Royal Academy of Engineering

EngineeringX
Founded by the Royal Academy of Engineering and Lloyd's Register Foundation

UNIVERSIDAD DE ANTIOQUIA
1803

Frontiers symposium

Systems approaches in a just energy transition for equitable access

22 to 24 April 2024

David Gabric (Unsplash)

Symposium report

Royal Academy of Engineering

Introduction to the Frontiers symposia

The Frontiers symposia bring together around 70 of the best early- and mid-career researchers, innovators and practitioners from industry, academia, non-governmental organisations (NGOs), and the public sector in multidisciplinary workshops that address fundamental development challenges.

The symposia's objectives are to encourage collaborative work that addresses international development challenges and to promote cross-disciplinary thinking among the next generation of engineering leaders.

Competitively allocated seed funding is available to strengthen the collaborations developed at the symposia.

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UNIVERSIDAD DE ANTIOQUIA

Contents

Symposium

Delegates met for four sessions over three days, which were interspersed with networking opportunities, receptions, and dinners. The symposium was held at the Universidad de Antioquia in Medellín, Colombia, in partnership with Engineering X and the Universidad de Antioquia.

Engineering X and Safer Complex Systems

Engineering X tackles global safety and sustainability challenges and promotes the contribution of engineering to solve global challenges. Using the expertise and networks of our founders, the Royal Academy of Engineering and Lloyd's Register Foundation, we connect and give a platform to people working on these challenges across (the X) disciplines, countries, and systems. We champion local leadership of solutions and the importance of taking a systems approach to improve safety and sustainability into the future. We convene, fund collaboration and innovation, and raise awareness of often overlooked challenges.

Our Safer Complex Systems programme seeks to enhance safety in complex systems globally. We do this through identifying and partnering with international systems convenors, systems experts, and systems innovators to better understand complex challenges and embed systems approaches in the way that solutions are designed, implemented, managed, communicated, and evaluated. Through this Frontiers symposium, we aspired to put systems approaches into practice around the energy challenge and inspire participants to take up these tools to better tackle complex challenges.

Introduction to complex systems and systems approaches

All around the world people rely on critical infrastructures to survive, stay safe, and maintain a good quality of life. Much of this infrastructure, for example food and water supply, healthcare, education, housing, transportation, and communications, is made up of socio-technical systems that are highly interconnected and interdependent on one another. When one system fails, many other systems are also affected, which can have catastrophic consequences for people's lives and the environment.

Therefore, there is a need to implement solutions that are able to acknowledge those interconnections, uncertainty and complexity. To overcome that challenge, there are toolkits, ways of thinking and skillsets that can enable decision-makers steer complex systems to prevent harm to people and to the environment. Those ways of addressing a challenge are called taking a systems approach.

A systems approach is a holistic and interdisciplinary way of understanding and solving complex problems. It views the world as a collection of interconnected and interdependent elements or people and emphasises the relationships and interactions between them.

A true systems approach does not deliver solely technical solutions. It ensures the appropriate alignment of technology, processes, interactions and policy to deliver innovative responses to today's most complex and pressing challenges.[1]

[1] raeng.org.uk/media/wwko2fs4/final-report-engineering-better-care-version-for-website.pdf

Universidad de Antioquia

Universidad de Antioquia is an autonomous public university committed—based on criteria of excellence—to the comprehensive education of human beings, the generation and dissemination of knowledge in the different fields, and the preservation and revitalisation of cultural heritage. Its main campus is located in the city of Medellín, Colombia; additionally, it has other campuses and facilities in the nine regions of the department of Antioquia, Colombia. In 2027, Universidad de Antioquia, as a public institution, will be recognised nationally and internationally for its academic excellence and its innovation in support of the community, the territories, and the environmental sustainability.

Frontiers insights: systems approaches for a just energy transition

The Frontiers event took place between 22 and 24 April 2024 at the Universidad de Antioquia in Medellín, Colombia and was co-organised with Engineering X and the Universidad de Antioquia. The event, co-chaired by Professor Yasmin Merali and Professor Franklin Jaramillo, saw over 70 delegates from different disciplines and 23 countries come together to discuss how systems approaches can support the transition to sustainable, equitable energy across the globe.

