of water and energy. It is updated annually [EMF 2022a].
2. **The Circular Buildings Toolkit,** with a high-level framework (build nothing, build for long term value, build efficiently, and build with the right materials) to bring the circular economy to buildings and real estate, going beyond just energy efficiency and aiming to future-proof assets as policies change rapidly. The toolkit includes examples, such as material passports, hiring building materials for temporary structures, modular lighting, and prefabricated timber structures [EMF 2022b].
3. **An actionable toolkit** for policy makers to deliver the circular economy, which has three principles (preserve and enhance natural capital, optimise resource yields and foster system effectiveness), using the ReSOLVE framework: REgenerate, Share, Optimise, Loop, Virtualise and Exchange [EMF 2022c]. Based on a pilot in Denmark, the toolkit has eight key insights:

- Transitioning to the circular economy has lasting benefits of greater innovation, resilience and productivity; creating jobs; reducing the carbon footprint; reducing the use of virgin materials and boosting GDP.
- Many circular economy opportunities are inherently profitable.
- Sector-by-sector analysis is important due to the variety of opportunities and challenges.
- Better measures of economic performance than just flow-based metrics are needed.
- Industrial involvement and collaboration across government are crucial.
- Even in advanced economies there are many circular economy opportunities.
- Policy interventions need to be aligned as many value chains extend across borders.
- The outcomes of applying the toolkit will differ across countries [EMF 2022c].

ReSOLVE focuses on economic systems rather than societal benefits (such as social services), and on production systems, while many cities are more centres of consumption. Further, ReSOLVE does not consider land and infrastructure [Williams 2021].

1.6 Key gains and losses associated with the current path

It is difficult to identify potential socio-economic gains from the current path of the largely linear South African economy, which has been struggling for many years, with high inequality, much unemployment, corruption, and concerns over the state of public infrastructure and public services. It has been estimated that in comparison to the base line (the economy that is largely linear), moving significantly to a circular economy would boost South Africa's GDP by 0.8% and employment by 1.3%, but increase CO2 emissions by 0.1% (because electricity production is currently dominated by coal) [Potgieter et al 2020]. Circular economy projects are also more likely to attract funding from international donors.

Key socio-economic problems (or losses) with the current linear economy include pollution, noise, biodiversity loss, health problems, greater travel costs (particularly for the poor), landfills that are over-full and become hazardous, scarce resources squandered on dealing with waste, infrastructure that is abandoned or underused, and shortages of key resources (and hence higher costs for them). Further, South Africa probably needs to move to a circular economy to ensure its exports are still accepted internationally. As discussed below, there are many opportunities for the circular economy in human settlements. For example, the industrialised production and 3D printing of building modules is likely to have the most significant impact for the circular economy in human settlements. Other

key opportunities are reuse, high value recycling, sharing and multi-purpose buildings [EMF 2022c].

2. Human Settlements: Circular development path

2.1 Circular economy opportunities in human settlements

Circular economy interventions cannot be considered in isolation, but should deal with other issues, such as South Africa's triple threat of poverty, inequality and unemployment. For example, moving to renewable energy will increase significantly the jobs in the energy sector worldwide [Pai et al 2021]. The concepts behind, and components of, the circular economy are also part of resilience, sustainability, inclusivity, the sharing economy and so on. Thus, circular economy interventions overlap with other desirable outcomes, such as occupational health and safety. For example, collecting and separating waste on a construction site not only facilitates reuse and recycling, but also neatens up the environment, removing tripping hazards, etc. The classic circular economy principles, such as of the Ellen MacArthur Foundation [EMF 2021] are:

- **Design out waste,** e.g., green, energy-efficient buildings, more compact cities, pedestrian-friendly neighbourhoods.
- **Keep materials in use,** e.g., circular construction value chains, circular organics, waste management.
- **Regenerate natural systems**, e.g., urban agriculture, renewable energy, green roofs, green and blue open spaces [EMF 2021].

Interventions can cut across all three of the principles, particularly as designing out waste could often keep materials in use or help to regenerate natural systems. For example, within a neighbourhood, one could design out organic waste (food and garden waste) by setting up a system for collecting, sorting and using the waste as compost for a regenerated natural system in the neighbourhood where useful resources are grown, such as vegetables, fruit and mushrooms. This has been done with Moja Gabedi, a site in Hatfield, Pretoria, that was an unofficial landfill – 4 metres deep – but is now a meaningful food garden. About 3000 tons of waste were removed and replaced with about 3000 tons of topsoil and 200 tons of compost [UP 2021].

We suggest that there are three further broad perspectives or views for understanding possible circular economy interventions in human settlements. There is the rationale for the interventions, such as improving how the economy is managed and society functions (governance); because people want it (culture); to reduce costs and improve performance (infrastructure); and to exploit new developments (technology – while being wary of technology push). Then, there is the agency of the interventions, that is, where the power and benefits lie and thus what is likely to make the intervention happen. Finally, we would suggest there is the sector where the intervention is made, which specifically for human settlements includes construction, existing buildings and structures, transport, formal and informal business clusters, and households (perhaps the most critical, to get everyone thinking about circularity and the benefits).

However, one circular economy intervention can clash with other perspectives of circularity, most obviously when new technologies are imposed on a community without consultation or considering cultural values. Further, the intervention might not have been considered carefully or might be primarily for circular washing or to tick boxes. The opportunities for the circular economy in human settlements can range from small interventions, such as an individual consumer reusing shopping bags, to large infrastructure projects, such as for renewable energy. The opportunities could be for new products and services, but also for helping to change perceptions. For example, a poor neighbourhood might be sceptical about the reasons for banning plastic bags, as they can be very useful. In Côte d'Ivoire in 2013, "the production, import, marketing, possession and use of plastic bags" was banned, but despite the ban and other interventions, over 200 000 tonnes of plastic bags worth over US$ 27 million are still produced annually in Côte d'Ivoire [Koumi 2020].

Each intervention needs compromises, most obviously over available resources, especially funding. Further, with many different types of stakeholders, the inputs and outputs, and the costs and benefits can easily be quite removed from one another. We would suggest it is relatively easy to sell initiatives where the costs and benefits occur quickly, but difficult to sell benefits that happen only in the long term while the costs occur in the short term. On the other hand, where the benefits occur in the short term but the costs in the long term, there is the risk future generations will have to carry the costs. When both costs and benefits occur well into the future, it is difficult to assess if the intervention is positive or negative, because so much can change. This correlates with the principles of distributive justice, how burdens and benefits are allocated; procedural justice, who decides; and recognition, basic respect and robust but fair engagement [Pörtner & Roberts 2022].

There is a risk of the tragedy of the commons where the common goods (such as air) get overused (such as by pollution) because few consider their own use excessive or inappropriate and can point to others who are far worse. Using the common goods can be regulated to ensure prudent use, but local communities can also mitigate against the tragedy of the commons through peer pressure, such as documented by Ostrom [1990].

Other concerns with the circular economy include:

- Basic, seemingly non-circular interventions might have a greater and quicker impact, such as maintaining infrastructure to prevent waste and inefficiencies (eg: leaks in potable water pipes).
- Conflict with consumerism where celebrities, influencers and the media thrust the glitzy, resource-intensive consumer lifestyle upon everyone: "Wealthy people set the tone on consumption to which everybody aspires" [Paddison 2021]. But on an individual level, happiness and status within the community could increase as circularity in their lives increase.
- Dangerous recycling with significant health and environmental risks, such as of used lead-acid batteries and electronic waste by untrained workers in the informal sector or without enforcement of regulations.
- The circular economy and localisation could contradict national policies or create displeasure amongst neighbouring countries, such as in implementing the African Continental Free Trade Agreement.
- Circularity could cause sanitary problems, particularly with human waste.
- Circular or local food systems could contravene food safety regulations.
- Overly complicated waste separation requirements imposed on households can create resistance.
- Policies, taxes, incentives and subsidies should encourage rather than discourage sensible resource use – and not be changed often, creating confusion.

Circular economy loops are dynamic. They represent flows of resources, materials, parts, goods, by-products and so on. These loops bring together organisations with different cultures, such as municipalities, international corporations, small and/or informal businesses and community organisations. Circular Economy suggests that there are four types of flows for the circular economy: narrow flows (use less), slow flows (use for longer), regenerate flows (make the flow clean) and cycle flows (use again) [Circle Economy 2021].

The quicker low and middle-income countries can move to a circular economy, the greater the chance they can avoid the waste mountains and bloated landfills typical of linear economies, and hence avoid the associated health and environmental problems [Gower & Schröder 2016]. Thus, it is necessary to promote sustainable lifestyles, aspirational sufficiency and quality of livelihoods in urban areas, particularly focusing on the growing middle class, and the next generation of would-be consumers: reshaping the collective societal imaginaries of success is vital.

2.2 Governance, legislation and policy

Establishing the circular economy and problems with the linear economy should be dealt with explicitly in the job titles and descriptions of senior managers. For example, Athens in Greece has a Chief Heat Officer and leads the Cool Cities Network (an initiative of the C40 Cities Network, a network of Mayors worldwide), which aims at "tackling urban heat by building greener cities" [C40 2022].

Building and construction policies and regulations need to be integrated with those for other issues, such as climate change, energy efficiency, water efficiency and waste. A controversial issue is legislating local content in procurement, such as South Africa's Industrial Policy Action Plan (IPAP) [The DTI 2018]. Proponents of localisation claim the benefits will be to grow and diversify the manufacturing sector, increase employment, reduce embodied energy (by reducing the required transport), ensure waste and pollution fall under local standards and legislation, and make it easier to repair and maintain components locally with local

skills (which should also increase the life of components) [Gibberd 2020]. However, some claim that localisation protects inefficient local companies to the detriment of efficient ones, increases costs and reduces quality. There is also a concern that initiatives could be "locally clean" but "globally filthy" [de Stage 2022]. Further, given how much South Africa supports Lesotho, for example, it might benefit South Africa to include Lesotho (and other neighbours) under the ambit of localisation, as boosting their economies should boost South Africa's.

In the United Kingdom, the new Environmental Act became law in November 2021 [DEFRA 2021] and perhaps provides a model that South Africa could follow. The Act provides legally binding environmental targets, such as on species abundance for 2030, sewerage discharge, stormwater overflows, and PM2.5 concentrations in the air. It deals with labelling on products of their recyclability and durability, it regulates hazardous waste shipments and requires consultation on street tree felling. It also targets the whole supply chain, requiring due diligence and traceability of resources, to help combat illegal deforestation, and to control the export of waste, for example. Connected to the Act are consultations on deposit return schemes for containers, charges for single-use plastics, producer responsibility for packaging and recycling collections, electronic waste tracking, tackling fly-tipping (illegal dumping) and waste crime (illegal storage, abandoning, transport or use of hazardous waste; misclassification of waste and fake documentation) [DEFRA 2021].

A key part of this new Environmental Act [DEFRA 2021] is biodiversity net gain (BNG), requiring development and land management to put the natural environment in a better state, by at least 10% of the Biodiversity Metric [Natural England 2021]: it uses habitat as a proxy for biodiversity, so is obviously a simplification of the real world, assesses a baseline and forecasts (size, type, condition and location), assesses delivery risk (difficulty of creating, restoring or enhancing habitat; temporal risk, the time to target condition; and spatial risk, the distance between the habitat loss and habitat compensation; and habitat quality measures (distinctiveness, condition and strategic significance). The metric is relative, not absolute. Currently, BNG concerns terrestrial and intertidal habitats and assesses three types of biodiversity units separately (area, hedgerow and river habitats). BNG aims at bigger, better and joined areas for biodiversity, encouraging enhancement not transformation, and coherent ecological networks more resilient to current and future pressures [PAS 2021].

2.3 Codes, standards and guides

Building codes provide rules or standards for construction to ensure safety and protect public health and welfare, during both construction and occupation. The key problem is they can become out of date and amending or revising them can take a long time. A code cannot just be changed without understanding the implications and without the new technologies having been tested properly. This can hamper some circular economy initiatives, such as reusing grey water (with health implications), reusing materials from deconstructed buildings or installing renewable energy systems that could feed back into the grid or use large batteries (where the electricity network has not been designed for such loads). Some considerations are:

- Reducing heat stress due to climate change, such as through low-cost, passive-cooling designs.
- Performance standards for energy use.
- Improving or tuning-up old buildings, such as when they are sold or leased.
- Restricting the rental of highly inefficient buildings [C40 2019a].

The International Organisation for Standardisation has established the Technical Committee ISO/TC 323, Circular economy, to develop standards for the framework of the circular economy, principles for implementation, guidelines on business models and value chains, measuring circularity and reviewing business models. ISO/TC 323 also collaborates with ISO/TC 324, Sharing economy.

As well as codes and standards, there are also useful guides, such as the 'South African Neighbourhood Planning and Design Guide: Creating Sustainable Human Settlements', known as the Red Book [CSIR & DHS 2019]. Sophisticated municipalities can use these codes, standards and guides to encourage inward investment by setting themselves up as being more advanced than other municipalities. They could promote the circular, green and sharing economies; green or zero-carbon buildings and public transport; and better building performance. The codes can nudge people and organisations towards better consumption patterns.

2.4 Recycling

Urban regeneration includes recycling buildings and land, and flexible uses of facilities and space. Improving the efficiency of buildings can be combined with removing all the toxic and unhealthy materials and residues, such as lead, asbestos and mould, with the added benefit of creating jobs [Kammen et al 2020].

Leafline Washable Sanitary Wear, a small company in Bathurst, Eastern Cape, uses fibres from pineapple leaves (stronger than cotton and they absorb moisture, smell and bacteria) to make washable, reusable, affordable and biodegradable sanitary products for adults and children (nappies, breast pads, sanitary towels and chair and bed protectors). Leafline also employs disabled women to make the products [Zama 2022]. The Welsh company, NappiCycle, processes used nappies into pellets for making fibreboard and insulation panels, and mixed with bitumen to make roads, which they estimate will last twice as long as conventional roads. The used nappies are collected by the local authorities at the kerb side [Morgan 2022]. C40 suggests the foundation for a sustainable waste management system is the infrastructure and system for the universal collection, transfer and safe disposal of waste for the whole municipality – and this needs good data on the waste and waste flows to set priorities, etc. Proper logistics planning is needed to ensure appropriately sized vehicles are used and to prevent part loads and duplicated routes. The municipality needs to work with informal waste collectors (to improve working conditions), with the main producers of waste (to segregate at source), and harvest gas from landfills for energy. C40 considers incinerating solid waste to be expensive, inefficient, requiring good environmental controls and encouraging diverting waste to incineration rather than recycling, waste reduction, etc [C40 2019b].

The priority should be food and organic waste because they are major parts of municipal rubbish and have great potential for recycling. The options should be tested through pilot projects, to segregate and collect the waste, and implement composting (cheap and simple) and anaerobic digestion to generate biogas, heat, fertilisers and other products. Unsurprisingly, C40 recommends starting with the largest sources of food and organic waste, as that would provide the benefits of scale [C40 2019b].

Successful recycling needs services that are clearly communicated, easy to use and readily accessible, such as door-to-door collection; drop-off schemes; convenient, single-stream bins; accepting many different types of materials; and revenue-sharing with waste collectors. Incentives include pay-as-you-throw policies, deposit schemes and bans on items that cannot be recycled. Further, the municipalities must identify potential loops to recover materials and pass them on for further use. Municipalities also need to reduce waste generation in the first place, encourage the circular economy, set ambitious goals for zero-waste, support reuse and repair enterprises (including in the informal sector) and promote renting and sharing of goods [C40 2019b].

In Africa, much waste goes to uncontrolled dumping or burning. While only about 4% of municipal solid waste is recycled in Africa, much of this is by the informal sector. This could be improved through waste microgrids, where waste gets reduced, separated and treated locally, such as within a neighbourhood. Local recycling reduces the need for municipal waste collection. The organic waste can be composted and used locally. Other waste can be stored separately until there is enough to transport to appropriate recycling and other facilities. This reduces transport costs and provides recycled material and fertiliser locally [Gibberd 2020].

There is a growing understanding of the problems of how electrical and electronic equipment are produced, consumed and disposed: electronic waste (e-waste). Excluding PV panels, the consumption of electrical and electronic equipment is increasing, with about 53.6 Mt of e-waste generated annually (about 7.3 kg per capita!) and is expected to reach 74.7 Mt by 2030. Africa generates about 2.9 Mt of e-waste annually (about 2.5 kg per capita). Global recycling is about 9.3 Mt annually, with about 0.03 Mt in Africa [Forti et al 2020]. A key problem is the lack of repair options, but this is being addressed by companies such as Fairphone and Shiftphones, who make smartphones that are easy to disassemble and repair, which encourages community networks where those with the skills help others fix their phones, often without charge [Schweiger 2022].

E-waste contains toxins and hazardous substances, so should be treated by specialised facilities to recover precious, rare and critical metals in an environmentally sound manner. E-waste must be separated from other waste early and be pre-treated. Training on e-waste needs to be provided to government officials, as is being done by the Global E-waste Statistics Partnership. E-waste generated annually contains metals worth about US$ 57 bn, particularly iron, copper and gold, with only about US$ 10 bn recovered annually [Forti et al 2020].

2.5 Construction processes

The construction industry varies widely from large multinational companies to very small enterprises (one person and their bakkie). While there are very sophisticated organisations in construction, many are not and could be considered conservative in outlook. Globally, construction has been notorious for corruption and organised crime. In South Africa local "business forums" are hijacking projects and terrorising government officials and managers of construction companies [Moatshe 2022]. Further, construction employs many workers with limited skills and education. Thus, it is difficult to initiate new ideas and processes.

There are many opportunities for making construction more circular. Construction waste is highly recyclable and with the likes of landfill taxes, more than 90% of construction and demolition waste in the United Kingdom is being diverted from landfill. The circular economy can reduce the costs of both raw materials and waste. Key enabling factors are designing out the waste (planning for deconstruction, reassembly and future flexibility), information (costs, condition, resource productivity, life cycle, ownership, warranties and traceability) and collaboration (share incentives, provide transparency, encourage innovation and new products and processes, and moving from short- to long-term business models). This should improve operations (better use and more choices for consumers), maintain assets at higher values for longer, provide greater certainty over maintenance and replacement, reduce costs and reduce waste [Carra & Magdani 2018].

The circular economy needs appropriate planning, designing and monitoring of construction processes and the resulting buildings and structures. It is essential to calculate resource requirements accurately. Further opportunities include using standard sizes when specifying materials, sharing expensive equipment, recovering unused materials from building sites, reusing materials (particularly concrete), extending the lifetimes of existing stock and disassembly rather than demolition. Clients, tenants and investors are placing greater demands on the construction industry for more advanced processes, particularly for operational health and safety, and for the green and circular economies. New innovations include the Building Information Modelling (BIM) standards for sharing and managing information; product passports to track resources through the supply chain; sensors to monitor in real time the status of components; and 3D printing of components and even entire buildings [Carra & Magdani 2018].

Many buildings in South Africa and other African countries are in poor condition and should be replaced before collapsing. This is a waste because they were not designed, built, maintained and/or operated properly. Building to higher construction standards and designing for repairs and maintenance extends the life of components and buildings and reduces waste. Premature obsolescence can be prevented by using non-toxic materials; facilitating repairing by ensuring access to components; and understanding life expectancies and environmental impacts [Gibberd 2020]. Alternative construction materials provide opportunities for research and innovation. For example, hemp shives and fibres can be used for building, which would absorb carbon dioxide long afterwards, eventually making these buildings carbon negative. When growing, hemp is twice as effective as forests for sequestering carbon. A recent development in India is a device that extracts particulate matter from polluted air and uses the materials to make floor tiles [Gerretsen 2021].

Construction waste can be reduced, if not avoided, when building products and materials are sourced locally and can be readily repaired locally. Further, waste can be reduced by simplifying buildings with standard components and fewer materials used and using locally grown and sustainable materials [Gibberd 2020].

Design should be at the core of sustainable human settlements. Opportunities include modular design; green and sustainable buildings; building fewer, but better, units; reducing overall floor space (small footprint); flexible and multi-functional space; co-housing; increased renovation and refurbishment; renewable energy technologies; environmentally-friendly construction constituents, such as natural or renewable materials; recycling and retrofitting concrete and other building materials; and leasing components, such as renting illumination from illumination experts, rather than buying oneself – that is, turning components into services.

Design must consider how buildings and infrastructure could be operated, by including flexibility to enable multiple functions and occupancy patterns. An old and simple example is having lanes in a road that can switch directions to accommodate rush-hour traffic, reducing the need for wider roads. Further, the circular economy is also about the existing stock in human settlements, through extending the lifetimes of stock, re-occupying underused and disused buildings, and retrofitting existing stock [Circle Economy 2021].

Designing out waste means planning to use only the resources needed, using them optimally, monitoring what is being done and communicating clearly with all stakeholders. Within human settlements, this has tended to be construction (and the waste from demolition, construction and excavation): prefabrication off site; avoiding virgin materials; recovering unused materials before they get discarded; keeping sites neat so materials don't become debris and in the way; separating waste; storing materials so that they do not deteriorate; and controlling pollution. Critically, designing out waste also covers planning for what happens afterwards: providing easy access for maintenance, repairing, refurbishing and replacing – and then doing them; extending the life of structures; reusing or repurposing structures; deconstruction (rather than demolition); and recovering materials for use elsewhere. Demolishing unwanted buildings wastes valuable resources and money, while deconstructing them salvages materials for reuse, creates more jobs, spurs innovation, and preserves local character and heritage. Even better is repurposing existing buildings [C40 2021a].

Setting targets (aiming at continual improvement), ongoing monitoring and reporting are essential to ensure all are aware of resource consumption and waste generation, such as by displaying on site reports on energy and water use; waste created, recycled or disposed of as debris; the carbon footprint; and costs and savings. Tools are readily available, such as the Site Waste Management Plan of Zero Waste Scotland [ZWS nd].

Deconstruction is not easy or the best option, so it is important to do cost-benefit analyses of deconstruction and options for reusing materials. Many stakeholders must be involved in planning and implementing demolition or deconstruction. For example, where an area has been devastated, deconstruction can bring a 'dignified end' to destroyed dwellings, while demolition can make the community feel they, too, were demolished. Designing for disassembly from the start makes it easier to recover components and materials when buildings are renovated or deconstructed. Repurposing buildings is more sustainable and less disruptive and should be cheaper, while preserving building character and perhaps the block's frontage [C40 2021a].

2.6 Sustainable and green buildings and structures

The concepts of the circular, green and smart cities (and buildings, structures and components) overlap, but there are differences. For example, a smart city could be energy intensive, to drive all the smart devices and the intensive processing of big data. Key for sustainable buildings and structures is maintenance to prevent waste and inefficiencies and to prolong life. These buildings and structures can address other problems, such as extreme heat for those living in informal settlements in hot countries.

Service delivery requirements represent the critical alignment of circularity with local government mandates. Decision makers must be supported to see the links between delivering basic energy, water, sanitation, mobility and waste services, and circular design, processes and technologies. For example, if investing in urban street lighting, using decentralised solar helps reduce the burden on stressed national grids and fossil fuel power, while still delivering the service.