Despite advances in energy technology over the last several decades, around 733 million people[2] worldwide still do not have access to electricity. At the same time, energy systems currently produce around 60% of total greenhouse gas emissions[3].

Opening the event, Professor Jaramillo outlined the trilemma of current problems that create the need for an energy transition: a lack of energy security, unequal access to energy, and unsustainable energy use and generation. At the centre of these issues are law and policy, which can facilitate the transition needed. Underlining this, he said, "The energy transition is not only a technological issue." In Colombia, and specifically Medellín, where the symposium took place, there is a high reliance on hydropower. Though it is a renewable source of energy, climate change-induced drought is threatening the stable supply of hydro-generated energy, risking energy security for the country. These types of challenges, he underlined, demonstrate the need to diversify energy sources and the urgency of the challenge for Colombia and many other low- and middle-income countries.

"The energy transition is not only a technological issue."
Franklin Jaramillo Isaza, Universidad de Antioquia

Energy systems are complex and require a holistic approach when addressing challenges, highlighted Professor Merali: "Integrating systems thinking in everything we do is important. But more specifically, if we look at the relevance energy has to achieve other SDGs, we can observe how critical that is to think about the energy access challenge holistically." A systems approach can help drive change sustainably, safely, and inclusively. It requires examining not only the technical parts of an energy grid, but all the people who impact it and are affected by it, the local environments, and potential pathways forward. In other words, the energy system holds the potential to improve lives across the globe and create a more sustainable, inclusive future, with collaboration and systems approaches.

"Integrating systems thinking in everything we do is important. But more specifically, if we look at the relevance energy has to achieve other SDGs, we can observe how critical that is to think about the energy access challenge holistically."
Professor Yasmin Merali, University of Hull

[2] www.undp.org/energy/our-work-areas/energy-access

[3] www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-7

The symposium brought together people from different disciplines also integrating systems practitioners in that mix. It used diverse systems methods to frame discussions around the energy transition challenge. It brought to life cross-cutting Engineering X themes on equity, inclusivity, and circularity while also upskilling participants in systems approaches to tackle complex challengesand contribute to safer and more sustainable systems more effectively. The event began with a session on how to cultivate systems thinking, which served as an introduction to the three sessions that would take place, centred around three sub-themes:

- Locally appropriate solutions and south–south collaboration for just energy transitions.
- Governance, justice, and access.
- Circularity and end of life technology.

This report summarises the wide range of expertise and insight from the discussions and activities that took place at the symposium. Overall, the following key findings were uncovered:

- **Community engagement and trust:** building trust and open dialogues with communities is key to ensuring projects are tailored to their needs and sustainable long term.
- **Need for new governance models:** given the interconnectedness of current challenges, new governance models are needed that can accommodate this complexity inclusively.
- **Circularity and end-of-life planning:** with the increase of renewable energy that both uses critical materials and produces new kinds of waste, profound effort must be made to integrate circularity in sustainable technologies to avoid ulterior negative impacts.
- **Applying systems approaches:** addressing challenges in complex systems like energy requires thinking holistically, identifying and engaging all stakeholders and contexts. Adopting systems approaches can help better navigate this complexity while listening to all voices, especially those often unheard.

Professor Yasmin Merali

Yasmin Merali is Emeritus Professor of Systems Thinking at the University of Hull. Prior to this she was Co-Director of the ESRC Doctoral Training Centre on Complex Systems Science at Warwick University, and Director of the Information Systems Research Unit at Warwick Business School. Her research transcends traditional boundaries between the natural and human sciences, drawing on Complex Systems Science to study the resilience of socio-economic systems in the networked world. Professor Merali is an Expert Evaluator for the EU, and her international engagements include membership of the Executive Committees of the European Complex Systems Society, UNESCO UniTwin for Complex Systems Science and the UNESCO Complex Systems Digital Campus.

Professor Franklin Jaramillo Isaza

Franklin Jaramillo Isaza is a Professor at the School of Engineering at Universidad de Antioquia. Previously served as the scientific director of the “Alliance for the Energy Sustainability of the Colombian Industrial and Transportation Sectors through the Utilization of Regional Renewable Resources. Energy Sustainability for Colombia”, Séneca. Currently, appointed as the scientific director of the “Program for the Development and Establishment of an Intelligent Network Enabling the Management, Utilization, and Storage of Unconventional Renewable Energies and Green Hydrogen in Residential and Industrial Sectors – Perseo” in Colombia. His expertise includes nanotechnology, nanostructured and flexible solar cells, semiconductor solution processing, building-integrated photovoltaics, precision agriculture and energy, materials for energy, green hydrogen, and energy sustainability.