Neighbourhoods should also be walkable, with good penetration by public transport, cycle paths, green spaces and viable neighbourhood shops and services [Cooper & Sebake 2018]. Urban dwellings should be designed and built to be affordable and to epitomise the circular economy, such as with small footprints, rainwater harvesting, renewable energy, sewerage harvesting for fertilizer and as a source of household water, and recycling and retrofitting concrete and other building materials. It is necessary to promote social justice with informality through documenting and supporting the ingenuity, flexibility and varied circular opportunities offered by the informal economy for urban sustainability. This can include showcasing existing initiatives, indigenous knowledge and traditional practices, but support is needed from local government and businesses.

C40 proposes five ways municipalities can reduce building energy demand.

- Leading by example by setting targets for municipal buildings and social housing to be net-zero-carbon by some deadline. This includes reducing emissions; setting performance standards; using public buildings as testbeds and showcases; building relevant capacity locally; and leveraging dedicated financing for retrofits, such as green bonds and financing models for energy-cost savings [C40 2019a].
- Creating a transparent and open repository of evidence, with reporting and disclosure requirements, benchmarking of resource consumption, energy audits and reporting on energy efficiency levels and green building ratings [C40 2019a].
- Setting performance requirements for new and existing buildings, such as caps on energy use and GHG emissions; bylaws for requiring buildings to be up to code (such as when sold leased); green building rating and certification schemes; and ready-made, prefabricated parts for retrofits [C40 2019a].
- Providing incentives, such as training and guidance for developers, builders, inspectors and building owners; communicating the many benefits; stimulating the market; reducing transaction costs; appropriate financing models; reducing real and perceived investment risks; and incentives [C40 2019a].

- Shifting energy supply to renewables for buildings [C40 2019a].

2.7 Urban planning

The legacy of Apartheid spatial planning can discourage the circular economy. Perhaps, some isolated or scattered human settlements should be shut down and their populations consolidated into areas more amenable to service delivery, employment opportunities and the circular economy. Drivers include climate change, making some places too hot for habitation and working outdoors [CSIR 2019], and losing key parts of local economies, particularly mines at the end of their lives and agriculture impeded by climate change.

Goal 11 of the Sustainable Development Goals (SDGs) is to make cities and human settlements inclusive, safe, resilient and sustainable. Goal 12 is to ensure sustainable consumption and production patterns. Because the SDGs are so wide ranging and because of the complexities over measuring indicators, there are gaps within them. The circular economy is not mentioned explicitly in the goals, targets and indicators, but is implicit in much of SDG 12. For SDG 11, the key Target is 11.b, which covers resource efficiency. However, its Indicators are specifically about disaster risk reduction strategies [UN 2022].

2.8 Synergies with other sectors

The circular economy interventions for human settlements generally overlap considerably with other sectors of the economy and society. The following examples draw on Godfrey [2021b].

Urban mining: the opportunities are primarily with processing various waste dumps and discarded objects, especially e-waste, to extract valuable materials, particularly metals such as gold, silver, copper and palladium. Urban mining can even offer higher grades for lower costs [Khan et al 2021].

Manufacturing: Premature de-industrialisation happened to South Africa's linear economy for two decades and manufacturing can reverse this sustainably and inclusively through circular opportunities [Fazluddin et al 2021]. There needs to be support for embryonic remanufacturing and repair industries, such as through public procurement and providing needed utilities. This is more effective when clustered together, to provide greater scale through collaboration and specialization. Such small enterprises can be intensive in labour use [Gower & Schröder 2016], providing sorely needed jobs. Circularity can be due to happenstance, such as when one factory's waste can be reinterpreted as a by-product and used by another factory. However, it is better to design in circularity from the start and to aim at continual improvement, rather than perfection at once.

Energy: Since 2008, South Africa has suffered with constrained electricity supply and loadshedding, hampering the economy. The extra generating capacity should come from renewables because they are generally cheaper, and to decarbonise [Msimanga et al 2021]. Energy interventions can contribute to the circular economy, with decentralised energy systems (renewable energy and from waste), reducing dependency on water intensive energy sources, reducing the energy consumption of existing buildings (such as mandatory solar water heaters), and zero-emission transport [UCCRN 2018]. Decentralised energy generation reduces the need for extensive energy transmission systems. Many organisations are now using rooftop solar for their power needs. Depending on the infrastructure, locally generated electricity can be fed back into the local or national grids with Golden Arrow Bus Services, for example, exporting over half of the power it generates to the City of Cape Town [Daniel 2022].

Mobility: An urban mobility system that is accessible, affordable, safe and effective, contributes to the circular economy by encouraging the shift from private to public transport for both passengers and goods. Key is logistics planning to design out the waste of parts and empty loads. Transitioning to public transport is constrained by criminals, such as cable theft encouraging Transnet to de-electrify train sets, and the theft and destruction of rails and infrastructure preventing services on some lines [Mokoena et al 2021].

Water: South Africa is a dry country, with 98% of the water supply already allocated and demand expected to exceed supply by 17% by 2030. Municipalities consume 27% and much of the projected increase in the water demand will be by municipalities. Circularity opportunities include decreasing water loss (leakage) and wastage; increasing efficiency; water sensitive design; on-site wastewater treatment and re-use; and for households, harvesting rainwater and reusing domestic greywater for watering [Seetal et al 2021].

Urban farming: About a third of food produced in South Africa is wasted due to inadequate or improper market infrastructures, cold chains, safe transport, standards, handling, packaging and processing. Sustainable urban farming includes vertical agriculture, hydroponics, aquaculture, aquaponics and aquafeed from agricultural waste [Okole et al 2021]. Food and organic materials provide great opportunities for circularity, as they are the largest material flows in most African cities. Generally, African cities have close ties to their hinterlands, providing incentives for processing urban organic waste into compost, mulch, fertiliser and feed for farms. Such waste can be used for growing algae, mushrooms and insects for food and feed; for fibres; for bioenergy; and for retrieving nutrients, bioplastics and bio-aromatics. Processing urban organic waste helps ecological restoration and regeneration, enhancing ecosystem services, reducing urban heat islands, and fixing atmospheric nitrogen and carbon. Urban farming can improve food security, supplement household incomes, provide jobs (especially for women and the youth), reconnect the urban environment with nature cycles, increase resilience amongst the urban poor to food price shocks, and smoothen seasonal food consumption fluctuations. Urban farming includes backyard, rooftop, school and community gardens. Establishing food markets in poor neighbourhoods can provide access to local, organic produce at controlled prices [WEF 2021; Mirzabaev et al 2021; UCCRN 2018; UC SAREP 2017]. Additional benefits include efficient land use close to consumers and markets, reducing transport costs and emissions; using treated wastewater, rainwater harvesting and return-flow systems; reduced water consumption; using renewable energy; higher yields and less loss due to weather, drought or pests; and year-round fresh, healthy and nutritious food [Okole et al 2021].

3. Conclusions

This chapter has examined the circular economy opportunities and constraints in human settlements and with municipal governments in South Africa. It has also provided overviews of the linear and circular economies and expected trends. There are many research questions, such as whether urbanisation enhances or defeats the circular economy; whether the circular economy increases or decreases costs, happiness, jobs, social cohesion, and delivery of suitable housing. Finally, it is critical to understand there can be no perfectly circular economy in human settlements, because of the need to balance competing requirements.

4. Acknowledgements

We would like to thank the CSIR for funding this work and the team members that worked on the other themes, for their inputs. We would also like to thank the editors and referees for their insightful comments.

5. References

- AGSA (30 Jun 2021) Consolidated general report on the local government audit outcomes: MFMA 2019-20 Auditor-General of South Africa (AGSA), Pretoria, South Africa [online].
- AGSA (15 Jun 2022) Consolidated general report on the local government audit outcomes: MFMA 2020-21 Auditor-General of South Africa (AGSA), Pretoria, South Africa [online]
- AGSA (31 May 2023) Consolidated general report on local government audit outcomes: MFMA 2021-22. Auditor-General of South Africa (AGSA), Pretoria, South Africa [online].
- Ballard, Richard; Hamann, Christian & Mosiane, Ngaka (15 Dec 2021) Spatial trends in Gauteng. Occasional paper #19, Gauteng City-Region Observatory (GCRO), ISBN 978-1-990972-20-1 [online].
- C40 (May 2019a) Five impactful actions cities can take to reduce building energy demand. C40 Cities Climate Leadership Group & C40 Knowledge Hub, New York, NY, USA [online].
- C40 (Sep 2019b) Six city actions to improve waste management and reduce greenhouse gas emissions. C40 Cities Climate Leadership Group & C40 Knowledge Hub, New York, NY, USA [online].
- C40 (Jul 2020) How to build back better with a 15-minute city. C40 Cities Climate Leadership Group & C40 Knowledge Hub, New York, NY [online].
- C40 (Jan 2021a) How to start deconstructing and stop demolishing your city's buildings. C40 Cities Climate Leadership Group & C40 Knowledge Hub, New York, NY, USA [online].
- C40 (Apr 2021b) Mayors' Agenda for a Green and Just Recovery. C40 Cities Climate Leadership Group, New York, NY, USA, 43pp [online].
- C40 (May 2021c) 15-minute cities: How to create 'complete' neighbourhoods. Implementation guide. C40 Cities Climate Leadership Group & C40 Knowledge Hub, New York, NY, USA [online].
- C40 (2022) Cool Cities Network. C40 Cities Climate Leadership Group, New York, NY, USA, 7pp [online].
- Carra, Guglielmo & Magdani, Nitesh (2018?) Circular Business Models for the Built Environment. Ellen MacArthur Foundation & The Circular Economy 100 (CE100) [online].
- Chamberlain, L (25 Jan 2022) The Surprising Stickiness of the "15-Minute City", Common Edge [online]. (Accessed: 1 November 2022).

- Circle Economy (2021). The Circularity Gap Report 2021. Platform for Accelerating the Circular Economy (PACE) [online].
- CNU (20 Apr 2015) The Charter of the New Urbanism, Congress for the New Urbanism (CNU) [online].
- CoGTA (2016) Integrated Urban Development Framework: A new deal for South African cities and towns [online].
- Cooper Antony K (2 Sep 2022) Circular economy and human settlements. 4th SA-GEO Symposium and 3rd Space for National Development (SND), Pretoria [online].
- Cooper, Antony K; Tinus Kruger; Godfrey, Linda & Napier, Mark (2021) Creating resilient, inclusive, thriving human settlements through a more circular economy. In Godfrey, Linda (editor), The circular economy as development opportunity: Exploring circular economy opportunities across South Africa's economic sectors, pp 36-43. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Cooper, Antony K & Sebake, Nosizo (Oct 2018) Neighbourhood 4.0: A response to urban futures. Out-Of-The Box 2018 Conference, Pretoria, South Africa, pp 16–28 [online].
- CSIR (2019) Green Book: Adapting South African settlements to climate change. CSIR, Pretoria [online].
- CSIR & DHS (Jul 2019) The Neighbourhood Planning and Design Guide: Creating Sustainable Human Settlements (Red Book). Department of Human Settlements, Pretoria. ISBN 978-0-6399283-2-6 [online].
- D'Acci, L (2013) Simulating future societies in Isobenefit Cities: Social isobenefit scenarios, Futures, 54:3-18 [online].
- Daniel, Luke (30 Jul 2022) Golden Arrow has gone solar – and is now eyeing 60 locally built electric buses. Business Insider SA [online].
- DEFRA (10 Nov 2021) World-leading Environment Act becomes law. Press release. Department for Environment, Food & Rural Affairs; Forestry Commission; Environment Agency; Natural England & Eustice, George (MP) [online].
- Demolition Depot (2022) The Demolition Depot, New York, NY, blog [online].
- EMF (2017) Cities in the circular economy: An initial exploration. Ellen MacArthur Foundation, UK [online].
- EMF (2021) Circular Economy Introduction. Ellen MacArthur Foundation, UK [online].
- EMF (2022a) Measure business circularity: Circulytics. Ellen MacArthur Foundation, UK [online].
- EMF (2022b) Circular Buildings Toolkit. Ellen MacArthur Foundation, UK [online].
- EMF (2022c) Delivering the circular economy: a toolkit for policymakers. Ellen MacArthur Foundation, UK [online].
- Fazluddin, S; Ojijo, VO; Nahman, A & Godfrey, LK (2021) Supporting the development of a globally competitive manufacturing sector through a more circular economy. In: Godfrey, LK (editor) The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp 27–35. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Feyertag, Joseph & Bowie, Ben (2021) The financial costs of mitigating social risks: costs and effectiveness of risk mitigation strategies for emerging market investors. ODI, London [online].
- Forti, Vanessa; Baldé, Cornelius Peter; Kuehr, Ruediger & Bel, Garam (2020) The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. United Nations University & United Nations Institute for Training and Research SCYCLE Programme; International Telecommunication Union & International Solid Waste Association. ISBN 978-92-808-9114-0 [online].
- GAHP (Dec 2019) Pollution and Health Metrics: Global, Regional, and Country Analysis. Global Alliance on Health and Pollution, New York & Geneva [online].
- Gerretsen, Isabelle (13 Sep 2021) How India's air pollution is being turned into floor tiles. BBC [online].
- Gibberd, Jeremy (Oct 2020) State of play for circular built environment in Africa. Final report. United Nations One Planet Network Sustainable Buildings and Construction Programme [online].
- Githathu, Mwangi (7 Nov 2019) 'Waste crisis' in spotlight as SA is running out of landfill space. Cape Argus [online].
- Godfrey, Linda K (2021a) Quantifying economic activity in the informal recycling sector in South Africa. South African Journal of Science, 117(9/10), Art. #8921 [online].
- Godfrey, Linda K, ed (2021b), The circular economy as development opportunity: Exploring circular economy opportunities across South Africa's economic sectors. CSIR, Pretoria. ISBN: 978-0-7988-5667-6 [online].
- Gower, Richard & Schröder, Patrick (2018) Virtuous Circle: How the circular economy can create jobs and save lives in low and middle-income countries. Tearfund, Teddington, United Kingdom [online].
- IEA (28 Jul 2022) Global coal demand is set to return to its all-time high in 2022 (Press release). International Energy Agency (IEA), Paris, France [online].
- Jacobs, J. (1961) The death and life of great American cities. New York: Random House.
- Kammen, Daniel; Bozuwa, Johanna; Cha, J Mijin; Cohen, Daniel Aldana; Fleming, Billy; Goodman, Jim; Johnson, Ayana Elizabeth; Brave NoiseCat, Julian; Paul, Mark; Patel, Raj & Riofrancos, Thea (23 Mar 2020) A Green Stimulus to Rebuild Our Economy: An Open Letter and Call to Action to Members of Congress. Renewable & Appropriate Energy Laboratory, University of California, Berkeley [online].
- Khan, S; Nontso, Z; Magweregwede, F; Godfrey, LK & Sereme, BV (2021) Placing the South African mining sector in the context of a circular economy transition. In: Godfrey, LK (editor) The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp. 9–17. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Koumi, Ahou Rachel (15 Sep 2020) Regulations, actions and management process for plastic waste in Côte d'Ivoire, West Africa. OECD [online].

- Tinus Kruger; Lancaster, Lizette; Landman, Karina; Liebermann, Susan; Louw, Antoinette & Robertshaw, Rory (2016) Making South Africa Safe: A Manual for Community-Based Crime Prevention. CSIR, Pretoria, South Africa [online].
- Landrigan, PJ; Fuller, R; Acosta, NJR, et al (2018) The Lancet Commission on pollution and health, The Lancet, 391(10119), pp 462–512. doi: 10.1016/S0140-6736(17)32345-0.
- Moatshe, Rapula (21 Feb 2022) Violent 'business forum' terrorise human settlements officials, hijack service delivery projects. IOL [online].
- Mokoena, R; Steenkamp, AJ & Godfrey, LK (2021) Facilitating sustainable economic development through circular mobility. In: Godfrey, LK (editor) The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp 44–52. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Moreno, Carlos 5 Oct (2016) La ville du quart d'heure: pour un nouveau chrono-urbanisme, La Tribune [online].
- Moreno, Carlos; Allam, Zaheer; Chabaud, Didier; Gall, Catherine & Pratlong, Florent (2021) Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities, Smart Cities, 4(1):93–111 [online].
- Morgan, Dafydd (26 Feb 2022) Nappies added to roads 'doubles life of surfaces. BBC [online].
- Msimanga, XP; Godfrey, LK & North, BC (2021) Decoupling South Africa's development from energy demand through a more circular economy, in: The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp 53–60. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Mthuli, Malusi (3 Apr 2022) This trend in South Africa's property market is accelerating thanks to a changing workforce. Businesstech [online].
- Nahman, Anton; Godfrey, Linda K; Oelofse, Suzan H & Trotter, Douglas (2021) Driving economic growth in South Africa through a low carbon, sustainable and inclusive circular economy. In: Godfrey, Linda (editor), The circular economy as development opportunity: Exploring circular economy opportunities across South Africa's economic sectors, pp 36-43. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- Napier, Mark; Cooper, Antony K; Holloway, Jennifer P; Thanjekwayo, Londeka; Graham, Nick & Le Roux, Alize (Apr 2022) A tale of two pathways: how the low-end Gauteng residential property market may be shaped either by state-driven supply or by a more enabled private sector. Understanding African Real Estate Markets. Routledge International Real Estate Markets Series. ISBN 978-0-367-23310-5.
- National Treasury (Jul 2018). Managing Urbanisation to Achieve Inclusive Growth: A review of trends in South African urbanisation and suggestions for improved management of urbanisation. South African Urbanisation Review [online].
- Natural England (7 Jul 2021) Biodiversity 3.0 Metric Launched in New Sustainable Development Toolkit. Press release. Department for Environment, Food & Rural Affairs, London, UK [online].
- Njwambe, Avela; Cocks, Michelle & Vetter, Susanne (2019) Ekhayeni: Rural–Urban Migration, Belonging and Landscapes of Home in South Africa. Journal of Southern African Studies, 45:2:413-431 [online].
- Okole, BN; Gordon, GE; Brown, B; Pillay, B; Schoeman, C & Godfrey, LK (2021) Supporting food security and economic development through circular agriculture. In: Godfrey, LK (editor) The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp 18–26. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.
- O'Reilly, Claire (22 Oct 2021) Illegal sand mines continue to profit. Mining Weekly [online].
- Ostrom, Elinor (1990). Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge. ISBN 978-0-521-40599-7.
- Paddison, Laura (25 Oct 2021) How the rich are driving climate change. BBC [online].
- Pai, Sandeep; Emmerling, Johannes; Drouet, Laurent; Zerriffi, Hisham & Jewell, Jessica (2021) Meeting well-below 2°C target would increase energy sector jobs globally. One Earth, 4(7):1026-1036 [online].
- PAS (Oct 2021) Biodiversity Metric 3 Training for Planners. Planning Advisory Service, Local Government Association [online].
- Petzer, Engela; Napier, Mark & le Roux, Alize (12 Feb 2020) Developing a Tool to Monitor Neighbourhood Spatial Transformation. Concept note prepared for the South African Local Government Association (SALGA). CSIR, Pretoria.
- Pörtner H-O & Roberts DC (2022) Summary for policymakers. In: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 37pp. Cambridge University Press, Cambridge, UK and New York, USA [online].
- Potgieter, JE; Rajput, J; Hemkhaus, M; Ahlers, J; Van Hummelen, S; McGovern, M & Artola, I (2020) Circular Economy in Africa-EU Cooperation: Country Report for South Africa. Submitted to the European Commission, ISBN 978-92-76-26834-5 [online].
- Ramaphosa, Cyril (8 Sep 2022) President Cyril Ramaphosa: SALGA Council of Mayors. SALGA Council of Mayors, East London [online].
- RIPESS (2023) What is Social Solidarity Economy. Red Intercontinental de Promoción de la Economía Social y Solidaria (RIPESS), Barcelona, Spain [online].
- SARB (17 Oct 2023) Monetary Policy Review – October 2023. Monetary Policy Committee (MPC), South African Reserve Bank, Pretoria, South Africa [online].
- Schweiger, Francesca (22 Feb 2022) The mobile phones you can take apart and repair yourself. BBC [online].
- SEA (2020) State of Energy in South African Cities 2020. Sustainable Energy Africa (SEA), Cape Town, South Africa [online].
- Seetal, AR; Mathye, SM & Godfrey, LK (2021) Decoupling South

Africa's development from water demand through a circular economy. In: Godfrey, LK (editor) The Circular Economy as Development Opportunity: Exploring Circular Economy Opportunities across South Africa's Economic Sectors, pp 61–69. CSIR, Pretoria. ISBN: 978-0-7988-5667-6.

- Statista (2021). South Africa: Urbanisation from 2010 to 2020 [online].
- Stats SA (19 Jul 2021a) Mid-year population estimates, 2021. Statistical Release P0302. Statistics South Africa, Pretoria, South Africa [online].
- Stats SA (13 Dec 2021b) Stats in brief 2021. Statistics South Africa, Pretoria, South Africa. ISBN 978-0-621-49663-5 [online].
- The DTI (2018) Industrial Policy Action Plan IPAP 2018/19-2020/21. Department of Trade and Industry, Pretoria, South Africa [online].
- UC SAREP (2017) Urban Agriculture. Sustainable Agriculture Research & Education Program, University of California Agriculture & Natural Resources [online].
- UCCRN (Feb 2018) The Future We Don't Want: How Climate Change Could Impact the World's Greatest Cities. Technical Report. C40 Cities, Global Covenant of Mayors, Acclimatise, and the Urban Climate Change Research Network (UCCRN) [online].
- UN (20 Oct 2016) The New Urban Agenda. Adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), Quito, Ecuador [online].
- UN (2022) The 17 Goals. United Nations Department of Economic and Social Affairs [online].
- UNEP (2022) Emissions Gap Report 2022: 2022: The Closing Window – Climate crisis calls for rapid transformation of societies. United Nations Environment Programme (UNEP), Nairobi, Kenya [online].
- UP (2021) UP's Moja Gabedi: From rubble to a meaningful garden. University of Pretoria, Pretoria, South Africa [online].
- Urban Surfer (2022) Urban Surfer: informal recycling solutions, home page [online].
- US Green Building Council (2022) LEED certification for neighborhood development [online]. (Accessed: 1 November 2022).
- Van Niekerk, Willemien; Petzer, Engela; Ndaba, Dumisani; Pieterse, Amy; Rajab, Azra & Tinus Kruger (Dec 2015) Revising the South African guidelines for human settlement planning and design (the Red Book). Smart and Sustainable Built Environment (SASBE) Conference 2015, Pretoria, pp 135-141. ISBN 978-0-7988-5624-9.
- Van Zyl, Terence L & Celik, Turgay (2021) Did We Produce More Waste During the COVID-19 Lockdowns? A Remote Sensing Approach to Landfill Change Analysis. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 14:7349-7358 [online]
- Verma, Anshul (31 Mar 2022) Ghazipur fire: Gasping for air as massive Delhi landfill burns. BBC [online].
- Von Blottnitz, H; Virág, D; Wiedenhofer, D & Haas, W (23 Feb 2022) An Economy-wide Material Flow Analysis to Develop Circular Economy Indicators for South Africa. University of Cape Town [online].
- WEF (Oct 2017) Migration and Its Impact on Cities – An Insight Report [online].
- WEF (Apr 2021) Five Big Bets for the Circular Economy in Africa. African Circular Economy Alliance [online].
- Weng, Min; Ding, Ning; Li, Jing; Jin, Xianfeng; Xiao, He; He, Zhiming & Su, Shiliang (2019) The 15-minute walkable neighborhoods: Measurement, social inequalities and implications for building healthy communities in urban China, Journal of Transport & Health, 13:259–273 [online].
- WHO (2021) WHO global air quality guidelines. particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Executive summary. World Health Organisation, Geneva. ISBN 978-92-4-003443-3 [online].
- Williams J (2021). Circular Cities: A Revolution in Urban Sustainability. Routledge Studies in Sustainability. [online].
- Zama, Siphokazi (2 Mar 2022) This Eastern Cape woman has turned pineapple-leaf fibres into cost-saving reusable nappies. You [online].
- ZWS (nd) Designing Out Construction Waste: A guide for project design teams. Zero Waste Scotland Ltd, Stirling. 46p [online].