Dimitry B (Unsplash)

Introduction to systems approaches: cultivating a systems mindset

Session chairs

Professor Yasmin Merali, University of Hull

Participants engaged in an introductory session on systems approaches led by Yasmin, aimed at providing them with tools that could be applied throughout the symposium and in their work.

Yasmin began by encouraging everyone to adopt a 'beginner's mindset' which would allow them to view challenges in a new light. She explained that at its core, systems thinking is examining the interactions between various elements and components. A system is identified by the interaction of its parts, and humans naturally seek patterns within these interactions. These patterns help us organise systems, though in many cases they can become complicated to define. Social systems, for instance, are particularly intricate due to their open nature.

She then turned to the methodologies that provide the philosophical framework and tools for managing and understanding complex systems, but also emphasised that adaptability is key: "You have to have the courage to decide when something is working, and when it isn't." Mentioning a wealth of tools that can help analyse systems, both soft and hard, Yasmin referred to traditional methods such as structural decomposition, which focuses on breaking things into their pieces in a hierarchical arrangement and structuring systems so they can be controlled. In addition, cybernetic approaches that prioritise more non-linear dynamics to adapt to changes and feedback loops were highlighted. However, with complex, networked systems such as climate change and financial systems, there will always be a level of uncertainty thus fostering long-term resilience becomes increasingly important.

"You have to have the courage to decide when something is working, and when it isn't."

Technological solutions are often used to address challenges in socio-economic systems, but their impact is dependent on three essential criteria:

- **Efficiency:** are the resources needed to deliver the innovation appropriate for the value delivered?
- **Efficacy:** does the innovation deliver its specified output?
- **Effectiveness:** is the innovation achieving the desired goal?

Shifting towards the practical application of systems approaches, Yasmin explained how to create a rich picture. Participants were instructed to identify all the stakeholders in a system, the changes needed from each of their perspectives, and how those changes could be achieved. This creates a bank of different values and views across a system, fostering a better understanding and capturing the voices of those who otherwise would be unheard.

Participants then created their own rich pictures by mapping out various systems. For instance, several groups focused on the energy transition from coal to sustainable sources, identifying stakeholders such as coal miners, farmers, supporting industries such as transportation, public health services, and more, as well as their interconnections. Through the activity, participants were able to visually represent and uncover the complexity and interdependencies within a system, illustrating the need for a holistic approach. By the end of the session, participants agreed that involving diverse perspectives is critical and that systems thinking principles could help drive change in addressing future challenges, especially in energy systems.

Session one

Locally appropriate solutions and south–south collaboration for just energy transitions

Session chairs

Andres Bustamante, EcoSwell

Professor Jairo Espinosa, Universidad Nacional de Colombia

Hannah Härtwich and Gianne Tillema, Systems Innovation Amsterdam Hub

Presentations

1. Complex cases of energy system implementations in Peru

   Andres Bustamante

2. Energy transition: an urgent race with many obstacles

   Professor Jairo Espinosa

3. 3D mapping the energy system

   Hannah Härtwich and Gianne Tillema

Key takeaways:

- Building trust with communities is key to ensuring the long-term uptake of solutions.
- To protect communities from marginalisation and displacement, land rights and governance are needed.
- Technologies must be suited to a community's capacities and need to be effective. At the same time, community capacities must be developed to ensure project sustainability.
- Complex systems like energy require cross-sector collaboration.
- Systems thinking methods like 3D modelling can help innovators – and especially in academia, which can often fall into siloed thinking – better understand the full system – its parts, stakeholders, and enabling environments.

Innovations can drive change, especially in energy systems. However, their efficacy is limited by their suitability in a community. Often, technologies are riddled with inequalities, from their sourcing to their design and implementation. In this session, participants discussed how to better ensure innovations are locally appropriate and foster greater south-south collaboration.

Complex cases of energy system implementations in Peru

Andres Bustamante, EcoSwell

To demonstrate the importance of tailoring technological solutions to different communities' needs, Andres shared his experiences installing a hybrid microgrid energy system in Nazca, Peru. Around 120 people live in Nazca, and prior to the project, they had been without access to energy for the last 80 years. From the onset, the project faced significant challenges. Due to its isolated location, the community could not be connected to existing electric grids. This would require increased investment in infrastructure, but energy companies were also not interested in investing for lack of expected returns. This also deterred potential new residents, impacting the community's growth and stability.

Employing a systems approach, Andres then identified the stakeholders involved in the project: the community itself, private companies like Enel, Waira Energia, and Marcobre, which viewed the community as invaders due to lack of official land titles, as well as government entities, non-governmental organisations (NGOs), and civil society. To address these challenges, the project engaged the local population and gained their trust. They consulted community members to define a shared vision, held elections for an electricity committee and built local capacity through workshops. They also outsourced technical aspects of the project to a private company but gave administration and management responsibilities to the community.

Despite difficulties such as low literacy rates and conflicts among community members, the project maintained transparency through community assemblies and regular reviews. The team also undertook extensive capacity building to give community members the skills needed to maintain the project. Since this initial phase of the project, the original funding sources have finished, which has presented challenges in terms of project sustainability and ensuring the community have the tools they need to continue maintaining the energy grid. Ultimately, Andres emphasised the complexity of implementing energy solutions, the importance of stakeholder management, and the need to maintain trust and involvement from the community for a successful and just energy transition.

Energy transition: an urgent race with many obstacles

Professor Jairo Espinosa, Universidad Nacional de Colombia

Building on the practical aspects of Andres' presentation, Jairo offered some guiding principles for an inclusive energy transition. To start, he underlined the importance of energy harnessing, which has been essential for the development of civilisation, from nuclear energy to biomass, wind, and hydropower, for example. Though the world still relies on old biomass energy such as coal and oil, it is imperative to find new sustainable sources of energy. To advance the energy transition, cooperation is key, he emphasised, "We have to change mindsets. We have to cooperate to build on something complex."

"We have to change mindsets. We have to cooperate to build on something complex."

Communities are built through cooperation, but to build societies, governance is needed. Governance, in turn, can ensure cooperation towards common goals and manage complex global interactions. In its most effective form, governance can foster cooperation between societies and implement policies for more sustainable futures.

This also feeds into wellbeing and trust, which are greatly influenced by culture and social environment. When they are strong, wellbeing and trust allow effective interactions between individuals, specialisation, confidence in the economy and societal satisfaction. In other words, to foster collaboration and governance, stakeholders must have trust, and to build trust, they must feel their wellbeing is being protected.

These elements can create confidence in a collaboration and encourage more long-term planning – critical for large, complex issues such as climate change.

Addressing these challenges, though, also involves the economy and social instruments. The economy can impact a community's wellbeing for better or worse, while policy can implement regulation to steer society towards climate-friendly practices, for example. Summarising, Jairo stressed the need to tailor methods such as using technology with these guiding principles to ensure change. Systems cannot be transformed in siloes, and thus efforts must be cross-cutting and inclusive as well.

3D mapping the energy system

Hannah Härtwich and Gianne Tillema, Systems Innovation Amsterdam Hub

Kicking off an interactive presentation, Hannah and Gianne introduced 3D mapping as a tool to help participants understand how to employ systems thinking in an energy context. This hands-on technique creates a model of a system, using different items such as toys to represent specific aspects of it.

To inspire discussions, they offered some examples of the complexity of the energy system. It requires considering how energy is generated, distributed, consumed, and maintained. Models must also account for the stakeholders that interact with the system, including consumers, regulators, energy companies, businesses, technologists, and more.

Hannah and Gianne also reminded the group to consider how a 3D model might represent interactions between these different elements and stakeholders. Using models such as these can help uncover problems in a system, people who are excluded but should be included, and where opportunities for improvement lie.

Group activity

Participants then worked together in groups to 3D map the energy system using toys and craft items such as ribbons and string to represent different actors and interactions and record their work in short videos.

Participants then reflected on their experiences and shared insights. Some groups had identified a need to divide their 3D maps between the Global North and Global South of their 3D maps to better represent the realities in different regions. For instance, the prevailing mindset of green growth in the North often impacts and even limits access to resources needed by those in the South. Many models illustrated the potential of moving beyond fossil fuels and highlighted the social impacts of the energy system. Creative interpretations allowed for more nuanced discussions, such as using a swinging monkey to show that government is involved across the energy system but can often be disconnected from the reality on the ground.