Author information

- Antony K Cooper; Smart Places, CSIR, Pretoria, South Africa. acooper@csir.co.za; Department of Geography, Geoinformatics & Meteorology, University of Pretoria, Pretoria, South Africa
- Tinus Kruger; Smart Places, CSIR, Pretoria, South Africa. dkruger@csir.co.za
- Linda K Godfrey; Waste RDI Roadmap, CSIR, Pretoria, South Africa. lgodfrey@csir.co.za; Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa
- Mark Napier; Smart Places, CSIR, Pretoria, South Africa. mnapier@csir.co.za; Centre for Development Support, University of the Free State, Bloemfontein, South Africa


SCAN ME
REGISTER NOW!
CESA
Consulting Engineers South Africa
INFRASTRUCTURE
Indaba
2024
Engineering the Future Now!
19 and 20 March 2024
Cape Town International
Convention Centre

SAICE – fostering infrastructure development for a brighter future

The civil engineering industry is the backbone of the country's development and against a background of deteriorating infrastructure, there's much work to be done to restore the country onto a growth trajectory. Good social infrastructure provides not only the life giving oxygen for economic development but provides opportunities for social mobility while improving the quality of human life. Without the solid foundation of engineers looking after critical infrastructure the country's growth cannot be sustained.

Let's Collaborate to Recalibrate, Rebuild and Restore for a Sustainable Future!

The South African Institution of Civil Engineering (SAICE), representing 15500 members, plays a crucial role in addressing critical issues aimed at stabilizing the economy through the sustainable development of infrastructure while supporting the growth and development of civil engineering professionals. SAICE's core principles include a dedication to skills development through knowledge sharing and mentoring, the advancement of sustainable practices and gender equality while pursuing lobbying and holding the government to account on behalf of the industry.

SAICE is of the opinion that a sustainable South Africa is possible through civil engineering by considering the triple bottom line of people, planet and prosperity in line with the sustainable development goals in every planned and on-going project, as well as environmental process. Engineers are vital in sustaining the country's growth, and SAICE's diverse initiatives demonstrate its commitment to actively promoting development through many initiatives such as its Student Chapters and Bridge Building Competitions that stimulate young minds; diversity drives; webinars; women's day events; panel discussions; and awards promoting excellence in civil engineering.

IRC focuses on South Africa's public infrastructure

Of particular importance is SAICE's Infrastructure Report Card (IRC) conducted by industry experts every five years as a relevant and reliable source of information - unpacking the state of the country's infrastructure and is the 'go to' source for experts countrywide. Highlighting discrepancies and challenges is not a sign of pessimism, but identifies where action is most needed enabling engineering minds to provide solutions. The provision of public infrastructure is a core responsibility of a functional and thriving State, and the overall goal of the IRC is to increase awareness and influence change for the better. Through its various communication channels, SAICE aims to stimulate debate on the condition of South Africa's infrastructure and its effect on quality of life aimed at growing the economy.

SAICE's proactive proposals to government on how to tackle the short comings in maintaining and upgrading vital infrastructure, such as transportation, water and sanitation and health care facilities, points to a holistic appraisal approach in assessing the viability of required infrastructure projects, as opposed to high net present values (NPV) and benefits cost ratios (BCR). SAICE's belief is that the emphasis must change from projects looking for the highest financial returns to projects looking for the highest societal impact.

Promoting gender equality in engineering and beyond

Responding to Deputy President Paul Mashatile's recent call to address the under-representation of women and marginalized groups in the engineering sector at the 9th UNESCO Africa Engineering Week and 7th Africa Engineering Conference in Pretoria, SAICE CEO Sekadi Phayane-Shakhane acknowledged, "The scarcity of women engineers in the country is a complex and pressing issue that demands concentrated and determined efforts to mobilize. It is time that we place our collective focus on tangible actions and their implementation. The time for tangible progress is now, and together, we can drive substantive change. What is called for is a not only a change in policy within both the public and private sectors but a societal re-alignment starting with Early Childhood Development programmes through to basic and tertiary education."

At the same conference, Innocentia Mahlangu, SAICE's Diversity and Inclusivity chairperson, called on government to engage proactively with associations like SAICE, armed with established programmes such as the Women in the Built Environment (WITBE) initiative in partnership with Mentorship 4 Success (M4S), aimed at amplifying women's presence in the built environment stating, "Together, we will forge an industry that is both inclusive and pioneering."

Development in a constrained financial environment

As part of the organisation's many lobbying efforts SAICE recently suggested an alternative solution that will assist National Treasury as it grapples with the country's constrained fiscus. In a letter sent to the Director General of National Treasury, the institution has proposed a Public Private Partnership (PPP) solution, where the advisory fees for transaction advisors can be funded through a bridging loan from a bank, where the loan is repaid on financial close of the project taken from project funding. This innovative solution will enable the continued investment in the development of infrastructure needed to boost the economy of South Africa, creating both jobs and enabling skills development.

What can SAICE do for you?

SAICE membership opens doors to opportunities, knowledge-sharing and collaboration allowing members to invest in their professional growth and contribute to the collective advancement of civil engineering. SAICE provides members access to CPD-accredited networking events and cutting-edge educational resources, as well as assisting with the road to registration with the Engineering Council of South Africa (ECSA). "SAICE has been at the forefront of advancing the civil engineering profession in South Africa for over a century. We are immensely proud of the legacy we've built and the role we continue to play in shaping the future of our nation. We invite all engineers to unite behind SAICE to push the sustainability agenda, making engineering truly great once again," concludes Phayane-Shakhane.

About SAICE

SAICE is a learned society and voluntary organisation that acts as a catalyst for innovation and good practice in the development of the civil engineering profession. SAICE has a membership base in excess of 15500 Civil Engineering professionals, and is involved in the development of policies, standards, structures and systems that impact infrastructure at national and international levels.

Contact details:
Nthabeleng Lentsoane
SAICE: Head of Marketing & PR
nthabeleng@saice.org.za
Call: (011) 805-5947

ENERGY

SUSTAINABLE ENERGY

Platinum (Pt)-based high-entropy alloy (HEA) nanocatalysts for green energy production and storage

Dr Gerard Leteba

The combustion of fossil fuels, as sources of energy, creates both environmental and health concerns. Therefore, there is an urgent task to reserve these non-renewable resources in the Southern regions while finding ways to meet the increased energy demands. In order to meet these increasing energy demands, alternative and renewable energy sources are needed.

The promising efforts are directed towards the development of fuel cell devices, which generate power by converting chemical energy directly into electricity. Fuel cells are environmentally benign and highly efficient. However, the fundamental barrier to the widespread commercialization of fuel cell devices stems from the prohibitively high cost of platinum (Pt), a standard catalyst. Within this industry the principal research driver is to embark on efficient ways to increase the efficiency of Pt by alloying it with other cheaper metals (Cu, Ni, Co, Fe, Cr, etc.). The design and engineering of single-phase multimetallic Pt-based nanoparticles (the so-called high-entropy alloys (HEAs) have thus emerged as an active area of research with the aim of fabricating masses of cost-effective, high performance, and durable electrocatalysts. HEAs consisting of five or more elements have gained substantial interest due to their distinctive surface structural properties. Nevertheless, synthesizing monodisperse HEA nanostructures is extremely challenging. The need for optimal utilization of Pt has driven research into the formulation of new protocols to synthesize monodisperse nanoparticles of homogeneously mixed multi elements.

The basic understanding of how bimetallic nanoparticles speed up reactions in fuel cell devices to generate electricity will establish a platform and transform research from intensive investigation efforts to applied and commercial aspects. Detailed characterizations of the structure of materials down to the atomic scale allow a much greater understanding of their properties. Thus, understanding the structure-performance relationships of heterogeneous Pt-based HEA nanomaterials is of fundamental importance for their successful application in the transportation and energy-storage industries. As a result of increasing energy demand and environmental concerns, the successful synthesis of these novel catalysts will help reduce the intensity of pollution concerns by burning fossil fuels as energy sources and accelerate catalytic reactions without producing any harmful wastes in industries.

South Africa is the leading and largest primary producer of Pt in Southern Africa. However, there is limited value added into its economy prior to Pt export due to shortage of skills and deficient capacity in materials research. Therefore, the development of novel metallic nanostructures will contribute to the economy by adding extra value to mineral resources in terms of job creation in the metal sector and building high-quality knowledge base in metallic materials. The mobilization of research knowledge, to and from academic and non-academic sectors, with the view to lead to intellectual and economic influence will benefit and impact on human capacity in materials development in Southern Africa. This advancing knowledge will also provide high-quality research training experience for emerging learners and researchers to address issues relating to the development needs of Southern countries, and to further collective understanding of mineral processing within this region.

Flexible Nuclear Energy Using Molten Salt Heat Storage

David Nicholls

In the drive for a "Net Zero" solution for the future of electricity generation one of the clear choices is nuclear power. At present nuclear power is used almost exclusively for the "baseload" purpose. While many see this as a function of current nuclear power being unable to follow the load changes in the grid this is not fundamentally true. Of all the standard power generation technologies nuclear has the highest investment cost (as in the cost of construction) and the highest fixed portion of its operating costs. Its fully marginal cost, that is the cost of the fuel it uses, is the lowest of its competitors.

This combination means that the most economic method of operation is to run at as close to 100% power as possible. This is shown by the fact that the normal operating of all such stations is to run at 100% power whenever it is available. The most successful nuclear operators (such as the USA) achieve a national average in the order of 93% production. This means that they are run at full power between refueling shut-downs, which normally occur every 18 months and last about 4 weeks.

This operating mode is not a function of the capability of the nuclear power plant design but the economics of lowest cost grid dispatch rules. This can easily be seen by considering the origins of the current Pressurised Water Reactors (PWRs) such as Koeberg. These make up the majority of nuclear power plants in the world and were developed from nuclear submarine power plants which are the original PWRs. Nuclear submarine plants were designed (and operated) to allow unrestrained power changes between about below 10% power to 100%, and given the nature of submarine options this flexibility was used frequently!

The figure below shows the comparison of capability of nuclear, coal and combined cycle gas turbines to change power when asked to do so. It is notable that the standard PWR nuclear core design allows a 10%/minute change of load between 20% and 100% power. The technical rules for Koeberg allow for this, which is more than that for any Eskom coal station but it is never exercised due to the economic issues discussed above.

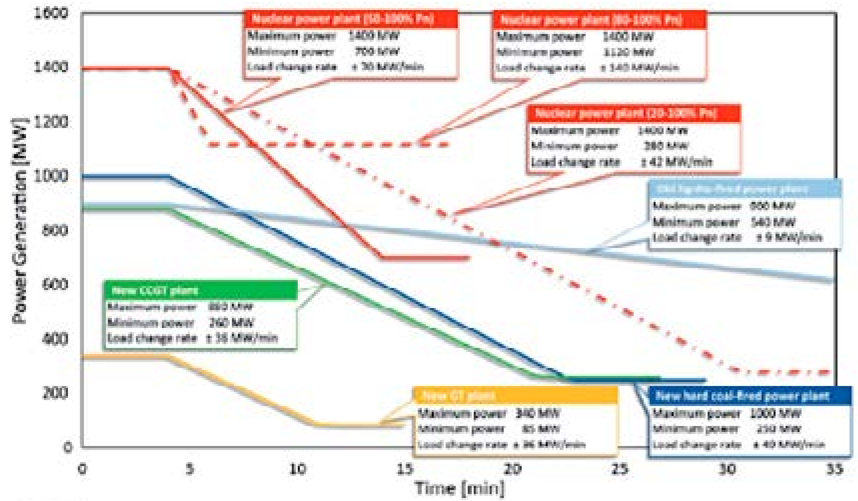
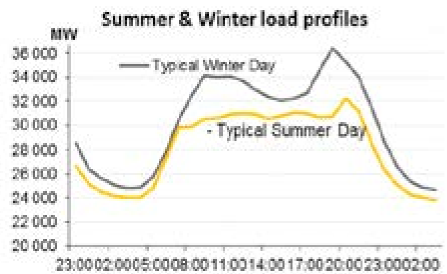


Figure 4
Comparison of load change rates of conventional generating units (adapted from [33] with data from [32] and [34]).

The only country that has used this flexibility on a regular basis is France because their grid is dominated by their nuclear power stations and they therefore had to use some of these plants to change load frequently to match the system demand. This profile is seen in the Eskom 2015 load profiles in the figure below. As can be seen, this clearly calls for flexible operation which does not appear to match the best economic profile of current nuclear power plant designs.



The issue therefore becomes how to create a nuclear power solution that can be economic in this very dynamic load situation. While it is technically feasible to build versions of current generation plant which can provide the flexibility required in the "modern grid" it is not really economic. If a current technology plant is operated at an average load factor of, say, 45% compared to the possible 90% it would effectively double its cost per kWh.

In considering the economics of a nuclear plant it must be recognised that the dominant fixed cost element is the nuclear part of the plant, both in terms of the capital cost, the operating cost and the overheads. Therefore it becomes important to operate the nuclear element with the highest possible capacity factor. The non-nuclear part (the "conventional island") is a far lower cost element. The issue is therefore of how does one create the energy buffer between the nuclear reactor and the conventional steam turbine?

In recent years this challenge has been solved by the Concentrating Solar-thermal Power (CSP) plants. CSP technologies use mirrors to reflect and concentrate sunlight onto a receiver. The energy from the concentrated sunlight heats a high temperature fluid in the receiver. The fluid is normally a molten salt or a mineral oil. There are two tanks of this fluid, a "hot" tank and a "cold" tank. The fluid is pumped from the cold tank to the receiver and is returned at the high temperature to the hot tank. When power is required the fluid from the hot tank is pumped to a steam generator that creates steam to drive a conventional turbine, making power for the grid. The fluid is then returned to the cold tank. Clearly the relative size of the tanks determines how much excess power can be made by the sunlight before being used by the turbine for power generation.

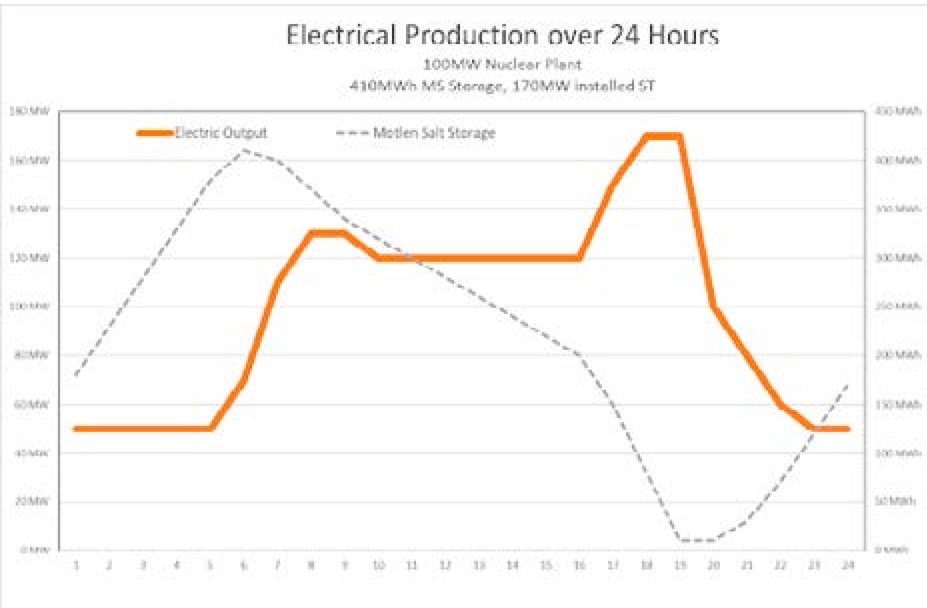
This technique clearly is beneficial for the CSP plants because they can generate electricity when the grid needs it and not just when the sun is shining. So it turns an intermittent source into a dispatchable supply. Unfortunately, while technically working, the costs of these plants across the world has not been seen to be competitive.

The same technology can, however, be used to convert a stable heat source into a variable one. If a nuclear reactor was to be used to heat molten salt with a two tank system, being a hot and a cold tank, then the steam turbine system linked to the molten salt driven steam generator could respond to the load changes at whatever rate required by the grid. A simple model of the results are shown in the figure below. In this case the nuclear plant is a nominal 100MW equivalent with a 170MW steam turbine and a storage capacity of 410MWh. This has been matched to a simile of a grid load profile. The reactor is assumed to be at 100% of its power throughout the cycle

As can be seen the proposed system could therefore meet the needs of the grid using current established systems.

For such a system to work it would need an appropriate input temperature from the reactor system. At present the CSP systems in the world operate with a hot tank temperature in the order of 565°C, with the cold tank temperature of around 290°C. This allows the steam generator to generate superheated steam to drive a standard steam turbine. The current South African Redstone CSP power plant uses this technology with a 100MW steam turbine and has 1200MWh of storage.[1]

The issue with this temperature range is that the current water-cooled reactors (PWRs etc) have a maximum working temperature of about 320°C. This is clearly inadequate. There are a number of



high temperature reactor technologies which do operate in the appropriate temperature range and have been technically proven. These include liquid metal cooled designs (sodium cooled or lead-bismuth cooled), molten salt cooled designs and gas cooled designs. Of these this article will discuss the High Temperature Gas-Cooled Reactor (HTGR) as it is the one which has a currently operating full-scale design (HTR-PM in Shandong, China) at the required coolant temperature (750°C) and with which South Africa has excellent technical understanding due the previous PBMR project.

The only technical item which has not been demonstrated at the appropriate level is the helium to molten salt heat exchanger. While this specific application has not been operated the temperature and pressures involved are well within the experience of the exchanger industry and should not present any serious technical challenges

Clearly the solution proposed will have a higher cost than a simple base load reactor of the same type. The current 210MWe HTR-PM in China, which has two 250MWth reactors linked to a single turbine, has a previously quoted capital cost of $1bn for the lead unit. This leads to a cost of $5000 per kWe. The analysis of a 655MW combination of 6 HTR-PM units (named HTR-PM600) leads to an expected cost of $2500 per kWe [2]. Clearly the extra cost over a nuclear plant with no thermal storage is that storage.

The US Department of Energy Office of Energy Efficiency & Renewable Energy has quoted [3] an expectation of a thermal energy storage cost of less than $15/kWh(th) with an exergetic efficiency of greater than 95%.

If a plant such as that listed in the earlier section is developed the target molten salt storage cost, based on 5 hours of storage with a 40% thermal efficiency of the turbine system, would lead to a storage cost per kWe installed of $15 x 5 x (1/0.40) = $187.50. Clearly this is a small increase on the costs of the nuclear plant. The impact of the exergetic efficiency can be seen to reduce the output of the overall system by less than 5%.

While these numbers are clearly estimates it would indicate that for an economically efficient fully load following HTGR based on the HTR-PM600 would lead to a lower estimate of ($2500 + $187.5)/0.95 = $2830/kWh for the average output of the station, and $2830/1.7 = $1500/KWe for its peak output.

These estimates are clearly optimistic but at present nuclear plants make a very competitive option in South Africa for the base load operation if the capital costs are in the order of $4000/kWe. It would therefore be logical to assume there is enough margin in the above calculation to show the real potential for this option.

- [1] Redstone Solar Thermal Power - https://en.wikipedia.org/wiki/Redstone_Solar_Thermal_Power
- [2] Next Big Future Nov 2021 https://www.nextbigfuture.com/2021/11/criticality-for-both-high-temperature-pebble-bed-reactors.html
- [3] US Department of Energy Office of Energy Efficiency & Renewable Energy https://www.energy.gov/eere/solar/thermal-storage-rd-csp-systems#:~:text=Thermal%20energy%20storage%20cost%20%3C%20%2415%2FkWh

SAEEC's 2 decades of Engineering Excellence: Advancing Energy Efficiency and Conservation in Southern Africa

The South African Energy Efficiency Confederation (SAEEC) is a Non-profit Company established in South Africa in 2002. The ethos of the SAEEC is advancing the cause of energy and resource efficiency, to combat the effects of climate change, improve sustainability, to promoting energy efficiency and sustainability, to develop green economies and to uplift communities in South Africa. The SAEEC plays a vital role in South Africa, in bringing together professionals, organizations, and stakeholders involved in energy efficiency, to collaborate, share knowledge, and advance sustainable practices in the energy sector. The SAEEC is the largest professional body in Africa, representing engineers, consultants, policy makers, and organsations involved in the energy sector. We are the local chapter of the Association of Energy Engineers (AEE), the international mother body, which is represented in over 100 countries, and has a membership of over 20,000 members.

In 2023, the Southern African Energy Efficiency Confederation (SAEEC), adopted the theme, 'Sustainability and Development Goals 2023'. These are the goals set-out by the United Nations and we used these guidelines to represent our sessions at our recent 18th SAEEC Conference.

Sustainability is the basis from where we take our first step forward, and this is an important step, as it is vital to the population of our Earth. How are we going to proceed ? The SAEEC has been discussing and promoting the efficient use of energy and water and environmental issues over the past 21 years. The population on Mother Earth has grown, and with it challenges – consumption and use of water, the importance of food security, the efficient use of energy, and considering the effect of emissions into our environment. These factors lead us to taking the vital step forward of net zero emissions and of how we care for our planet. Sustainability encompasses all engineering disciplines, from chemical, to mechanical and electrical, and further to architecture, town planning,

agriculture, and much more. It is a holistic approach to living and working and respecting the environment.

Development of Industry is important in every country, manufacturing, mining, agriculture, are all vital to a country's economy and better living standards of its people. Looking forward and considering the remarkable development of industrial automation, engineers have developed solutions to many problems faced in industry. Innovation and development in industry can and does promote energy efficiency, and the efficient use of water. The digital transformation has led to better management of plants and factories with easier means to measuring and verifying the use of energy and water and to considering responsible consumption and reduction.

The Goals of the SAEEC, as the established Association and local chapter of the Association of Energy Engineers (AEE) in Southern Africa, is on the promotion of how to save energy, electricity, water and the environment, and to keep engineers informed. There have been many remarkable technical papers presented at the SAEEC Conferences, over the past 18 years. This is testament to the high level of engineering in South Africa, and the dedication our engineers show towards the growth and development of our beautiful country. The SAEEC, in 2021, introduced the GO2Energy Technical Journal. We invite our speakers to publish the technical papers they present at our Conferences in our Journals. These technical journals are a great source of information and are available to our Members, through the SAEEC website. We offer training sessions for individual professionals to develop further in the fields of energy engineering, energy management, renewable energy, alternative energy and sustainability, this in partnership with The Institute of Energy Professionals. The courses are internationally recognized, and are vital to engineers in the energy industry.

We encourage excellence and annually hold 'The SAEEC Energy Awards', awarding engineers and companies for their endeavors towards energy and water efficiency. Our annual energy awards ceremony recognizes best practice, innovation and leadership in the industry and serves as an inspiration to promote good work ethics within Southern Africa. All the recipients of an energy award are then submitted into the AEE International and Regional awards, and are recognized for their achievements and commitment towards sustainability and development goals. We in turn as the local chapter of the AEE, have been recognized for our achievements, and have received a total of 8 awards over the past years.

We have an affiliation with the Clean Energy Ministerial, an international body, who hold The Clean Energy Ministerial (CEM) Energy Management Leadership Awards for companies using the ISO 50001 global energy management system standard. It is a motivation for Industry to continuously work towards sustainability and energy and water efficiency.

The SAEEC believes that energy is one of the single most important drivers of socioeconomic development and human well-being. Energy efficiency saves money amidst rising energy costs. It also drives innovative green technologies, supports a cleaner environment and strives to enhance competitiveness in a world committed to reducing GHG emissions through climate change.

Climate action and awareness with the focus on net zero carbon emissions, are actions that need to be considered very seriously. For business owners it is important to understand how to make your business Net Zero, how to progress with saving energy and water and as a direct result monetary savings.

As a non-profit Association, we offer our members great support in training, skills development, networking at our events and much more. Our Board Members led by Mr. Zadok Olinga, President of the SAEEC, and together with the Secretariate are always available to offer assistance. We look forward to your consideration in joining the SAEEC Family.

"Human behavior grows from three main sources : Desire, Emotion and Knowledge" - PLATO

Proudly the SAEEC encompasses all three sources: the desire to achieve, the emotion of elation from achieving and the knowledge to share.

Please visit our web-site www.saeeconfed.org.za
Helen Couvaras : BA Honours (Byzantine Studies)
Membership Secretary and GO2Energy Technical Journal.

SUSTAINABLE ENERGY

How to ensure home energy security during intermittent grid times

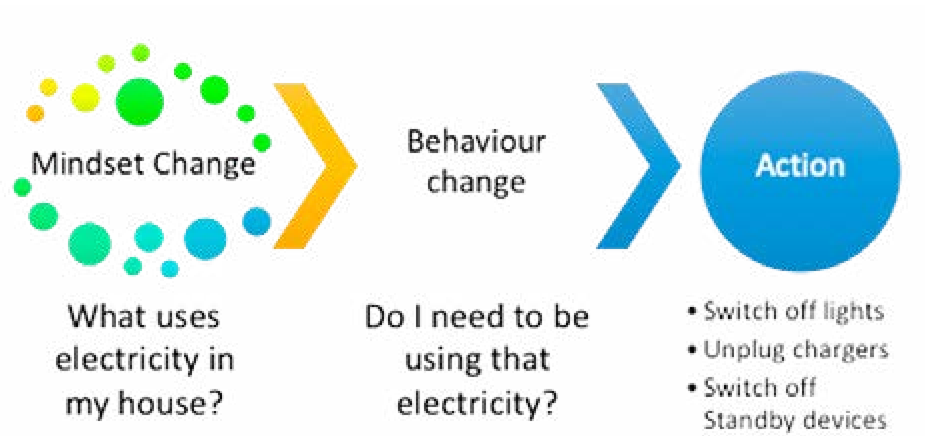
Dr Karen Surridge, Project Manager Renewable Energy and Cleaner Fossil Fuels, South African National Energy Development Institute (SANEDI)

South Africa is currently in an extremely electricity constrained environment due to a number of contending factors. As such there is a lot of pressure being placed on the economy in terms of the commercial and industrial sectors, but also on the residential sector. Homeowners are finding it increasingly frustrating and/or threatening to be without electricity for prolonged periods of time during load shedding and possible associated technical power outages. This opinion piece highlights how one can assess ones energy requirements, become more energy efficient and then implement energy solutions to meet the requirements of the household during times when electricity from the grid is not available. It is important to remember that although there are a number of renewable energy sources that are considered to be free, the technology to implement and harness them is not. Therefore understanding your energy requirements, becoming more energy efficient and ultimately sizing a backup system to meet these energy requirements can ease your day-to-day living.

Home Energy Security

Loadshedding's intense impact on the economy is ever present, but for most South Africans food going off in their fridges, being unable to put a hot meal on the table and spending hours in the dark is far more of a reality. While solving the national electricity supply problems is out of our hands, there is much we can do to improve energy security in our homes, writes Dr Karen Surridge from the South African National Energy Development Institute (SANEDI).

South Africa is in the fortunate position of having a variety of energy resources available, including renewable energies. While wind energy is not necessarily a homeowner's initial thought when considering a household intervention, solar energy has become the go-to solution. However, before you invest in a solar system – or any other energy solution for your home – take three basic steps to make your household as energy efficient as possible: a mindset change, followed by a behaviour change leading to actions that result in energy efficiency. This will reduce load on the grid, which will help to reduce loadshedding, but also benefit you by reducing your electricity bill.



Having done all you can to lower your electricity use, you can turn your attention to backup energy technologies.

For quite some time, a petrol or diesel generator was our first thought. However, concerns around air and noise pollution, not to mention the cost of fuel and of running and maintaining an engine, are making generators less attractive.

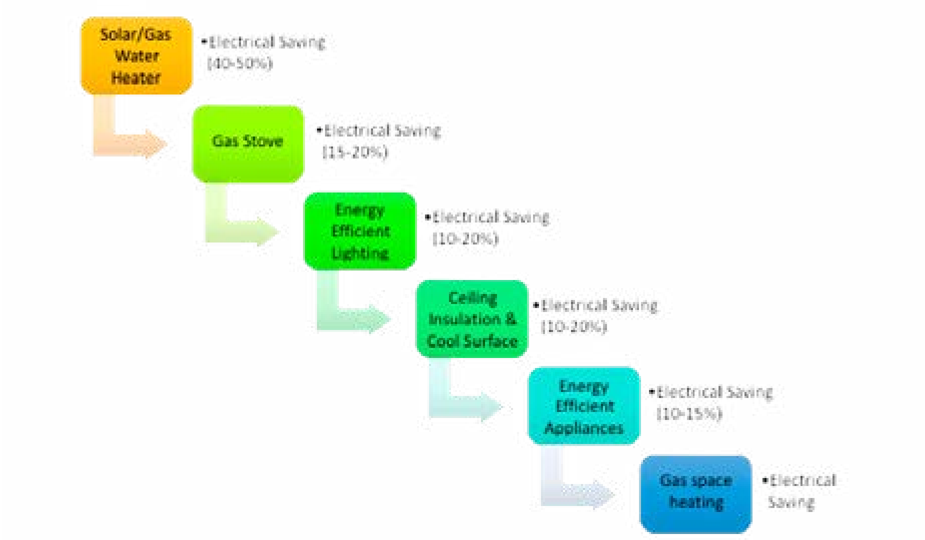
Another option is a battery backup with an inverter. The battery charges while the electricity is available and when it's not, the stored energy is channeled through the inverter to feed the alternating current requirement of the house. You can also install photovoltaic panels on the roof of the house to generate a direct current that runs through an inverter to feed the alternating current of the house during daylight hours when the sun is shining. The ultimate energy security option would be a combination of these two technologies: using solar photovoltaics as an electricity supply to the house, but also to charge a battery backup system that will come online when the sun goes down.

Different types of technologies have different cost implications, which is why it is essential to first make your household as energy efficient as possible so that when you do a technological intervention, you can keep costs down because the requirement for the system is lower.

Appliances that provide heating and cooling use the most electricity, particularly an electrical geyser. Start, therefore, by investing in technology like a solar or gas water heater and/or an instantaneous or heat pump water heater. Such an energy-efficient or energy-neutral technology will immediately reduce your household electricity bill by up to 50%. The same applies to space-heating and cooking needs, both of which can be met with gas. When appliances reach the end of their lifetime, choose an energy-efficient replacement (this SANEDI article on standards and labelling is a handy guide). In addition, good insulation and cool-surface technology (see this article for more information) can ensure that your house remains cool when you have cooled it down, or warm once you have heated it.

The most underrated of all potential interventions, despite it's significant energy- and cost-saving impact, is lighting. Simply switching from old incandescent or fluorescent light bulbs to LED bulbs can shave as much as 20% off your bill every month. As one of the cheapest energy-efficient interventions, LED bulbs should be the first thing you do. The bulbs also last far longer than their less electricity efficient counterparts.

The message to take from all this is that every household can improve its energy-security situation. Consider your day-to-day energy requirements to determine, firstly, how you can become more energy efficient and, secondly, which energy-secure solution will best meet your needs. The result is the ultimate win-win scenario: a home that is energy secure, considerable savings on your electricity bill and a contribution to reducing loadshedding stages.



There are multiple home-energy solutions available in the photovoltaic, inverter and battery backup sector. Use this infographic to develop the most cost effective, reliable, and energy-secure solution for you and your family.

How to be smart when going with PV

In the urgency to shield your household from the worst of loadshedding, you could end up with an investment that doesn't deliver the promised returns. Here's how to avoid the pitfalls when installing a PV system.

Solar panels have become a feature of the South African residential landscape over the past few years as homeowners seek a measure of energy self-sufficiency. Once you have made your home as energy efficient as possible with LED lights, a solar/gas/efficient geyser, gas cooker and energy-saving habits, the time is right to invest in a PV system with battery backup to keep you going during loadshedding.

It is always a good idea to know what your monthly electricity consumption in terms of kilowatt hours, this will be asked of you by any installer worth his/her salt. You can find this on your electricity bill, and it would be a good idea to compare what you were using before your energy efficiency interventions versus what you are using now. Once you know what you are consuming you will also know whether or not the installer is quoting you with specifications that will meet your needs.

"How much can I expect to pay for a PV system and will the ROI be worth it, are questions I get asked often, quickly followed by what can I do to not get taken for a ride," says Dr Karen Surridge, Renewable Energy Project Manager of the South African National Energy Development Institute (SANEDI). The answers are not simple one liners, but the guidelines Surridge gives will go a long way towards ensuring a happy PV and/or battery system investment.

1. Find the right installer

The starting point is a reputable installer with a solid reputation and good references. You can find installers in your area registered with the South African Photovoltaic Industry Association (SAPVIA) on the PV GreenCard website (https://pvgreencard.co.za). Registration means that the person has had the proper safety and quality training and will issue you with proof of compliance for the installation for insurance, finance and regulatory purposes.

You can also Google your potential installers and ask friends or social-media community groups for references, word of mouth can be a powerful recommendation. A certificate of compliance (CoC) as a line item on your quote is usually an indication of capability, since only registered tradespeople can issue such a document.

2. Know what you should be paying for

A PV system consists of PV panels, an inverter, batteries and the components that tie the system into your home's electrical system. The quote from your installer should be itemised and specify all these items.

- The inverter inverts the direct current (DC) produced by the PV panels (or batteries) into alternating current (AC), which makes the electricity available

to your home and appliances. An inverter on its own is of no use. Never skimp on the inverter and always choose one with a built-in surge protector. While prices differ, a good 5 kVA inverter that is sufficient for an average four-person household should cost between R25 00 and R30 000.

- In terms of photovoltaic (PV) panels, go with a well-known brand that has a good reputation. Insist that the installer specifies the brand they intend to use so that you can do your own research. Nowadays, PV panels have a relatively high efficiency of about 20% and it is usually a 545 – 555 Watt panel that you will purchase. You are looking at a price range of approximately R 2 000 – R 4 500 per panel. For an average household, with a family of about four, 8 of these panels should be more than enough. Once again do your research, make sure that you are satisfied with the specifications on the make of panel for which you are quoted.
- When it comes to batteries, there are a number of options from which you can choose, however, there are two factors that you need to consider the first one is the depth of discharge (DOD) and the second one is the number of cycles in the lifespan of the battery.

o Ideally, if it suits your pocket, Lithium Ion should be your battery of choice, but it is the most expensive option, coming in at about R25 000 – R30 000 for a 4.8kWh to go on your 5kW inverter. They are more energy dense than lead acid or gel batteries, meaning they last longer (up to 3000 cycles) and have a deeper cycle discharge ability. In laymen's terms this means that a lithium ion battery can comfortably go down to 20-5% power (discharging 80-95% into your household needs) before it needs to be recharged; not negatively effecting the lifespan of the battery.

o In terms of cost vs DOD and cycles, the next best option is to consider gel batteries. One would expect to pay around R 4000 – R 7000 for a 3.2kWh. These should only be run to 50% discharge, anything beyond this and you will risk negatively affecting their lifespan (100-1500 cycles).

o Similarly, deep cycle lead acid batteries should be discharged to no lower than 50%, never fully discharge a deep cycle lead acid battery because the deeper you discharge the battery the more it will reduce the battery's total lifespan (500-1000 cycles). Lead acid batteries are the least cost to buy and prices range from R3 000 – R 7 000 for a 3.2kWh (12V)

- Whatever Battery you select, insist on a brand name that you know or can research, both in terms of performance and price.
- Request an itemised quote for all the components needed to get the electricity from the panels into your home. These include roof brackets, wiring, the combiner box (which sits between your home distribution board and the inverter), labour costs, the certificate of compliance (CoC), switches, cables ,fuses (it is always good to buy a few of these to keep in reserve, they are inexpensive) and trunking.
- Switchgear and surge protection, which is the "brain" needed to balance the system, must also be specified, along with the level of tech integration that is offered.
- Lastly, don't be seduced into buying functionality and/or capacity you might not use, remember you are energy efficient now so you don't need such a large system, things such as wi-fi communication etc. are also a nice to have, but not essential.

"It is important to get a spec for the wattage on the inverter, panels and batteries," says Surridge. "You sometimes need a few more panels than you'd think, and you never want to run your inverter at its maximum. For example, if you have 2,8 kW coming in from the panels, you want a 5 kW inverter. In this way, you don't put strain on the inverter, which extends its lifetime. As far as possible, you want your inverter to last as long as your batteries."

3. Negotiate

Just because you have a quote from a reputable installer doesn't mean you have to accept it. Negotiate if you feel it is unreasonable, but without skimping on either quality or safety for the equipment, safety for your home electrical system and safety for you and your family.

"A PV and/or battery back up system can add tremendous quality to your life and up the resale value of your home," says Surridge. "It is therefore worth investing the time and effort to make sure you get the best value for your investment."

SUSTAINABLE ENERGY

WATER

Water sector follows electricity sector in South Africa-an opinion from the SA Water Chamber CEO

Benoît Le Roy

The fiasco that unfolded this past long weekend in September, so for me the "Fiasco Public Holiday", was a perfect storm of dominoes falling one after the other. What has led to these very serious events?

Over the past three decades we have seen most of our infrastructure assets being sweat until they fall over, rail and road networks, electricity generation and municipal distribution systems and the past few years water shedding and Day Zero threats spread nationally.

Let's start with the Day Zero phenomenon, I think this emanates from Cape Town that has always had water scarcity issues to deal with and thankfully is reasonably well equipped with resources to manage its water cycle. However, over 60% of the city' water comes from nationally owned and managed dams.

SUSTAINABLE WATER

This means that the national operator decides on water allocations where the city reportedly uses 64% of the Western Cape Water Supply System, WCWSS, which is the equivalent to our inland IVRS, Integrated Vaal River System. Both are completely controlled and managed by the national government. It is in the record that the national government hesitated to reduce water allocations until very late allowing the agricultural sector to continue unthrottled with the city and its own agriculture and industry being throttled out of proportion. This continued for years until the gravity started sinking in and agriculture was cut off and the city's allocation halved, too late and too drastic causing untold economic damage.

Currently our dams nationally are mostly full after well above average rains last summer and this winter in the Western Cape with several damaging floods to top it all. It is therefore ironic that we suffer water shedding and continuous outages in Gauteng despite the dams being full. What has surfaced is that despite having sufficient water, so water scarcity is not the current issue, our Gauteng metros are unable to deliver the full volume of water from their bulk supplier, Rand Water, to the customers as reportedly around 40% to 50% is lost in leaks in their distribution system. Rand Water was instructed earlier last year around the same time to increase its capacity beyond its water use licence to try and keep the demand satisfied but it did not work as the leaks merely increased. The term NRW, Non-Revenue Water, is used as the international standard to describe water that is delivered in bulk to the distributor and not billed as revenue to the consumer. It has several components such as leaks, stolen and unmetered/unbillable subsets that all point to the inefficiency of the water delivery system. Imagine a food or automotive production plant having a 40% to 50% production efficiency, it's impossible to stay in business. So, are we out of business in the business of delivering urban water in SA, yes must be the obvious answer?

Eskom also does not have a shortage of coal, but its generation units are unreliable and have an efficiency also of around 50% to 60% and declining rapidly for the past decade, same as the water situation surely? Do we have a water or electricity problem? The simple answer is not as they are the symptoms of a much greater issue at hand, the inability to maintain basic services and their assets. The burning question is where to now!

The reality is that this systemic collapse of our basic services has taken three decades to materialise where the assets were developed over the past century and a half but at a heightened pace after the second world war, so around seventy-five years. One piece of good news is that the water crisis is no longer swept under the carpet but how long and how much will it take to get us back to acceptable norms. Electricity generation systems are designed to have an EAF of 97% as are water reserves for urban supply. This means that in a hundred years there would be a total outage over the period of three years or three percent. The best run water distribution systems in Japan, Singapore and central Europe have less than 5% NRW where 10% to 15% is generally deemed as good practice. We have some experience in SA of reducing NRW in a major metro from over 30% to less than 15% over a decade ago in Cape Town. The approach was recognised then as a global leading one by the IWA, International Water Association, where pressure demand management was used. This is when the pressure in the system is reduced when there is low demand so that physical losses are also reduced in an ageing distribution network. This is not the final solution but a key intervention that helps reduce the system losses whilst asset rejuvenation programs should be carried out.

Johannesburg reports that its water assets have a replacement value of over R100 billion. Roughly 50% are the bulk and distribution water networks, so, R50 billion in round numbers with more than half of these assets left with less than five years life or R25 billion. The other two Gauteng metros would equal this number roughly, so R50 billion is the funding required within less than five years, so, R10 billion a year where COJ currently spends around R1,2 billion on asset replacement. The reality is that we are short of at least R7,5 billion annually in the Gauteng metros. The national quantum would be at least four times this, so R30 billion annually.

The severity of this crisis in financial terms means that the normal approach of fiscal support will not work, especially with the national fiscus under severe strain, and that new ways of managing the short-term crisis are required. What could these be?

1. Pressure demand management.
2. Digitisation of all assets including telemetry.
3. Digitalisation, smart analytics.
4. Private sector participation for funding, operations and support.
5. All of the above simultaneously?

The digitalisation of the water sector is a relatively recent global initiative where many regions suffer from inefficiencies that only digital interventions can address in the short term and drive efficiencies otherwise impossible to achieve, from operations to maintenance to funding. SA with its dire NRW symptom and fiscal constraints has only one choice which is to embrace digitalisation urgently as the required turnaround will take at least a decade to overcome once embarked upon.

There has been much to say about the national government induced "water shifting" in Gauteng which is the only immediate intervention realistically possible to try and keep all systems wet. Once distribution systems run dry, they risk water hammer and pressure spikes further causing bursts and increasing leaks in a decrepit set of assets, so, it's imperative to keep the systems wet above all other issues to avoid total destruction.

Is the situation helpless, no! Government has eventually acknowledged its failures after decades of denials and has established private sector friendly policies where unlike the electricity privatisation, water does not need to be privatised to rescue it. PSP, Private Sector Participation, is indeed feasible and necessary to reinstate the required water security in South Africa.

The impact of Water saving car wash on your Environmental, Social and Governance goals.

E-Wash

Over the past several months, we have meticulously examined the Integrated Reports of numerous major corporations. It is evident that a substantial commitment is being made across the board to enhance environmental impact and promote water conservation. However, amid the commendable initiatives undertaken by these companies, a crucial aspect remains notably overlooked.

Some of the prominent water-saving endeavors that companies are actively pursuing include:

- Waterless Urinals: Significantly reducing water consumption, these urinals save an impressive 1 liter per flush.
- Waterless Hand Sanitizers: Boasting 90% alcohol content, these sanitizers eliminate the need for water, albeit at a higher cost.
- Chemical Flushing Toilets: These innovative toilets contribute to water conservation by saving 11 liters per flush.
- Aeration Taps: Fitted with reduced water flow, these taps promote efficient water usage.
- Borehole Water Management: Companies are increasingly optimizing the efficient use of borehole water.
- Rainwater Harvesting: Employing rainwater for garden irrigation is a growing trend among environmentally conscious corporations.
- Waterless Car Wash: A novel approach to maintaining corporate fleets without compromising water resources.

In the context of South Africa, where major corporations often employ a workforce ranging from 1,000 to 3,000 employees nationwide, the impact of these conservation measures is extensive. A substantial portion of these employees commutes to work, spending a minimum of 7 hours within the office premises. The sprawling car parks surrounding corporate campuses in Johannesburg vividly illustrate the magnitude of vehicular presence.

Our emphasis on this issue stems from the recognition that a considerable number of employees—700 in the case of a medium to large corporation with around 1,000 staff members—rely on personal vehicles for commuting and parking during working hours. To underscore the significance of our proposal, let's consider the installation of a waterless car wash facility at business campuses. This example will focus on a corporation with 1,000 employees, 700 of whom drive and park on-site regularly.

By integrating waterless car wash services into these corporate campuses, not only can substantial water savings be achieved, but a tangible contribution to overall environmental sustainability can also be realized. The implementation of such initiatives aligns with the broader industry trend towards comprehensive water conservation practices. It serves as a practical and impactful step towards creating more environmentally responsible corporate environments, contributing to the global effort to address water scarcity and environmental sustainability.

Case Study 1:

Traditionally, each employee engages in a weekly car wash at a conventional facility, predominantly on weekends. The water consumption per car wash ranges from 60 to 100 liters, with a total of 700 cars in play. Consequently, the cumulative water usage for car washing by employees on a weekly basis is estimated at a staggering 70,000 liters.

Case Study 2:

In contrast, the introduction of a water-saving car wash facility on the corporate premises yields a transformative impact on water conservation. With a minimal consumption of only 1 liter per car, and considering the same fleet of 700 cars, the total weekly water usage for employee car washes plummets to a mere 700 liters.

The implementation of a water-saving car wash at the corporate campus results in substantial water savings, amounting to an impressive 69,000 liters per week. This translates to a monthly conservation of 277,200 liters and an annual conservation of a remarkable 3,326,400 liters.

By examining the stark contrast between the traditional and water-saving car wash approaches, it becomes evident that integrating environmentally conscious practices within the corporate setting not only significantly reduces water consumption but also aligns with broader sustainability goals. The adoption of water-saving measures not only benefits the immediate corporate community but also contributes meaningfully to addressing broader environmental challenges. This case study underscores the tangible impact that small-scale, yet widespread, initiatives can have on fostering sustainable practices within corporate environments.Importance of your Environmental Social Goals

ESG and Integrated Reports. What are the benefits of showcasing your sustainability goals to your stakeholders:

ESG factors are becoming increasingly important to investors and other stakeholders. Companies that adopt integrated reporting can benefit from the following:

ESG (Environmental, Social, and Governance) practices offer a range of benefits for large companies:

1. Risk Management: Integrating ESG factors helps companies identify and manage risks associated with environmental and social issues, such as climate change, resource scarcity, and labor practices. This proactive approach can prevent potential legal, financial, or reputational risks.
2. Cost Savings: Implementing sustainable practices often leads to resource efficiency, reducing waste and energy consumption. This not only lowers operating costs but can also enhance long-term profitability by optimizing resource use.
3. Brand Reputation: Demonstrating a commitment to ESG principles can enhance a company's reputation. Consumers, investors, and other stakeholders increasingly value socially responsible and environmentally conscious businesses, leading to improved brand image and customer loyalty.
4. Access to Capital: Many investors are incorporating ESG criteria into their decision-making processes. Companies with strong ESG performance may find it easier to attract investment and secure financing. This trend is particularly noticeable among ESG-focused funds and socially responsible investors.
5. Employee Engagement and Productivity: ESG initiatives can positively impact employee morale and attract top talent. Employees often prefer working for companies that align with their values. Engaged and motivated employees can contribute to increased productivity and innovation.
6. Regulatory Compliance: Adhering to ESG standards ensures compliance with evolving regulations related to environmental conservation, labor practices, and corporate governance. This proactive stance minimizes legal and regulatory risks.
7. Long-Term Sustainability: ESG practices contribute to the long-term sustainability of the business by addressing environmental and social challenges. This, in turn, enhances the company's resilience in the face of changing market dynamics and societal expectations.
8. Innovation and Competitiveness: Companies that embrace ESG principles are often more innovative, developing products and services that align with sustainability trends. This innovation can improve competitiveness and open up new markets.
9. Supply Chain Resilience: Assessing and managing ESG risks in the supply chain can enhance resilience and reliability. This is particularly important as disruptions in the supply chain become more common due to various factors, including climate-related events.
10. Stakeholder Relations: Prioritizing ESG considerations fosters positive relationships with various stakeholders, including customers, employees, communities, and regulators. This proactive engagement helps build trust and goodwill.

In summary, incorporating ESG practices into business operations goes beyond compliance; it has the potential to drive long-term value, resilience, and positive societal impact for large companies.

AGRICULTURE & FOOD SECURITY

AGRICULTURE & FOOD SECURITY

Putting the AI in SustAInability: Is Data the new Soil?

Priaash Ramadeen, CEO, The Awareness Company

Imagine a world where every drop of water is accounted for, every kilowatt of energy is optimised, and every acre of land is used sustainably. This is not a distant utopia, but a reality within our grasp, thanks to the integration of Artificial Intelligence (AI) in sustainability efforts. The modern era, marked by an unprecedented focus on balancing economic growth with environmental stewardship and social well-being, finds a powerful ally in AI. As we stand at this pivotal junction, the question arises: Is data the new soil in which the seeds of a sustainable future are sown?

Harnessing the power of AI to drive sustainable practices is not just about technological innovation; it's about reshaping the future of our planet. With its unparalleled ability to analyse large datasets, forecast trends, and offer predictive insights, AI is uniquely positioned to enhance our understanding of environmental systems and facilitate smarter decision-making. This capability is crucial, as the gap between the data we collect and the insights we glean from it can be the difference between preserving a forest or losing it, between a city with clean air or one shrouded in smog, between a community with access to clean water or one plagued by scarcity.

In this context, data is both a challenge and an opportunity. The challenge lies in the sheer volume and complexity of the data we must navigate to make informed sustainability decisions. The opportunity, however, is to employ AI to cut through this complexity, transforming raw data into actionable intelligence. The potential applications are vast, encompassing energy, water, agriculture, conservation, buildings, and critical infrastructure — each vital to the pursuit of a sustainable future.

Data Dilemmas: The Barrier to Solutions

Sustainability is fraught with challenges that are as diverse as they are pressing. From the need to reduce greenhouse gas emissions to preserving biodiversity, ensuring water security, and promoting renewable energy, the scale of the problems requires robust solutions. These challenges are compounded by the fact that the data necessary to tackle them is often siloed, inaccurate or missing, or simply not utilised effectively. Recent studies suggest that up to 80% of the data within organisations is not being used, a veritable treasure trove of insights left in the dark.

The lack of situational awareness that arises from these data challenges is not just an inconvenience; it's a critical barrier to progress. The United Nations' Sustainable Development Goals (SDGs) provide a blueprint for global sustainability efforts, yet without accurate and timely data, the path to achieving these goals is obscured. For instance, the World Resources Institute highlights that over one billion people face severe water scarcity for at least one month each year, yet the policies and investments needed to alleviate this issue often lag due to inadequate data.

Moreover, the urgency of these challenges is growing. Climate change is leading to more frequent and severe weather events, as the Intergovernmental Panel on Climate Change (IPCC) reports a rise in global temperatures, sea levels, and extreme weather patterns. Protecting our critical infrastructure from these events, as well as from human-induced threats like pollution and overconsumption, has never been more important.

Situational Awareness for Sustainability

The advent of AI and data analytics has opened up new frontiers in the pursuit of sustainable development. The role of AI in deciphering complex environmental data cannot be overstated. It provides us with the precision and speed required to transform vast amounts of raw data into meaningful insights that can inform policy and practice.

Global investment in AI for sustainability reflects its potential. According to PwC, AI applications have the potential to reduce global greenhouse gas emissions by 4% in 2030, an equivalent of 2.4 gigatons of CO_2, which would deliver economic gains of up to $5.2 trillion by enhancing productivity and creating new AI-driven markets.

In the realm of situational awareness specifically, AI is a game-changer. It enables real-time monitoring and forecasting, which can predict resource shortages, track environmental degradation, and even prevent disasters. By integrating AI with geographic information systems (GIS), we can now monitor deforestation, water levels in reservoirs, and the migration patterns of endangered species with a level of detail that was previously unattainable.

However, the application of AI extends beyond monitoring and into the realm of active management. For instance, AI algorithms can optimise the operation of water treatment plants, reducing energy consumption and costs. In agriculture, machine learning models are being used to predict crop yields, which helps farmers make informed decisions about the use of water, fertilisers, and pesticides, leading to more sustainable farming practices.

Each sustainability issue presents unique challenges, but AI offers tailored solutions that can drive sustainability in each domain.

Energy: AI is revolutionising the energy sector by optimising the balance between supply and demand, especially for renewable sources like wind and solar. Smart grid technologies, powered by AI, not only predict energy demand spikes and adjust supply accordingly but also enhance overall energy efficiency. For example, Google's DeepMind AI has reduced energy consumption for cooling by up to 40% in data centres. These advancements can lead to a significant reduction in energy costs and reliance on fossil fuels.

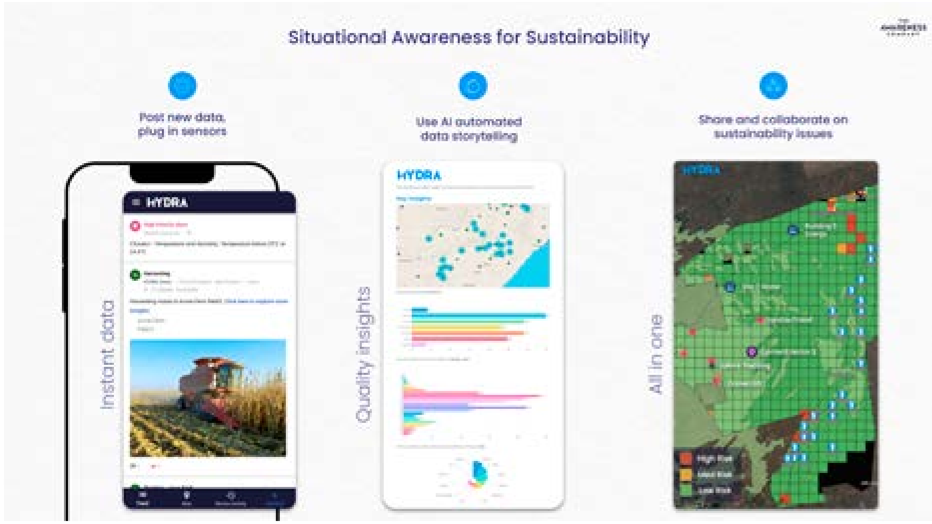
Water: In water management, AI plays a critical role in predicting and responding to issues like droughts and floods, and in optimising water usage. AI-driven systems enhance water conservation efforts by analysing weather patterns and usage data, reducing waste by up to 25%, and optimising distribution in cities and agricultural areas. This technology can be pivotal in managing water scarcity, potentially reducing consumption through smart irrigation and leakage control.

Agriculture: AI-driven precision agriculture is transforming farming practices by allowing more efficient resource use and improving crop health monitoring. This technology analyses soil data and climate conditions, leading to more informed decisions about planting, irrigation, and harvesting. The result is an increase in agricultural efficiency by up to 20%, a reduction in pesticide use, and a boost in crop productivity, making farming practices more sustainable.

Conservation: In conservation, AI aids in combating poaching and monitoring wildlife populations by analysing images from drones and satellites. This technology improves the detection of illegal activities, such as deforestation, by 27%, and enhances the understanding of species population dynamics. AI-driven conservation efforts lead to more effective management of protected areas and contribute significantly to habitat preservation.

Buildings: AI is key to making buildings more sustainable, optimising energy use, and managing consumption dynamically. Smart building systems, which learn usage patterns and adjust systems like lighting, heating, and cooling, can enhance energy efficiency by up to 35%. This leads to significant cost savings and a reduced carbon footprint for urban centres, as these systems adapt to occupant behaviour and environmental conditions.

Critical Infrastructure Protection: AI significantly boosts the security and resilience of critical infrastructure. It not only anticipates equipment failures, reducing downtime by up to 30%, but also enhances physical security. In applications like railway systems, AI aids in operational efficiency and threat detection, improving service availability by 10% and safeguarding against risks like sabotage and theft, ensuring uninterrupted and secure infrastructure functionality.



Situational awareness software, like The Awareness Company's platform HYDRA, emerges as a pivotal solution in addressing specific sustainability challenges. By integrating real-time data creation, instant AI automated analysis and high quality predictive insights, it empowers sustainability-solvers in energy, water management, agriculture, and beyond with the agility to anticipate, adapt and action.

Building a Sustainable Future

The journey towards a sustainable future is not without its challenges, including ethical considerations and the need for global collaboration. But with each advancement in AI and data processing, we edge closer to a world where sustainability is not just an aspiration but a reality. The development of more advanced machine learning algorithms, coupled with improvements in data processing and sensor technology, will unlock even greater potential. In the near future, AI could enable fully autonomous systems that manage resources with minimal human intervention, creating a more sustainable world.

For instance, AI could lead to the development of smart cities where traffic flows are optimised to reduce emissions, waste management is automated and efficient, and energy use is balanced across a network of interconnected buildings and devices. In agriculture, AI might bring about a new green revolution, with precision farming techniques that maximise yield while preserving soil health and biodiversity.

As we harness the power of AI and data for sustainability, we are laying the groundwork for a future that is not only more efficient and prosperous but also more harmonious with the natural world. The journey towards this future is underway, and with each advancement in AI, we move closer to realising the full potential of sustainable development for planet, people and profit.

Contact us:
The Awareness Company
+27 084 554 5598
priaash@awarenesscompany.co.za
awarenesscompany.co.za


FOOD & TREES FOR AFRICA.

CORPORATE SOCIAL INVESTMENT

One of Food & Trees for Africa's missions is to inspire positive change across our food system with the help of our funding partners. By pursuing the Sustainable Development Goals within each of our programmes, we are building a greener, more food sovereign and food secure future for all.

ENTERPRISE SUPPLIER DEVELOPMENT

We aim to support under-resourced farmers to conquer the barriers to entry to the commercial marketplace, enabling them to earn an income. We understand what it takes to develop sustainable, reliable businesses and incorporate them in the supply chain.

CONTACT US:

trees.org.za
info@trees.org.za
011 656 9802

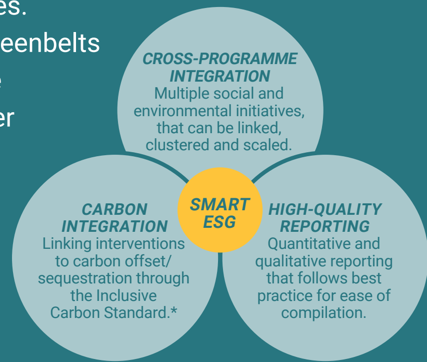
CARBON

As part of our collective responsibility to reduce and offset global emissions, Food & Trees for Africa promotes easy access to a socially inclusive carbon market that supports under-resourced communities. We emphasise processes that promote transparency, affordability, accessibility and accountability.

URBAN & COMMUNITY GREENING

We aim to preserve and protect our terrestrial environment and transform landscapes by planting trees in shared spaces. We plant at schools, community centres, as well as at informal homes.
Food & Trees for Africa has created strategic greenbelts in major city centres across the country and are currently driving greenbelt initiatives in a number of townships nationally.

Inclusive Carbon Standard



The butterfly effect is leading to a climate change cascade but we can mitigate the impact on our food systems

Food and Trees For Africa

In our rapidly changing world, the considerable effects of climate change have emerged as an urgent global concern. As weather patterns shift, we find ourselves amidst a cascade of impacts that ripple through every aspect of our natural environment.

One particularly concerning consequence is the profound disturbance of our food chain, a critical system upon which all life on Earth depends. This interconnected web of life is intricately woven, and climate change has begun to unravel it. However, there is hope, as conscious agricultural practices and tree planting initiatives stand as formidable tools to mitigate far-reaching repercussions.

Unraveling the Web of Life

Our planet's ecosystems have evolved over millennia, shaped by a delicate balance that depends on a stable climate. Unfortunately, human activities have sent shockwaves through this balance. The burning of fossil fuels, deforestation, and unsustainable agricultural practices have led to a dramatic cascade of ecological consequences.

One of the most concerning consequences of climate change is its impact on the food chain. This chain is a web of relationships that connects producers and consumers in a harmonious cycle of life. From microscopic plankton in the oceans to large terrestrial predators, all species are interlinked. As the climate changes, the delicate balance that sustains life falls into disequilibrium.

One such impact of climate extremes on our food systems is its effect on the growth and distribution of species. For instance, research indicates that a shifting climate has increased the overwintering range of the diamondback moth by 1.4 million square kilometres, an area slightly larger than the whole of South Africa. The larvae of this moth, also known as the 'cabbage moth' are notorious for damaging brassica (Brassicaceae) crops such as broccoli, cauliflower, cabbage and kale.

"Infestations, such as the one we are currently witnessing in the Western Cape, directly disrupt food production and jeopardize the livelihoods of subsistence farmers as well as the stability of the wider food system and food prices in South Africa," explains Robyn Hills, Head of Programmes at Food & Trees for Africa.

The moth species has furthermore evolved to being practically pesticide resistant. Meanwhile, ground beetles, a natural predator of the diamondback moth, often used as a biological control mechanism, are just as susceptible to the impacts of climate extremes. Long-lasting periods of drought decrease the diversity and size of populations. In the absence of large enough communities of beetles, the proliferation of the moth population goes largely unchallenged. This is just one example of the countless ways in which our changing climate is driving the food chain and our unsustainable food systems to the brink of collapse, challenging us to think more critically about our anthropogenic interferences.

Conscious agricultural practices provide hope

To maintain the equilibrium of our ecosystems and secure our food chain, the preservation and restoration of natural habitats linked to our food systems are

paramount. Creating climate-resilient habitats allows for the possibility of predatory species - from insects to larger prey animals - to maintain a natural balance within the food chain and nitrogen cycle. Embracing conscious agricultural practices - such as conservation agriculture, permaculture, agroecology and regenerative agriculture - contributes to building this resilience.

The Koberwitz Experiment was one of the earliest research mandates that challenged the direction and practice of contemporary agriculture and laid the philosophical and practical foundations for an alternative agriculture that would promote ecosystem restoration. The researchers found several key balance-restoring outcomes, including that of increased biodiversity.

Over a century later, an excellent example of ecosystems-centric agriculture in practice originates in the heart of South America. In Central and South America, coffee is a significant cash crop that is affected by climate change. Additionally, traditional, intensive coffee farming methods have often led to

habitat destruction, pesticide use, and a loss of bird species.

Agroecological approaches, which integrate ecological principles into agricultural systems, have been implemented to restore ecosystem balance at many of these coffee farms. Research conducted on coffee farms in Mexico and Costa have found that agroecological practices promoted bird diversity, pest control and ecosystem balance. Coffee plants cultivated under the canopy of native shade trees provide habitat for a variety of bird species and contribute to a cooler microclimate. The diverse tree canopy not only acts as a refuge for both migratory and resident bird species, but also improves the quality of the coffee beans. Furthermore, the increased presence of insectivore bird species provides a natural pest-control service, reducing farmers' reliance on chemical pesticides. This approach helps maintain pest-preying bird populations, and also contributes to the pollination of various plant species.

AGRICULTURE & FOOD SECURITY

A forest of solutions

In the fight against climate-related damage to our food systems, we must also look to the benefits of conserving and restoring forest ecosystems. Trees can play a role in controlling pests through the application of agroforestry and forest integrated pest management (forest IPM). Trees contribute to building diverse ecosystems. These ecosystems provide habitats that boost the services provided by nature. Farms that incorporate trees into their design benefit from natural pest control as trees replicate the insect and predator diversity found in forests. Additionally, these forests are major global carbon sinks and are key to climate change mitigation. They are the largest land-based absorbers of carbon, removing around 7.6 billion tonnes of carbon dioxide (CO2) from the atmosphere annually.

"A farming system where the vegetation cover is varied, and includes trees and understory, has more natural checks and balances built in, and is more resilient than the simplified systems that dominate much of the farmed landscape," notes Stephen Briggs, Agroforestry Farmer.

Final Thoughts

Building a resilient planet is about supporting forest biomes, and protecting and improving existing agricultural habitats so that the unintended consequences of our actions on Earth can be better managed. Understanding the ecosystem services that food and forests render; acts as Food & Trees for Africa's (FTFA's) blueprint for the types of production workshops we run and the content of our environmental education curriculums. Education delivered in this way is a powerful tool for empowering communities to work alongside nature and take steps toward a more climate resilient and biodiverse food production system. In order to avoid a series of secondary impacts - extinction and infestation - (the cascade) we must work to bridge gaps in the web of life so that we can empower natural systems.

About Food & Trees for Africa

Our vision is one where everyone has access to nutritious, naturally grown food that promotes health and happiness. We aim to help build a society made up of communities where our ecosystems

are preserved and an urban balance of biodiversity is restored through tree planting. This is a world where the people of South Africa are provided a sustainable livelihood that does not negatively affect the environment. We envision a sustainable future that provides for everyone, as the effects of man-made climate change are halted and reversed. Our vision works toward a point in time where people are educated, understand, and respect the link between the environment, themselves and their prosperity.

Contact Details:
Nicole Ras, Communications Manager
info@trees.org.za
011 656 9802
Trees.org.za

Enhancing Supply Chain Visibility and Traceability with the SIZA Digital Recordkeeping Programme

In the fast-paced world of agribusiness, buyers and retailers face the ongoing challenge of ensuring the sustainability and efficiency of their supply chains. SIZA has heard and recognised retailers' and buyers' need for a cost-effective and streamlined monitoring programme to evaluate and monitor their supply chains and, therefore, has incorporated a digital recordkeeping traceability functionality as part of the well-established MySIZA platform.

The SIZA Digital Recordkeeping Programme

The SIZA Digital Recordkeeping Programme provides cost-effective monitoring for buyers to evaluate their supply chains effectively so that they can source sustainably with confidence from South Africa. The programme further allows buyers to monitor and evaluate their suppliers to determine sustainability and the progress made to reduce their environmental impact in terms of a Carbon Footprint.

The Power of Traceability

The SIZA Digital Recordkeeping Programme offers an integrated approach to environmental sustainability, allowing producers, packhouses, and processing facilities to meticulously record their inputs and outputs. This includes data on products grown, packed, or processed, as well as water, energy, and chemical usage. It also covers waste production and assesses the efficiency with which these resources are managed. The collected data can easily be uploaded to the SIZA platform, where it is analysed and converted into impact assessments. This process ensures that buyers can confidently assert the sustainability and risk mitigation of their entire value chain through the MySIZA visibility platform.

Enhanced Visibility and Traceability

One of the core strengths of this programme is the enhanced visibility it provides. Annual risk-based reports are available on a supplier level, along with digital dashboards that summarise data from suppliers over the course of a year. This means buyers can gain real-time insights into the sustainability and efficiency of their supply chain, promoting well-informed decision-making. It also allows brands and buyers to download CSV files so that they can incorporate this data into their own data platforms.

Streamlined Real-Time Monitoring and Evaluation

The SIZA Digital Recordkeeping Programme simplifies the complex process of monitoring and evaluating supply chains. With the MySIZA platform as its backbone, it offers a user-friendly and efficient way to track every aspect of the production process, from the farm to the store shelf.

The digital dashboards and annual reports available through the MySIZA platform are buyers' windows into their supply chains. Buyers can access the necessary information in real time, enabling them to stay informed about the performance of their suppliers and any potential risks. To date, 28 buyers, exporters, and importers have requested visibility on 189 sites' data across the supply chain, with more visibility links being requested every day. The programme helps buyers identify and address potential risks in their supply chain promptly, allowing for data-driven decision-making about sourcing, production, and distribution. These data-driven decisions lead to more sustainable practices throughout the supply chain.

Confronting Climate Change Partnership Ensures Credibility

A particularly exciting feature of the SIZA Digital Recordkeeping Programme is its partnership with Confronting Climate Change. This collaboration allows producers to request the calculation of their carbon footprint from a 3rd party after which the reports are seamlessly integrated into the information available to buyers. The result is a comprehensive, centralised platform on MySIZA that offers complete visibility and traceability with credible data across the South African supply chain.

Improving Supplier Productivity and Sustainability

As a monitoring tool, the SIZA Digital Recordkeeping Programme empowers stakeholders to track their suppliers' production inputs and assess the effectiveness of daily operations. This oversight allows buyers to identify areas for improvement and ultimately enhance the productivity of their suppliers.

The pursuit of sustainability targets, such as improved water and energy use efficiency, waste reduction, and emissions reduction, becomes more manageable with these insights.

Current Usage

Since the programme's inception, 344 sites across 168 businesses have registered for the SIZA Digital Recordkeeping programme, which continues to grow on a daily basis. 43% of these sites are currently in the process of completing a year's data, while 20% have already finalised a year's capturing and/or completed a carbon footprint calculation. The remaining 20% are in the process of gathering information to commence data capture.

Having SIZA as a compliance partner

As always, the SIZA office consistently delivers on its promise of providing excellent service and support to help brands and buyers efficiently manage their supply chains in South Africa. Over the years, SIZA has proven itself as an organisation that can be trusted to fulfil its commitments. Our hands-on approach and deep understanding of the South African landscape contribute to a valuable and outstanding partnership."

To learn more about the SIZA programme or the Digital Recordkeeping functionality and how it can be used throughout your supply chain, please contact the SIZA office on 021 852 8184 or send an email to admin@siza.co.za.

AGRICULTURE & FOOD SECURITY

Diseases on farms in South Africa: recent outbreaks point to weaknesses in the system

Wandile Sihlobo

South Africa has had a number of outbreaks of animal diseases in recent months that suggest there are weaknesses in the country's biosecurity system – the measures in place to reduce the risk of infectious diseases being transmitted to crops, livestock and poultry.

The outbreaks pose a major challenge for South Africa's domestic animal farming sector. Fears of weaknesses in the system have been raised by agribusiness for some time, suggesting that pressures and concerns are mounting.

Biosecurity breaches are not unique to South Africa. They have become a significant challenge globally. It's not easy to put a monetary figure on it, but reports of disease outbreaks across the world, and indeed in South Africa, suggest the problem has intensified.

In South Africa, reports about foot-and-mouth disease in cattle, African swine fever in pigs and avian influenza in poultry have become frequent. But few countries have had to deal with these disease outbreaks almost simultaneously, as South Africa has.

In 2022, six of South Africa's nine provinces reported foot-and-mouth disease outbreaks. This was the first time in the country's history that the disease had been spread this wide.

The situation remains critical.

All these outbreaks have had a notable impact on South African agricultural exports, and the growth prospects of the sector. For example, South Africa's beef exports for 2022 were down by 12% year-on-year, according to data from Trade Map. This decline was primarily due to the temporary closures of various export markets following the outbreak of foot-and-mouth disease in South Africa. Farmers are being hit hard.

Livestock and poultry account for roughly half of agriculture's gross value added.

Based on this history and the experiences of the agricultural sector, there is concern that South Africa's biosecurity breaches signal serious capacity challenges in farm biosecurity measures and the country's veterinary and related support services (mainly the laboratories) that control the movement of livestock and vaccine production.

The South African government, organised agriculture and industry bodies should work together closely to address the country's biosecurity challenges.

Disease outbreaks

On 4 November this year, the Department of Agriculture, Land Reform and Rural Development announced it was investigating a suspected outbreak of foot-and-mouth disease in one district.

This means the issue that was identified a year ago remains a challenge. These outbreaks weigh heavily on the cattle industry's fortunes. The beef industry accounts for a sizable share of the South African agricultural economy, and is positioned to absorb new entrant farmers in the sector. Beef exports were about 1% of agricultural exports, valued at US$151 million, in 2022, according to Trade Map.

The sheep industry was also affected by the 2022 outbreak. China, a significant market for South African wool, suspended imports. This resulted in a 21% year-on-year decline in the export value of wool in 2022, to US$337 million, according to Trade Map data. Wool still made up 3% of South Africa's record agricultural export value of US$12.8 billion in 2022.

China's official reason for the suspension was the foot-and-mouth disease outbreak. But it might not be all that clear cut. China may also have had capacity issues at its ports at the time because of the tail-end effects of COVID-19 and the restrictions there.

China has a unique protocol to handle wool shipments and avoid any contamination during a foot-and-mouth disease outbreak in South Africa. This was agreed in 2019 after an outbreak.

In 2022 South Africa's pig industry was put under fresh pressures. Towards the end of the year outbreaks of African swine fever were reported. The disease remains a challenge.

Most recently, the focus has been on avian influenza. More than a hundred commercial poultry facilities have reported cases. There are major losses for breeders of layers and broilers. As a result, there has been a spike in imports of fertilised eggs to rebuild the parent stock flock. This is key for stabilising the industry.

Major producers have announced serious losses. Consumers are also seeing a rise in the price of eggs.

Policy considerations

The growth prospects of farming businesses remain at risk if there are no material improvements in biosecurity. This is particularly true for sub-sectors that are crucial for inclusive growth. For example, the National Agricultural Marketing Council estimates suggest that black farmers account for 18%, 13% and 34% of wool, mohair and cattle production, respectively.

The department of land and agriculture should consider earmarking a share of its annual budget for emergencies to deal with biosecurity risks. These funds should be used only in the case of notifiable animal disease outbreaks and under strict rules and in concurrence with the South African National Treasury. This will be necessary to control animal movements, procure vaccines and permit vaccination in certain areas, employ additional staff and compensate producers when animals must be culled.

Notably, the government should also work the private sector on vaccine manufacturing as national laboratories have experienced failures in the recent past, thus weakening disease control efforts. Additionally, the government should increase the number of veterinarians and animal health technicians.

Also necessary is the repair and maintenance of international fences, which fail to keep wild animals and infected animals from neighbouring countries out of South Africa. Collaboration between Public Works and the National Treasury in this respect is critical.

In essence, most interventions require better management, coordination, restructuring of departments, and investment in fencing, new laboratory equipment and vaccine production.

Beyond the technical matters, the relationship between the regulators and farmers should also be improved so that disease outbreaks can be managed collaboratively with no hostility.

Wandile Sihlobo is chief economist at the Agricultural Business Chamber of SA and author of 'A Country of Two Agricultures'.

Empowering Women in Agriculture: Unleashing Africa's Potential

Agricolleges International

The agricultural landscape in Africa is undergoing a dynamic transformation fuelled by technology, innovation, and a growing recognition of the essential role women play in the industry. As we delve into the challenges and triumphs of agriculture, Jill Whyte, the chairperson of Green Farms Nut Company in Mpumalanga, South Africa, serves as a beacon of inspiration. This blog explores the untapped potential of African agriculture, the pivotal role of women, and the crucial link between education, skills development, and empowerment.

Unlocking Africa's Agricultural Potential

Africa's social and economic fabric is intricately woven with the threads of agriculture. McKinsey's insights reveal that over 60% of sub-Saharan Africa's population engages in small-scale farming, contributing 23% to the region's GDP. Despite this, the full potential of African agriculture remains untapped. Enhanced skills, increased productivity, and formal employment on commercial farms have the power to revolutionise the industry and uplift the lives of those working within it.

Jill Whyte: A Visionary Farmer

Jill Whyte, at the helm of Green Farms Nut Company, plays a vital role in South Africa's macadamia nut industry, handling a significant portion of the country's production. Beyond her agricultural success, Whyte sees farming as a catalyst for job creation and poverty alleviation in South Africa. She emphasises the responsibility of farmers as custodians of the land, advocating for sustainable practices to preserve the nation's natural treasures.

Jill's Journey: Breaking Barriers in Agriculture

Whyte's journey into farming is a testament to resilience and determination. Growing up on a cattle farm, she initially pursued art and business management, even embarking on a career in advertising in bustling cities like Johannesburg and London. However, the call of Africa brought her back, leading to a marriage with a farmer and her eventual rise as a highly successful female farmer.

Farming, especially in her youth, presented challenges for women. In a male-dominated environment, Whyte initially positioned herself as a support figure and mentor on the farm. Building confidence and claiming a position of authority took time. Today, she stands as a symbol of success, highlighting the evolving acceptance of women in agriculture.

Embracing Change: Women's Positive Role in Agriculture

While strides have been made in recognizing the positive role women play in agriculture, challenges persist. Whyte acknowledges the remarkable progress made by women breaking into various levels of the industry. However, she underscores the importance of self-investment, seizing opportunities, and building confidence to propel oneself forward.

Technology and Opportunities in Agriculture

Technology continues to reshape the agricultural landscape, making it an exciting and dynamic field. Whyte points out the myriad opportunities available, ranging from livestock production to horticulture and even the production of high-end pharmaceutical products. However, she doesn't shy away from addressing the challenges, with financing and skills shortage topping the list.

The Crucial Role of Education and Training

The success of future farming is intrinsically tied to technical improvement and the skills to implement cutting-edge technologies. Whyte emphasises the need to build analytical capacity, financial competence, and the ability to harness innovation. To achieve this, the industry must prioritise finding and training individuals eager to develop their skills for long-term careers in agriculture.

Empowering the Next Generation

For young women aspiring to make their mark in agriculture, Whyte's advice resonates: invest in your skills, seize every learning opportunity, and shield your confidence from external pressures. Acknowledging the resourcefulness and innovation of women, she firmly believes there's no reason why women cannot be as successful as men in the industry.

Reflecting on her own journey, Whyte wishes she had believed in herself sooner and acted with confidence, emphasising the importance of self-belief in a career often side-tracked by others' agendas.

Changing Mindsets for a Progressive Future

The path forward for the agricultural industry involves a collective shift in mindset. Modern agriculture is not confined to manual labour in the fields; it's a forward-thinking, technologically advanced sector. From drone operators to irrigation engineers and food scientists, diverse career opportunities abound. It's a call to think differently about ourselves and the industry, paving the way for a more inclusive and sustainable future.

Conclusion

In conclusion, the agricultural landscape in Africa holds untapped potential, and women like Jill Whyte are leading the charge in unlocking it. As we celebrate the evolving role of women in agriculture, we must recognize the pivotal link between education, skills development, and empowerment. Investing in the next generation of skilled individuals, regardless of gender, is crucial for the industry's sustainable growth. Together, with changed mindsets and a commitment to education, we can cultivate a future where agriculture is not just a career but a dynamic force driving economic prosperity and social change.

AGRICULTURE & FOOD SECURITY

Revolutionising agriculture through urban farming

Educate To Grow

All across Africa, populations are growing rapidly. Many people are vulnerable to malnutrition and other food-related diseases, limited healthcare and high rates of unemployment.

The result is that more and more people are streaming towards cities hoping to find jobs and earn an income. According to the United Nations, in 2013, sub-Saharan Africa's annual urban growth rate was 3.6% – almost double the world average. Importantly, as this migration takes place, an increasing number of urban gardens and farms are taking root too. The growth in urban agriculture is helping poor people cope with food scarcity and hunger. These urban populations are taking control of much of their own food production, growing crops or raising livestock in backyards or on undeveloped plots of land. This not only helps to alleviate hunger, but also offers many people a viable income as they find markets for their produce. In turn, this reduces the economic burden on productive communities and opens new doors of opportunity as urban informal markets gain traction. Across Africa, stories of resourcefulness in urban agriculture abound as people fight for their livelihood. So much is being

AGRICULTURE & FOOD SECURITY

achieved through sheer necessity. Imagine what could be achieved with additional support, knowledge and resources?

Urban farms and farmers of the future

Roadside traders could be transformed into the farmers of the future as community vegetable gardens created along roadsides and rivers are converted into city farms, vertical window food gardens, and horizontal pipe or water gardens. Teaching young people to implement urban agriculture through a variety of modern methods and practices would not only improve their yields and income potential but also give them a sense of achievement and the self-confidence that they are struggling to achieve through meaningful employment elsewhere.

According to a 2017 report published by The Sustainable Development Goals Centre for Africa, the continent has 65% of the world's arable land. However, food demand in Africa is expected to rise by over 60% by 2050 due to population growth. Simple shifts in thinking can result in better efficiencies and more environmentally friendly produce that is less prone to climatic changes, and which ultimately has a positive influence on production yields. And with urban farming, we don't need vast tracts of remote land to make it possible.

Bringing urban farming knowledge to urban communities

In order to transform the urban farming industry into a thriving and growing sub sector, more skills and training are needed. Agriculture education organisations and e-learning platforms will play a pivotal role in bringing the required urban farming knowledge, via mobile devices, to these urban communities. The whole of Diepsloot in Gauteng, for example, with a population of more than 850,000 people, now has permanent access to the internet. Adding access to short crop production and skills development courses at the touch of a button, along with the ability to continue to earn while they learn, will open exciting new opportunities for growth in the sector.

Achieving sustainable food security for both urban and rural citizens remains an important priority for African governments. The reality, however, is that food security depends not only on a tricky balance between knowledge, availability, and affordability but also on coordinated partnerships between the various stakeholders in the agricultural sector.

Rethinking and redesigning urban agriculture

According to a report by the Food and Agriculture Organisation (FAO) of the United Nations, market gardening in African cities has grown with little official recognition, regulation or support. And while the commercial production of fruit and vegetables provides livelihoods for thousands of urban Africans, and food for millions more, in some cases market gardeners are using ever larger quantities of pesticide and polluted water to maximise returns.

It's becoming increasingly important to explore newer and more innovative approaches to successful farming. Urban agriculture is one of the techniques considered to be at the cusp of advancements within the sector, and one that can contribute towards the provision of sustainable access to nutritious food.

Considering the way in which our earth is changing, re-thinking and redesigning urban agriculture and what it means in a built-up urban environment is of paramount importance. The number of people migrating to urban areas makes the urban environment a potential and important food basket for sustainable food production and increased employment.

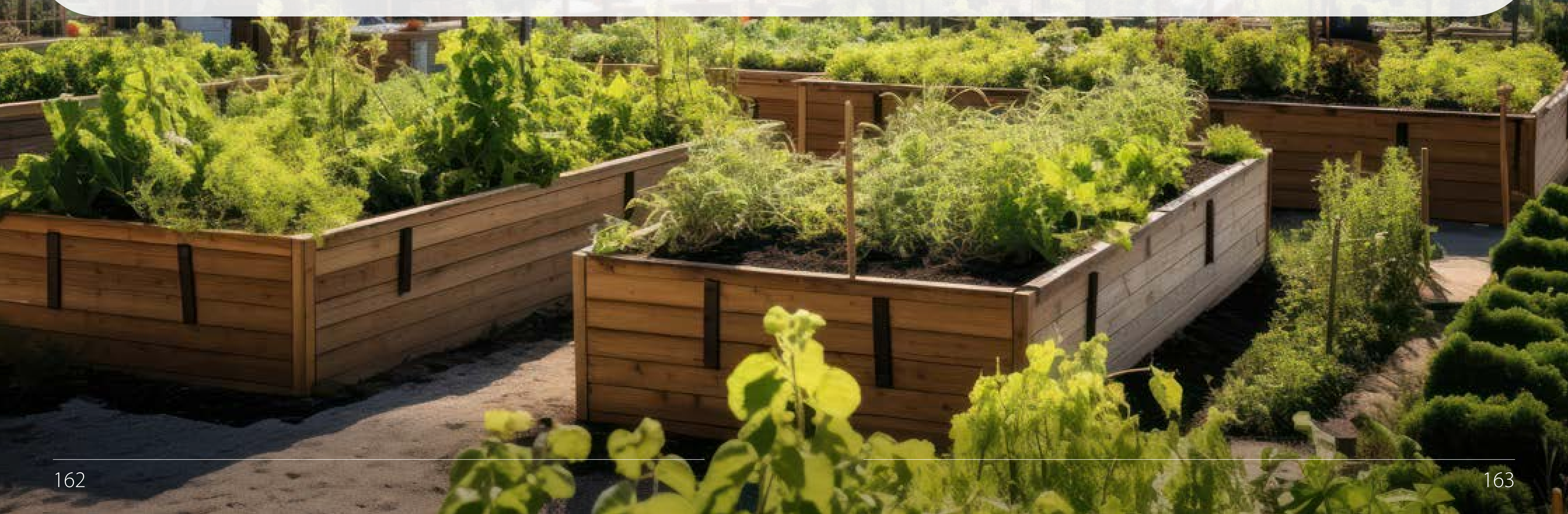
A step towards creating a more sustainable future

South Africa is no stranger to gross inequality and consistently has one of the highest Gini coefficients (measurement of inequality) in the world. Providing food security and sovereignty to marginalised urban 'boundary' communities is key to helping free South Africa from its greatest burden of food and health inequality.

If we could educate people to implement urban agriculture with health and sustainability in mind, it would be a great step towards creating a more sustainable future in all countries throughout the African continent.

Conclusion

Urban farming is not just a response to the challenges posed by rapid urbanisation; it's a vital step towards a more sustainable and equitable future for Africa. As communities embrace urban agriculture, there is a pressing need for education, skills development, and innovative thinking. By transforming urban spaces into food baskets and fostering a sense of self-sufficiency, we can address food inequality and create a foundation for a more sustainable future across the African continent. It's time to invest in the potential of urban farming to revolutionise agriculture and improve lives.



WASTE

The Dry Modification Method for Incorporating Polyolefin Plastic Waste in Asphalt: International Experiences and Opportunity for Implementation in South Africa

Johan O'Connell, CSIR, Georges Mturi, RMC and Melusi Simelane, CSIR

Only about 9 % of plastic is being recycled worldwide and the rest end up in landfills or the environment. The World Wide Fund for Nature (WWF) reported that South Africa generates about 2.4 million tons of plastic waste per year. This implies that on average each person produces about 14 kg of plastic waste annually, while only about 14 % is recycled. Various organisations, government-led initiatives and forums, as well as national standards bodies such as the South African Bureau of Standards (SABS) have raised awareness about the need for recycling plastic waste. This has encouraged efforts to find applications for plastic waste in the construction of road surfacing, especially for the use of low-value plastic waste as typified by polyolefin waste.

An international review was carried out on the use of polyolefin waste in road construction using the so-called 'dry modification method'. The dry modification method of adding plastic waste in road construction materials represents a relatively simple, low-cost technique that presents an opportunity for rapid implementation in developing countries such as South Africa. The development of new markets for polyolefin waste plastic will reduce waste, as well as reduce the demand for natural raw materials, normally used in road construction. Secondary goals for incorporating polyolefin waste in asphalt mixes include reducing construction costs and improving the performance properties of the modified asphalt mix.

The intention of the literature search was to summarise international developments, thereby gathering sufficient information for the rapid implementation of the dry modification method in South Africa. Prior to the literature review, the suitability of different plastic waste types found in South African landfills and waste management facilities were evaluated for ease of incorporation of such plastic waste into hot mix asphalt. This involved the consideration of thermal properties for plastic waste in relation to asphalt behaviour at handling temperatures and in-service performance based on South African climatic conditions, as well as any concurrent safety issues. These considerations led to the selection of polyolefin plastic waste as the most suitable plastic waste for road construction.

The main research question explored during the literature was whether polyolefin waste technology is feasible in South Africa from a theoretical point of view, thereby laying the foundation for practical implementation. Outcomes indicate that the addition of polyolefin to asphalt mix surfacing could be feasible, with a resultant increase in stiffness of an asphalt mix and a decrease in binder absorption being the most likely performance outcomes.

1.0 Introduction

The world is facing a plastic waste crisis, which worsened after China stopped importing plastic waste in January 2018. It is estimated that only 9% of plastic is being recycled worldwide and the remainder ends up in landfills or the environment (NAPA, 2020). According to the World Wide Fund for Nature (WWF), South Africa generates about 2.4 million tons of plastic waste per year, or about 14 kg of plastic waste per person (WWF, 2023). To increase the level of plastic waste recycling, there have been international efforts to find applications for plastic waste in road surfacing applications (Austroads, 2021).

The use of plastic waste sustains the environment and conserves natural raw materials used in the manufacture of hot mix asphalt. Secondary goals include a reduction in construction costs and improvement of the performance properties of modified asphalt (Mturi, et al., 2021a).

A literature review was conducted to support a feasibility study on the use of plastic waste in road construction in South Africa, and a pre-requisite for the literature review was that it be directed towards the use of low-value plastic waste that is not fully reclaimed in the plastic recycling industry (Mturi, et al., 2021a). The selection of the plastic waste type must also support a rapid implementation of its use in the manufacture of hot mix asphalt in South Africa (Mturi, et al., 2021b).

Based on preliminary information obtained, as well as the recommendations made by the plastics industry in South Africa, polyolefin plastic waste was selected as the best available source of plastic waste for investigation. The plastics industry characterised polyolefin plastic as an underutilized, low-value waste plastic fraction that ends up in landfills (Mturi, et al., 2021a). High-value waste plastic fractions, such as polyethylene terephthalate (PET), which have high recycling rates, and hazardous fractions, such as PVC, were eliminated during deliberations.

The choice of polyolefin plastic waste as the subject of the review limits the number of publications for review because the use of isolated polyolefin plastic waste (without the presence of other types of plastic waste) for the dry modification of asphalt has limited implementation, internationally. A likely reason could be the cost of separation, processing, and cleaning of polyolefin waste. Separation and processing, on the other hand, lead to a more consistent product with increased predictability with regard to performance.

2.0 Polyolefin (PE) plastic waste in asphalt mixes

The addition of plastic waste directly to the aggregate before the manufacture of the asphalt mix is commonly called the "dry method" of modification. Generally, for the dry method, plastic components are used that have melting points below the mixing temperature of hot mix asphalt. This allows the plastic waste to form a melt and adhere to the aggregate surface, forming a partially plastic-coated aggregate (PCA). PCA generally has a diminished effect on the bitumen properties after the manufacture of the mix, because of the low compatibility and miscibility between polyolefins and the bitumen binder normally used in hot mix asphalt.

In contrast, the addition of plastic waste to directly modify bitumen, before the manufacture of hot mix asphalt, is known as the "wet method" of modification. Due to the low compatibility between bitumen and polyolefin plastic waste, agents or additives are required for this method of polyolefin plastic waste incorporation, in order to improve compatibility between the binder and plastic, without which, the plastic waste would separate from the binder after mixing. The wet method requires advanced reaction conditions related to the type of plastic waste and bitumen chemistry, and, as such, does not lend itself to a rapid implementation of technology.

The dry method enhances aggregate interlock whereby all the plastic waste melts and partially coats the aggregate, resulting in PCA. The melted plastic on the PCA promotes adhesion between aggregate, acting as "hot glue", thereby improving the stability of the asphalt (see Figure 1).

Figure 1: Adhesion Between Aggregate, Plastic Functioning as "Hot Glue" (Mturi, et al., 2021a)

2.1 Types of Polyolefins

Polyolefins are saturated polymers consisting of carbon and hydrogen, having low polarity and low reactivity. In plastic waste, polyolefins chiefly consist of polyethylene (PE) and polypropylene (PP). There are four main types of PE, namely (Padhan & Anand, 2018):

High-Density Polyethylene (HDPE): a highly linear polymer, which enables close packing of the polymer molecules. resulting in a higher density. Because of their strength, HDPE bags are well-suited for use as grocery bags, bags for clothing and air cushions for packaging. Typically, HDPE has a density of greater than 0.94 g/cm3.

Medium-Density Polyethylene (MDPE): a less opaque resin than HDPE but not as clear as low-density polyethylene. Bags made of MDPE generally do not stretch well and are not associated with a high degree of strength. MDPE is typically used in consumer packaging for paper products such as paper towels and toilet paper.

Low-Density Polyethylene (LDPE): a highly branched polymer, preventing close packing in the crystalline state. This results in a lower density. LDPE is used to make bags with moderate stretch and strength properties. LDPE bags tend to exhibit a high degree of clarity and are commonly used in consumer packaging as bread bags, thick bags for newspapers. Typically, LDPE has a density of between 0.91 and 0.94 g/cm3.

Linear Low-Density Polyethylene (LLDPE): a stretchy consistency polymer. These films typically feel tacky and exhibit a moderate degree of clarity. Generally used for stretch wrap, dry cleaning film, agricultural films, and thin newspaper bags.

2.2 Sources of Polyolefin Plastic Waste in South Africa

In South Africa, waste management facilities exist where "high-value" plastics are removed from the waste stream for recovery and recycling (see Figure 2). An analysis of the "low-value" waste discarded at the end of the recovery process for the Kraaifontein Waste Management Facility in Cape Town, South Africa, is given in Figure 3 (Madonsela, 2019). The analysis was done on randomly collected samples totalling 318 kg over 5 days. This characterization was not repeated and the variability in the composition of the tailings remains undetermined. The tailings are transported to a landfill.

At landfills, the polyolefins are isolated by an informal, visually-based and demand-driven waste collection industry (see Figure 4), then supplied to a recycling facility for processing. Processing includes sorting, washing, melting, filtering and extruding (see Figure 5). The following is noted for the polyolefin recycling industry in South Africa (Mturi, et al., 2021a):

- There is very little control over the composition of the tailings sent to landfill.
- The recycling of polyolefin is sorted according to LDPE, HDPE and PP
- There will always be cross contamination between different types of plastic. For example, HDPE will contain a small amount of PP and LDPE.

Figure 2: Sorting where "High Value" Waste is Removed in the Background with "Low Value" Waste in the foreground (Left). Accumulation of "Low Value" Waste also Referred to as the Waste Tailings (Right) (Madonsela, 2019)

SUSTAINABLE WASTE

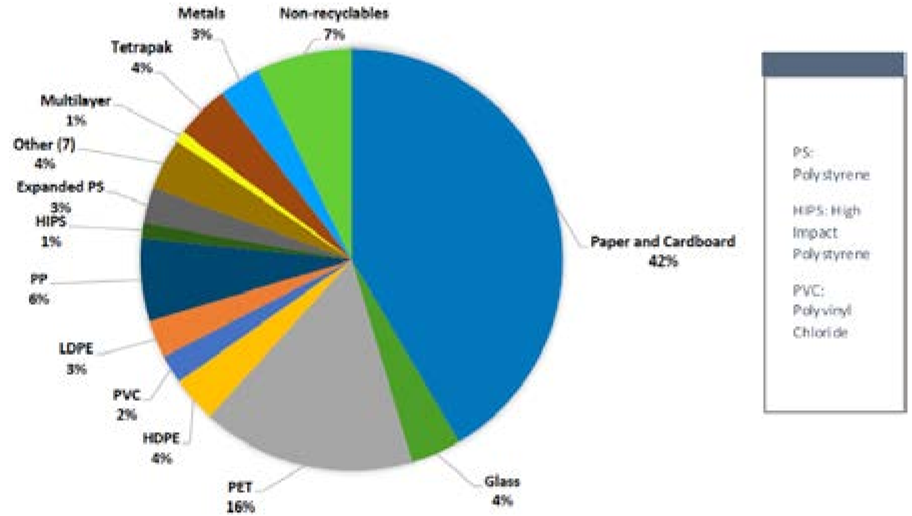


Figure 3: Waste characterisation of the tailings after the sorting process at the Kraaifontein Waste Management Facility) (Madonsela, 2019).

2.3 Characterization of the polyolefin plastic waste

Plastic testing can vary widely from mechanical testing (static loading, impact loading, fatigue behaviour, etc.) to chemical testing to thermal analyses (Mturi, et al., 2021a). In general, the following properties and tests are deemed to be of interest to the asphalt industry (Mturi, et al., 2021a):

- Polymer component identification
- Melt flow index (MFI)

Figure 4: An informal trader sorting out waste material at the Hatherley Landfill Facility in Mamelodi, Gauteng

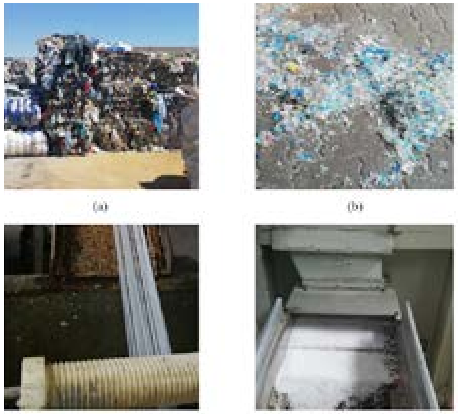


Figure 5: Photographs showing (a) Arrival of Tailings from the Landfill, (b) Washed Polyolefin Waste, (c) Extrusion of the Filtered Melt and the (d) Final Pelletized Recycled Product (Mturi, et al., 2021a)

- Degree of Crystallinity
- Heat Flow studies
- Density
- Melting Point Range

Polyolefin plastic waste properties reported in the literature are given in Table 1. The values where sourced from the work of Casey, et al. (2008); Attaelmanan, et al.

(2011); Vasudevan, et al.(2012); Indian Roads Congress (2013); and Saroufim, et al. (2018). The polyolefin product ranges for typical products used in South Africa have also been included (Mturi, et al., 2021a).

The most common property in distinguishing polyolefins from one another is the MFI, an indicator of molecular weight. The polyethylene categories are divided based on density and branching, with the molecular packing causing differences in the crystallinity content, and together with the molecular weight influencing the melting point.

Table 1: Properties of Polyolefins Reported in Literature.

Polyolefin	MFI** (g/10 min)	Degree of crystallinity (%)	Specific Gravity	Melting Point Range (°C)
PP*	1-90		0.90-0.91	140-160, 160-168
LLDPE*	0.8-20		0.920-0.939	110-125
LDPE*	0.3-20, 0.27, 0.76, 0.54	32	0.918-0.922, 0.935	109-111, 110, 109
HDPE*	7, 7.0, 6.1	67	0.946-0.958, 0.943	130-133, 131, 149
HDPE-EX 3-80 S	4		0.954	
HDPE-EX 5 HS	7.5		0.950	
HDPE-EX 3-80	12		0.945	
HDPE-EX 1 S	21		0.944	
HDPE-EX 7C	63		0.946	

* Grade not specified

** MFI test done at 190°C for PE and 230°C for PP

2.4 Selection of polyolefin plastic waste

Factors to be considered when selecting a source of plastic waste are:

- Handling properties: Melting point range, should be compatible with the mixing and compaction temperatures of the asphalt mix. Based on the melting point ranges, the mixing temperatures favour: LDPE/LLDPE > HDPE >> PP
- The warm mix effect, whereby the softening point range of the polyolefin waste is significantly less than the compaction temperature of 125 - 135°C. The warm mix effect allows for ease of compaction at lower temperature and ensures a significant energy saving. LDPE/LLDPE is the only source of polyolefin waste that provides this advantage.
- Low temperature properties: Asphalt low temperature properties can be affected by major transitions such as those linked to the glass transition temperatures. Low temperature asphalt behaviour favours: HDPE > LDPE/LLDPE >> PP
- Economic considerations: A polyolefin plastic waste faction that represents a larger fraction of the total waste before recovery can be recovered more economically. A higher purity requirement for the selected polyolefin

2.5 Consistency of the polyolefin plastic waste

A maximum consistency of the final modified asphalt mix can be obtained by controlling the source and composition of the polyolefin waste; controlling the recycling process; as well as specifying the properties of polyolefin recycled waste to be used in the dry modification in asphalt. At a minimum, acceptance limits should be established for the consistency, cleanliness, and particle size of recycled plastics (NAPA, 2020). Consistency of the polyolefin waste and modification process would improve consistency of the modified asphalt mix after modification (Mturi, et al., 2021a).

Ideally, evaluating asphalt modification using polyolefin plastic waste should include the characterization of the polyolefin plastic waste at regular intervals. A database of results would (Mturi, et al., 2021a):

- Indicate the consistency of the modifier. For common plastic bags, the composition is consistent (an important advantage of using shopping bags as HDPE modifiers).

- Allow for correlation between the modifiers results and the asphalt properties. In theory, this could allow researchers to establish specification requirements for the polyolefin plastic waste modifiers.

3.0 Evaluation of modified asphalt mixes

Most of the literature pertains to the use of polyolefin plastic waste in continuously graded (or dense graded asphalt (DGA)) asphalt mixes. A general requirement for the addition of polyolefin plastic waste to asphalt mixes is that it should not affect the properties and performance of asphalt mix negatively or increase the cost of production.

Typical performance criteria will include workability, moisture sensitivity, deformation resistance, dynamic modulus, and fatigue performance. In addition, an assessment of the durability and life expectancy of the asphalt mix should be considered (Austroads, 2021).

3.1 Summary of results reported internationally

Table 2 summarises the literature reviewed along with the type of plastic waste used and the methodology employed for dry modification of the asphalt mix. (Martin-Alfonso, et al., 2019)

(See table 2)

The following general impressions are obtained from the review of the literature:

- Results reported in the literature are not fully reproducible as the plastic waste used to produce results has an inherent variability.
- The literature fails to address the repeatability of test results, leaving the statistical significance of the results and conclusions uncertain.
- Selective Evaluation - Authors tend to focus on the positive aspects of implementing the dry method and give improved performance indicators such as deformation resistance greater attention. Indicators such as skid resistance, which could theoretically be negatively impacted by the addition of polyolefin waste, are generally neglected during the evaluation process.
- Results from polyolefin plastic waste-modified mixes are compared to reference mixes that have not been modified, and which have often not undergone similar thermal and mechanical processes. A modified mix may have undergone extended heating, giving an additional advantage to deformation resistance, which can then be erroneously attributed to the waste polyolefin plastic.
- Researchers often did not report the air voids of the hot mix asphalt samples, even though the specific sample voids could have influenced the performance results obtained.
- At times the polyolefin plastic waste asphalt mixes were not manufactured at optimum binder content, complicating comparisons between modified and unmodified asphalt mixes.
- Negative environmental effects such as the production of micro plastics have been investigated to only a limited extent.

3.3 Effect on aggregate properties

Generally, researchers have reported an increase in strength and soundness for the PCA and a decrease in water absorption with an increasing degree of plastic coating. Decreased binder absorption could result in reduced bitumen requirements for the asphalt mix, leading to financial inducements for the use of polyolefin waste in asphalt mixes.

An illustration of specific results is presented in Table 3 (Vasudevan, et al., 2012). The results imply that marginal aggregate materials can potentially be brought into the specification by plastic coating. Water absorption is used as an indicator of binder absorption. Water absorption is limited to 1% maximum (SABITA Manual 35, 2023). Plastic waste fills the pores and voids of the aggregate during the manufacture of PCA, thus water absorption is decreased with an increase in plastic percentage (Vasudevan, et al., 2012). The Aggregate Impact Value (AIV) test is used to test the resistance of the aggregate for fracture under repeated load impact AIV should not exceed 30 % for a wearing course (AASHTO T 96, 2002). The decrease in AIV with waste plastic is due to plastic coating film resisting cracking in the aggregate surface when loaded, thus the aggregate toughness increases. This also reduces roughness, leading to a decrease in aggregate wear (Vasudevan, et al., 2012). The Los Angeles abrasion test determines the wear of aggregates caused by rubbing the aggregates and a steel ball, which should not exceed 30 % for pavements (AASHTO T 96, 2002). However, typical addition of plastic to the aggregate rarely exceeds 0.5 %m/m of the aggregate for the dry

Table 2

method before undesirable effects on the mix exceed the improvements brought about by plastic addition. Improvement in aggregate properties is therefore limited by the maximum plastic that can be added.

3.4 Effect on the asphalt mix properties

The effect of modification has most commonly been evaluated using Marshall stability as a performance indicator, with a significant increase in Marshall stability being reported (Vasudevan, et al., 2012). However, the repeatability of the Marshall stability test is not considered when reporting and evaluating this trend. The recommended optimum addition of polyolefin waste is typically 10% of bitumen content of the reference mix, using Marshall stability results as the performance indicator. The improvement in Marshall stability values have been supported by improved wheel tracking results for the modified mixes (Sangita, et al., 2011).

Rut resistance studied by Lastra-González et al. (2016) have shown that polyethylene waste (e.g., waste plastic shopping bags) improved the properties of mixes the most. Some researchers have reported that the addition of plastic waste leads to a reduction in skid resistance (Lastra-González, et al., 2016). This has road safety implications. However, it is unclear whether the reduction in skid resistance results in performance that does not comply with specified limits or whether acceptable performance levels are still maintained after the reduction. Vesudevan et al. (2012) concluded that several construction sites reported no improvement in skid resistance,

Table 3: Improvement in Aggregate Characteristics as a Result of Plastic Coating (Vasudevan, et al., 2012).

Plastic (% aggregate mass)	Water absorption (%)	Aggregate Impact Value (AIV)	Los Angeles Abrasion Test (%)
0 %	4	25.4	37
1 %	2	21.2	32
2 %	1.1	18.5	29
Specification	*≤ 1*	*≤ 30*	*≤ 30*

Table 4: Summary of the literature reviewed for life cycle assessment.

Reference	Assessment Method	Methodology	Summary Result
Guðmundsdóttir, 2018	Performance, lifespan, and recycling. Use of EASETECH Software	(i) Unprocessed and (ii) Cleaned and pelletized residential plastic waste Dry Method	Traditional asphalt had a useful lifespan of 7 years, and PCA asphalt had an increased useful lifespan of 8.5 years.
Santos, et al., 2021	Compares wet method and dry method LCA	Considers LCA for plastic production during production of asphalt. Case study analysis	The dry method consumes a larger quantity of recycled plastic waste compared to the wet method. The dry method does not result in reduced greenhouse gas emissions

Table 5: Proposed conditions for incorporating polyolefin using the dry method

Item for consideration	Proposal
Waste plastic source.	Use a single waste plastic source such as plastic shopping bags (HDPE) to ensure a consistent source of plastic waste. Alternatively, use a relatively consistent source of LDPE or combined polyethylene fractions (LDPE + HDPE) from a recycling establishment. Combined fractions increase the amount of waste polyethylene available to the roads industry. Polypropylene is not recommended due to its high melting point range (140 – 168°C), which is incompatible with the current conditions under which asphalt mix is manufactured (140 – 150°C)
Olefin waste mass	The olefin waste added to the aggregate should be equivalent to 7% of the bitumen content of the original refence asphalt mix design prior to optimization of the mix design.
Aggregate fraction	Add the polyolefin waste to the coarse aggregate fractions, excluding the crusher dust and fine aggregate fractions.
Aggregate temperature	Mix the plastic waste and aggregate at 170°C

Table 6: Proposed requirements for the polyolefin waste used for the dry modification method

Property	Test Method	Units	Requirement
Macro Waste Polymer Homogeneity	ISO 1183	%	Variation in density between 4 random samples must be less than 2 %
Density	ISO 1183	g/cm^3	0.918-0.958
Melting Temperature, T_m	ASTM D 3418	°C	109-133
Glass Transition Temperature, T_g	ASTM 7028	°C	<-22

but an analysis of his results show a decrease in skid resistance, to the extent that the values reported are below what is considered acceptable for safe road performance for the roads authority in the areas investigated. These findings are generally in line with the reduced texture depths they had reported.

3.5 Effects on the Life cycle assessment and life cycle cost analysis: Environmental, feasibility and Economic

A literature review to determine the feasibility of using plastic waste in road construction was conducted. There is no literature that has focused on polyolefin waste only. The alternative was to review the literature for general residential plastic waste, which would include polyolefin waste (exceeding 50% of the total plastic). The analysis considers the cost and the environmental implications of using plastic waste in the cradle to grave design life of roads (material production, construction, maintenance, end of useful life, and recycling). Table 4 presents the results of literature evaluated to investigate the Life Cycle Assessment (LCA) of using plastic waste as a road construction material when using the dry method. Most studies evaluate environmental impact, and LCA using the ISO 14040/44 (ISO, 2006a; 2006b), and FHWA-HIF-16-014 which is a pavement life cycle assessment framework (USFHWA, 2016).

4.0 Summary and conclusions

Australia has used recycled waste plastic in asphalt mixes of up to 0.7% by mass of the mix (Austroads, 2021). India, which has reported extensive application of the dry method using plastic waste, recommends 6 – 8% of the binder mass (Indian Roads Congress, 2013).

South Africa has an established plastic waste recycling industry that can provide the road building industry with a steady supply of recovered polyethylene plastic waste. Established processing plants have the potential to impart a degree of consistency to the plastic waste, based on composition and characteristics. South African asphalt mix plants do have the capability of incorporating plastic waste after minor modifications.

There is limited independent or comprehensive research undertaken on the Health, Safety and Environment (HSE) impacts of incorporating general recycled plastic waste (which encompasses polyolefin plastic waste) in asphalt. This includes issues such as potential microplastic generation, leaching, fuming, reuse of asphalt incorporating recycled waste plastic and sustainability (Austroads, 2021). This needs to be addressed in future research studies.

The LCA indicates that the use of polyolefin waste in the dry method may have economic benefits. A long-term pavement data collection and analysis of such modified pavements will provide better evidence for future LCA analyses.

Research is required to correlate polyolefin plastic waste properties with the properties of modified asphalt mixes, to enable the establishment of standards and specifications that would ensure the production of asphalt mixes with consistently superior performance properties.

5.0 Recommendations for implementation

Based on the limited literature available, a recommendation for implementation is outlined in Table 5 for the proposed mixing of the polyolefin waste into the aggregate and Table 6 for a proposed specification for the recovered polyolefin waste. The way forward will involve input from all role players of the asphalt road industry in South Africa, including producers, road authorities and research institutions.

ACKNOWLEDGEMENTS AND DISCLAIMER

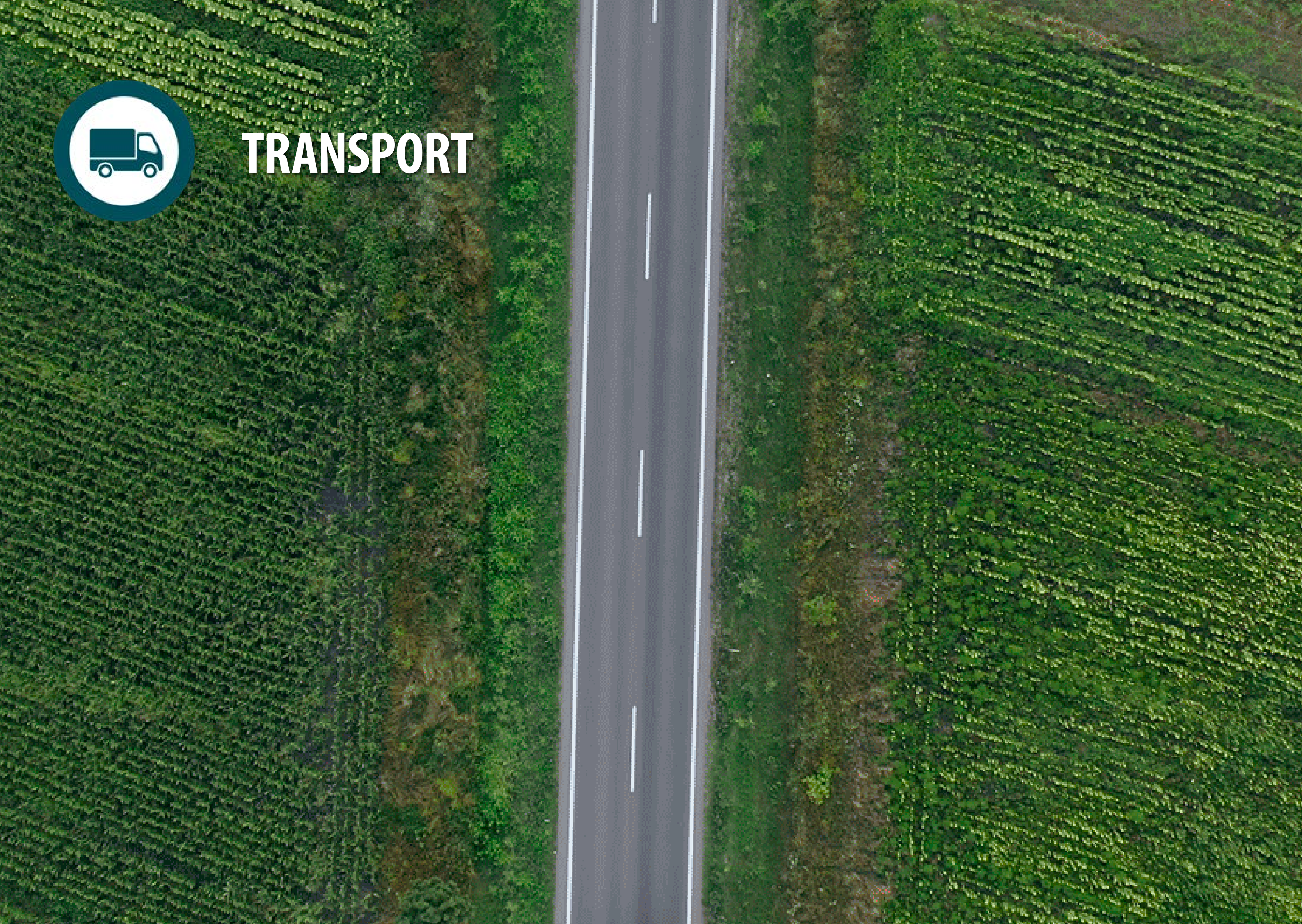
The authors would like to thank the Department of Science and Innovation (DSI), Republic of South Africa, for funding the research into recycling plastic waste, of which this paper is one of the multiple outputs.

The contents of this paper reflect the views of the authors who are responsible for the interpretation of the literature, and these views do not necessarily reflect the official views or policies of any agency or institute. This paper does not constitute a standard, specification, nor is it intended for design, construction, bidding, contracting, tendering, certification, or permit purposes.

REFERENCES

- AASHTO T 96, 2002. Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (ASTM Designation: C131-01). first ed. Washington, DC: American Association of State and Highway Transportation Officials.
- Angelone, S., Casaux, M., Borghi, M. & Martinez, F., 2016. Green Pavements: Reuse of Plastic Waste in Asphalt Mixtures. Materials and Structures, Volume 49, pp. 1655-1665.
- Attaelmanan, M., Feng, C. & Al-Hadidy, A., 2011. Laboratory Evaluation of HMA with High Density Polyethylene as a Modifier. Construction and Building Materials, 25(5)(DOI: https://doi.org/10.1016/j.conbuildmat.2010.12.037), pp. 2764-2770.
- Austroads, 2021. Interim Guidelines for the Use of Recycled Waste Plastic in Local Government Road Surfacing Applications. Australia: Austroads Publication No. AP-G96-21.
- Bajpai, R. et al., 2017. Study on the Plastic Waste Treatment Methods for Road Construction. International Journal of Advance Research, Ideas and Innovations in Technology, 3(6), pp. 559-566.
- Casey, D., McNally, C., Gibney, A. & Gilchrist, M., 2008. Development of a Recycled Polymer Modified Binder for use in Stone Mastic Asphalt.. Resources, Conservation and Recycling, 52(10)(DOI: https://doi.org/10.1016/j.resconrec.2008.06.002), pp. 1167-1174.
- Dos Santos Ferreira, J. et al., 2022. The feasibility of recycled micro polyethylene terephthalate (PET) replacing natural sand in hot-mix asphalt. Construction and Building Materials, 300(DOI: https://www.sciencedirect.com/science/article/pii/S0950061822009564), p. 127276.
- Guðmundsdóttir, G., 2018. Plastic waste in road construction in Iceland: An environmental assessment. DOI: https://www.vegagerdin.is/vefur2.nsf/e02ba2887015e3fd0025771b005580a4/1f18cdc35c7f148b002583cc002fe8f2/$FILE/-Plaast%C3%BArgangur%20n%C3%BDttur%20%C3%AD%20vegager%C3%B0%20-Plastic_Waste_in_Road_Construction_in_Iceland__an_Environmental_Assessment..pdf ed. Denmark: Technical University of Denmark.
- Gulotta, T., Mistretta, M. & Praticò, F., 2019. A life cycle scenario analysis of different pavement technologies for urban roads. Science of the total environment. Science of the total environment, 673(https://www.sciencedirect.com/science/article/pii/S0048969719315657), pp. 585-593.
- Indian Roads Congress, 2013. Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) in Wearing Courses (IRC:SP:98-2013). New Delhi: Indian Roads Congress.
- ISO, 2006a. ISO International Standard 14040: Environmental Management – Life Cycle Assessment- Principles and Framework. Geneva, Switzerland: International Organization for Standardization.
- ISO, 2006b. ISO International Standard 14044: Environmental Management – Life Cycle Assessment- Requirements and Guidelines.. Geneva, Switzerland: International Organisation of Standardization.
- Lastra-González, P. et al., 2016. Comparative Analysis of the Performance of Asphalt Concretes Modified by Dry Way with Polymeric Waste. Construction and Building Materials, 112(DOI: https://doi.org/10.1016/j.conbuildmat.2016.02.156), pp. 1133-1140.
- Lastra-González, P. et al., 2017. Analysis of the Skid Resistance and Adherence between Layers of Asphalt Concretes Modified by Dry Way with Polymeric Waste. Construction and building Materials, 133(DOI: https://doi.org/10.1016/j.conbuildmat.2016.12.063), pp. 163-170.
- Linyi, Y. et al., 2022. Environmental and economic assessment of collective recycling waste plastic and reclaimed asphalt pavement into pavement construction: A case study in Hong Kong. Journal of Cleaner Production, 336(DOI: https://www.sciencedirect.com/science/article/pii/S0959652622000518), p. 130405.
- Madonsela, B., 2019. Waste Characterisation and Brand Audit at Kraaifontein Waste Management Facility (JGA Ref. No. 5009, Rev 14), Cape Town: JG Afrika.
- Martin-Alfonso, J. et al., 2019. Use of Plastic Wastes from Greenhouse in Asphalt Mixes Manufactured by Dry Process. Road Materials and Pavement Design, 20(1)(DOI: https://doi.org/10.1080/14680629.2019.1588776), pp. S265-S281.
- Mturi, G. et al., 2021a. The Use of Plastic Waste in Road Construction, Pretoria, South Africa: Council for Scientific and Industrial Research. CSIR/SLOG/TIE/ER/2019/0056/C.
- Mturi, G. et al., 2021b. The Use of Plastic Waste in Road Construction. In: Sustainability Handbook Vol 3. Cape Town: Alive2Green, pp. 98-107.
- NAPA, N. A. P. A., 2020. Recycled Plastics in Asphalt Part A: State of The Knowledge, Asphalt Institute. Greenbelt, Maryland: NAPA - IS-142.
- Padhan, R. & Anand, S., 2018. Enhancement of Storage Stability and Rheological Properties of Polyethylene (PE) Modified Asphalt Using Cross Linking and Reactive Polymer Based Additives. Construction and Building Materials, 188,10(DOI: https://doi.org/10.1016/j.conbuildmat.2018.08.155.), pp. 772-780.
- Praticò, F., Giunta, M., Mistretta, M. & Gulotta, T., 2020. Energy and environmental life cycle assessment of sustainable pavement materials and technologies for urban roads. Sustainability, 12(2)(DOI: https://www.mdpi.com/2071-1050/12/2/704), p. 704.
- SABITA Manual 35, 2023. Design and Use of Asphalt in Road Pavements. Sixth Edition ed. South Africa: SABITA.
- Sangita, T., Khan, A. & Sabina, D., 2011. Effect of Waste Polymer Modifier on the Properties of Bituminous Concrete Mixes. Construction and Building Materials, Volume 25, pp. 3841-3838.
- Santos, J., Pham, A., Stasinopoulos, P. & Giustozzi, F., 2021. Recycling waste plastics in roads: A life-cycle assessment study using primary data. Science of the total environment, 751(DOI: https://www.sciencedirect.com/science/article/pii/S0048969720353717), p. 141842.
- Saroufim, E., Celauro, C. & Mistretta, M., 2018. A Simple Interpretation of the Effect of the Polymer Type on the Properties of PMBs for Road Paving Applications. Construction and Building Materials, Volume 158, pp. 114-123.
- USFHWA, 2016. Pavement Life Cycle Assessment Framework, FHWA-HIF-16-014, s.l.: U.S Department of Transportation Federal Highway Administration.
- Vasudevan, R., Sekar, A., Sundarakannan, B. & Velkennedy, R., 2012. A Technique to Dispose Waste Plastics in an Ecofriendly Way – Application in Construction of Flexible Pavements. Construction and Building Materials, 28(1)(DOI: https://doi.org/10.1016/j.conbuildmat.2011.08.031.), pp. 311-320.
- Vasudevan, R., Velkennedy, R., Sekar, A. & Sundarakanna, B., 2010. Utilization of Waste Polymers for Flexible Pavement and Easy Disposal of Waste Polymers. International Journal of Pavement Research and Technology, Volume 3(1), pp. 34-42.
- WWF, 2023. World Wide Fund for Nature. [Online]
- Available at: https://www.wwf.org.za/lifestyle_plastic_smart/

TRANSPORT



Energy Efficiency on the New Energy Vehicles Transition

Hiten Parmar, Executive Director:
the electric Mission

As many cities and countries aim to tackle the poor air quality in regions globally, there is an increasing demand for new energy vehicles in the transition away from the polluting petrol and diesel based technologies of the last century. Each generation of the global vehicle emission standards released have continued to lower the application of fossil fuels due to emission controls. The introduction of the Euro 7 standard will limit the capability of combustion engine technology to meet the specific emission regulations. Electric mobility (e-Mobility) has become one of the rapidly developing opportunities to contribute to nations' climate and development goals, including climate change mitigation, fiscal burden reduction (for oil importing economies), energy efficiency, sustainability, air quality improvement, and promoting modal shift where applicable. Global experiences show that with the appropriate technology, policy and financial interventions, e-Mobility could present opportunities to not only decarbonize both the energy and transport sectors, but also create diverse set of social, environmental, and economic co-benefits, including jobs, due to the establishment of new value chains.

Along the energy transition for vehicle technologies towards new energy vehicles, there are a number of variations that are being introduced into the market. Hybrid Electric Vehicles (HEVs) have two complementary drive systems, an internal combustion engine with a fuel tank, and an electric motor with a battery. Both the engine and the electric motor can operate at the same time. HEVs cannot be recharged from the electricity grid – all their energy comes from the engine and from regenerative braking. Plug-in hybrids (PHEVs) use an electric motor and battery that can be plugged into an external source of electricity to charge the battery, but also has the support of an internal combustion engine that may be used to recharge the vehicle's battery and/or to replace the electric motor when the battery is low. A battery electric vehicle (BEV) runs entirely using an electric motor and battery, without the support of a traditional internal combustion engine, and must be plugged into an external source of electricity to recharge its battery. Like all electric vehicles, BEVs can also recharge their batteries through regenerative braking, which uses the vehicle's electric motor to assist in slowing the vehicle, and to recover some of the energy normally converted to heat by the brakes. Fuel cell electric vehicles (FCEVs) use electricity to power an electric motor as like all electric vehicles. However, in contrast to other electric vehicles, they produce electricity using a fuel cell powered by hydrogen, rather than drawing electricity from only a battery. The amount of energy stored onboard is determined by the size of the hydrogen fuel tank. This is different from a battery electric vehicle, where the amount of power and energy available are both closely related to the battery's size.

With different technology types and mixes, there is a consideration of energy efficiencies across each of these. On the transition of the energy sector to renewables, the image profiles the efficiency of different passenger vehicles technology pathways based on common baseline of 100% renewable electricity.

With battery electric vehicles, only five percent of the energy is lost before the electricity is stored in the batteries of the vehicle. When the electrical energy used to drive the electric motor is converted, another 18 percent is lost. This gives battery electric vehicles an efficiency level of between 70 to 80 percent, depending on the vehicle model.

With the hydrogen powered vehicles, the losses are significantly greater: 39 percent of the energy is already lost during the production of hydrogen through electrolysis. Of this remaining 61 percent of the original energy, another 31 percent is lost when hydrogen is converted into electricity in the vehicle. This means that the hydrogen-powered electric vehicle only achieves an efficiency of between 25 to 35 percent, depending on the vehicle model. With traditional internal combustion engine vehicles, when alternative fuels are burned, the efficiency is even worse: only 10 to 20 percent overall efficiency.

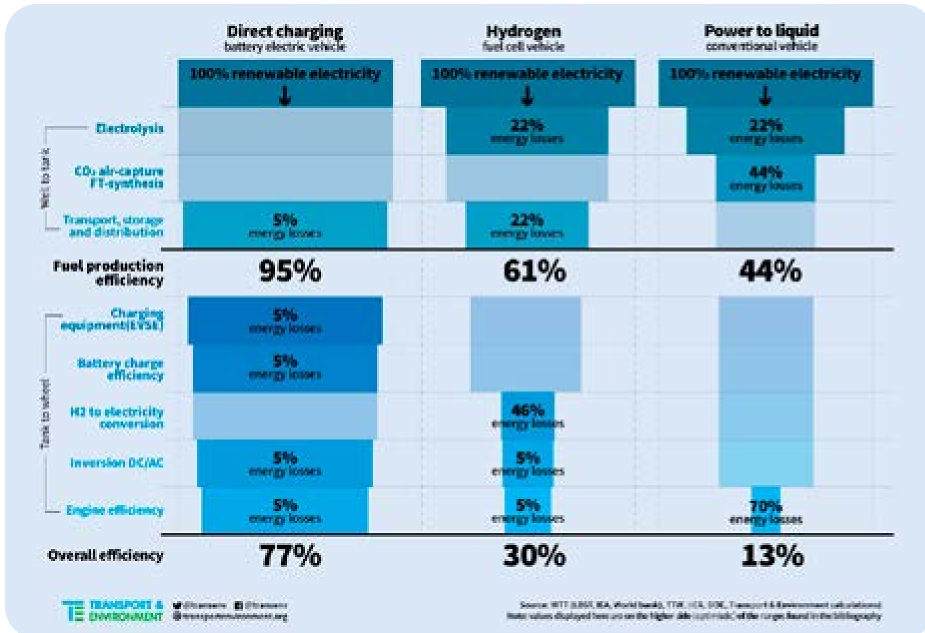


Figure1: Efficiency of different passenger cars technology pathways

A case for optimism: The potential of a data- and technology-driven future to enable sustainable transport in Africa

Catherine Larkin APR CMILT – Executive Director: Chartered Institute of Logistics and Transport: South Africa

"Sustainability is not a destination, it's a journey."
- M.P. Mueller, environmental scientist

Published in June 2023, the report "Leapfrogging to Sustainable Transport in Africa - Twelve Insights into the Continent's Sector Transformation" is an interesting and informative read. Compiled through a dialogue with African and international experts and practitioners, this paper aims to spark and perpetuate the discussion on the African transport transformation

– not only for changemakers in African countries, but also linked with the global climate and transport community. Through 12 insightful and thought-provoking perspectives, the paper tackles various areas such as enabling a just transition, electrifying vehicles based on renewable energy and shifting investments to sustainable infrastructure.

The publication was jointly developed by Germany agency GIZ on behalf of the German Federal Ministry of Economic Affairs and Climate Action (BMWK) and Agora Verkehrswende.

Sustainable transport is a broad term encompassing ways of transportation that are environmentally responsible, socially equitable, and economically viable in the long term. It aims to meet the needs of present and future generations without compromising the planet's resources or causing undue harm to people.

Of particular interest to me in the report was Insight 05, which focuses on how digital data can ensure that the transition to sustainable transport keeps apace with dynamic development in Africa.

By embracing digital technologies and data-driven approaches, African cities can leapfrog traditional limitations and build sustainable transport systems that meet the needs of their citizens. Open data, responsible data use, and collaboration between public and private sectors are key to unlocking the full potential of this transformation. As Africa's urban landscape continues to evolve, data will be the driving force behind efficient, inclusive, and sustainable mobility for the continent's future.

Africa is fortunate. Our tech-savvy population presents a workforce that embraces digital transformation. Our population is young – and growing: Over 60% of the Continent's population is under 25 years old, making it the youngest continent in the world. By 2050, Africa is projected to have the largest youth population globally. African youth have a strong desire for education and skills development. Over 50% of secondary school graduates on the Continent enroll in tertiary education - compared to the global average of 38%. It is also strongly evident that young Africans are driving the Continent's entrepreneurial boom. They are starting businesses, creating jobs, and innovating in various sectors. Over 60% of new businesses in Africa are started by young people.

Data-driven solutions in transport can create new jobs and drive economic growth

While paratransit fuels the veins of many African cities, its secrets remain unknown. City planners and passengers alike grapple with unknowns: who rides, when, and where these phantom vehicles roam. Similar shadows shroud urban and long-haul logistics, where a multitude of small players navigate the goods. This information vacuum cripples decisions, leading to investments that miss the mark.

If policymakers could truly see how people move, they could avoid costly traffic planning blunders. The old way of doing things involved tedious vehicle counts, paper surveys, and drivers filling out route diaries. But smartphones have thrown open the window to a whole new world of data.

Mobile tracking paints a far more detailed and dynamic picture than ever before, paving the way for smarter traffic planning. Over 80% of Africa's urban areas are now blanketed by 4G networks, and even though mobile internet access in Africa requires a bigger bite out of the income pie compared to developed countries, 41% of the Continent's residents are already online.

However, the data landscape isn't uniform. There are stark differences between urban and rural areas, between the wealthy and the less fortunate, and even between countries. But the potential is undeniable. By harnessing the power of mobile tracking, African cities can leapfrog outdated methods and build transportation systems that truly serve their people.

Beyond personal navigation, mobile phones are transforming transportation across Africa. They're helping to optimise truck routes, pinpoint accident hotspots, and share real-time traffic updates, paving the way for smarter planning. Pioneering initiatives like Digital Matatus, a Nairobi minibus network map, and WhereIsMyTransport, gathering data from over 50 cities, are already making waves. This data empowers transport authorities to make informed investment decisions, prioritising safety and efficiency.

DigitalTransport4Africa (DT4A) is a driving force behind this revolution. They not only share research findings, but also provide resources and training for municipalities, ensuring collected data is used ethically and effectively for sustainable transportation improvements.

Expansion of transport infrastructure brings opportunities for leapfrogging in data collection technologies

Africa's infrastructure boom presents an unprecedented opportunity to leapfrog traditional data collection methods and embrace a data-driven future for urban planning. Gone are the days of relying solely on GPS-enabled smartphones. Sensors on vehicles and drones can now monitor road conditions in real-time, while existing infrastructure can be outfitted with cameras and sensors for automated traffic counting. Electronic payment systems, already widespread in some countries, offer valuable data streams, and even space technology can provide insights through satellite image analysis.

This data deluge unlocks the potential for intelligent transport systems and data-driven urban planning. A World Bank report on Dar es Salaam's foray into data-driven transport planning highlights both the immense possibilities and the crucial political and institutional preconditions for success. Notably, developing local expertise for data evaluation and interpretation is paramount.

As Africa's infrastructure expands and cities burgeon, integrating data collection technologies into the early planning stages is key. But data collection alone isn't enough. City administrations need dedicated experts who can transform raw data into actionable knowledge. Fortunately, Africa's youth possesses the potential to thrive in this data-driven future. The digital transformation in transport not only promises access to new data but also job creation and economic growth.

The need for a skilled workforce

Underpinning the successful use of data and technology, is the need for a skilled workforce. "The intersection of technology and people to drive outcomes, technology on its own is a fantastic opportunity, but it is not the solution for all the challenges we are currently experiencing; it needs people to drive it," says Reza Suleman – Lead, Digital and Innovation practice from Africa International Advisors. "There is a need for business outcomes, upskilling, education, and broader ecosystem collaboration involving partners, suppliers, and the public sector." Suleman warns against the potential threat of technology surpassing human capabilities, emphasising the role of people in driving technological advancements.

Gerhard van Zyl, Group Operations Director at Asimotech, has also expressed concerns about tools like Artificial Intelligence hindering innovation and problem-solving skills among the younger generation. Van Zyl urges a balanced approach, cautioning against over-reliance on AI and digitalisation. "We need to have backup plans and be wary of making everything centred around AI and digitalisation," he cautions. "We need to find the balance between where we automate, where we use AI, and where we are going to still employ human beings, because challenges such as the lack of training for plumbers, electricians, welders, and boiler makers in Africa has resulted in a massive shortage of skills around the world. These are not things that can be solved with robotics and automation, and that already shows that we have a huge task in upskilling people in South Africa in the next coming 10 years."

Henry Smith, Sales Director: Fleet (Africa) at MiX Telematics, echoes the sentiment that data and technology alone cannot fix transport problems. "There are three critical ingredients for successful digital transformation: the right digital talent, adjusted business models, and processes, and the right mix of technology," he says. Smith highlights the transformative power of AI in planning, executing, and optimising the movement of goods, outlining the tangible benefits businesses would gain through real-time insights, improved forecasting, optimised inventory levels, reduced transportation costs, and enhanced customer service.

In conclusion, the potential of data and digitalisation for Africa's logistics sector to drive sustainability, while recognising the challenges that demand immediate attention, is immense. The consensus among experts is clear: a balanced approach that combines technological innovation with human skills and collaboration is key to unlocking the full potential of data, AI and digitalisation in the African logistics landscape, to ensure a sustainable future for all.

Catherine Larkin APR CMILT
Chartered Institute of Logistics and Transport: South Africa
087 822 2858 / 083 300 0331
cvlarkin@ciltsa.org.za
www.ciltsa.org.za


MINING

CSIR's Visionary Leadership in Sustainable Mining: A Holistic Approach to Acid Mine Drainage Management and Circular Economy Transformation

Dr Ryneth Mbhele

"A firm commitment to sustainable mining extends beyond the theoretical" - Dr Ryneth Mbhele

The Council for Scientific and Industrial Research (CSIR) emerges as a trailblazer on the African continent in the continuously changing mining arena, managing the difficult challenges of Acid Mine Drainage (AMD) with its innovative circular economy approach. This article looks at the CSIR's strategic value chain, market analysis, and the significant ways the organization uses its current resources and competencies to transform the mining landscape.

CSIR's Strategic Value Chain: Our emphasis on the AMD value chain exemplifies a complete strategy, encompassing AMD treatment and prediction as well as cleanup and sustainable practices. Recognizing the limitations of present approaches, such as high sludge output and variable efficacy, we advocate for long-term improved treatment efficiency, effectively offsetting operating costs and boosting resource recovery. The organization's focus on sustainable AMD practices and bulk supply production demonstrates its dedication to transformational, industry-leading solutions.

Market Analysis of Rare Earth Elements and Minerals: "At the CSIR, we believe that market analysis must go beyond traditional bounds, investigating the recovery of rare earth elements and minerals from AMD through the lens of circular economy perspectives," Reyneth explains. The entity presents itself as a thought leader at the nexus of environmental responsibility and economic viability by navigating the complexities of mining waste management market drivers, AMD market overviews, and rare earth elements market dynamics.

Impactful Contributions to Sustainable Mining: Our unwavering commitment to sustainable mining goes beyond the theoretical. The group exploits its current resources and competencies to redefine industry norms, based on a pragmatic understanding of the mining industry's difficulties. The CSIR addresses significant environmental challenges by minimizing the use of key resources such as water and energy. Our comprehensive approach ensures not only long-term mine closure but also the establishment of new job prospects, paving the path for mechanization and innovative industry practices.

The CSIR advocates for the generation of food, energy, and clean water, aligning its objectives with broader sustainable development goals. By actively seeking collaborative opportunities with other mines and municipalities, the CSIR fosters a sense of industry unity and shared responsibility

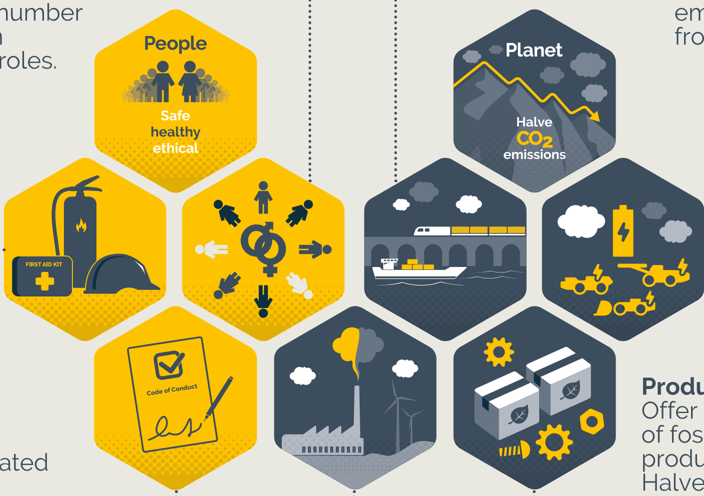
Driving Innovation through Research & Development: The organization's dedication to innovation is a transformational Future. This is demonstrated by substantial research and development activities. The CSIR pushes itself at the forefront of pioneering solutions for AMD management and circular economy principles by exploring new technologies and feasibility studies. This commitment emphasizes the entity's role as a vital partner in the mining industry's journey toward sustainability.

Collaborating for a Sustainable Future: Our visionary leadership and groundbreaking initiatives in this research space is set on propelling the mining industry toward a sustainable, circular future. Our strategic value chain, market insights, and impactful contributions underscore its pivotal role in driving transformative change across the industry.

Your collaboration with the CSIR isn't just a strategic choice; it's an investment in a sustainable, resilient future for the mining sector and our planet. Together, we forge a path towards responsible mining practices and a circular economy that safeguards both the industry and the environment for generations to come.

Em*ail Dr Mbhele:rmb*hele@csir.co.za

Epiroc 2030 goals
for People and Planet



Balanced workforce
Double the number of women in operational roles.

Safety and Health
No work-related injuries.

Walk the talk
Have all employees and business partners comply with our Code of Conduct.
Responsible Sales Assessment Process implemented.

Transport
Halve CO_2 emissions from transport

Products
Offer a full range of fossil-free products.
Halve CO_2 emissions from machines sold (in 2030 compared to machines sold in 2019).

Operations
Halve CO_2 emissions in operations.
90% renewable energy in own operations.

Suppliers
Require 50% reduction of CO_2 emissions from relevant suppliers

United. Inspired.

We drive the future in intelligent mining and infrastructure. Innovative, safe and sustainable solutions for increased productivity are key for us.

Epiroc

epirocgroup.com/en/sustainability