Participants agreed that often academia can create a more limited mindset, but interactive and interdisciplinary activities such as 3D mapping can help illuminate new relationships or elements in a system. They also emphasised the need to tailor energy solutions for different communities and use resources responsibly.

Jimmy Woo (Unsplash)

Governance, justice and access

Session chairs

Stella Leona Deppe, Development Cooperation Agency Germany (GIZ)

Professor Andrés Felipe Colorado, Universidad de Antioquia

Dr Pedro Pablo Cardoso Castro, University of Exeter

Presentations

1. Mission-oriented innovation policy as a transformative governance approach for complex systems: hype or hope?

   Stella Leona Deppe

2. Renewable energy and Indigenous rights: the Colombian case of balancing sustainability and social justice

   Professor Andrés Felipe Colorado

3. Exploring the use of critical systems heuristics in community-based projects

   Dr Pedro Pablo Cardoso Castro

Key takeaways:

- Putting a mission at the centre of policy can help increase inclusion and ensure intersectoral collaboration.
- Communities facing poverty must reckon with urgent needs such as access to clean water and healthy food – consider how this may impact their engagement with a project that does not address immediate needs beforehand.
- Governance, stakeholder incentives and power dynamics must be considered when addressing a complex challenge
- Adopting a systems approach may help address multifaceted challenges to improve community wellbeing overall.
- Critical systems heuristics offers a framework to identify boundaries and limiting mindsets in a project.

Energy systems are complex and involve a variety of stakeholders with different priorities. Facilitating the just energy transition means navigating this web of interconnected groups. Examining the energy transition from different angles, this session delves into the need for inclusive governance, frameworks for better understanding systems and challenges, as well as ensuring Indigenous rights.

Mission-oriented innovation policy as a transformative governance approach for complex systems: hype or hope?

Stella Leona Deppe, Development Cooperation Agency Germany (GIZ)

While many participants and researchers set out to make positive impacts on the world, often these approaches lack a central, focused, and innovative mission. Opening the second session, Stella affirmed: "If we really want to reach this huge social and ecological transformation, we need to start within."

"If we really want to reach this huge social and ecological transformation, we need to start within."

Driving this forward requires two elements: establishing a 'moonshot' mission that addresses inequalities and has directionality, or focused efforts, as well as improved coordination between stakeholders. An approach for ensuring these elements remain central to development and policy decisions is "mission-oriented innovation policy". This features several pillars to guide action:

- it should be **innovation-focused**
- it requires **cross-sectoral collaboration**
- **state actors** must have open dialogue
- there must be a **clear goal** that is specific and transformative
- the mission must be **understandable, measurable, and time-bound**.

Governments, for instance, are often siloed in their work, but facilitating an energy transition requires coordination from many different ministries, from energy to environment, economy, and more. Stella referenced frameworks to achieve mission-oriented innovation developed by Marianna Mazzucato which call for:

- alignment of missions with development goals
- ensuring the engagement of the private sector; science, technology, and innovation; civil society organisations; and marginalised groups
- strengthening of local innovation ecosystems
- supporting adaptive governance mechanisms.

Closing her presentation, Stella called for participants to consider their own governments and question whether they were driving forward development in a mission-oriented way.

Renewable energy and Indigenous rights: the Colombian case of balancing sustainability and social justice

Professor Andrés Felipe Colorado, Universidad de Antioquia

To achieve a just transition, innovators must balance sustainability and social justice. Exemplifying the complexity of this task, Andrés detailed his experiences working in La Guajira, a region in Northern Colombia largely populated by Indigenous peoples. On one hand, the region has a high potential for renewable energy as solar radiation levels are 60% higher than the national average and wind speeds are double the global norm. By itself, La Guajira could provide Colombia's national energy demand multiple times over.

However, the region is also wrought with social issues. It is one of the most impoverished areas, with high rates of malnutrition and drought. In the past, local communities were marginalised, and excluded from the economic benefits of coal plants, for example. Regulations can be a huge help to communities because they give them rights over their lands. This, in turn, protects them from displacement by groups seeking to profit from the region's resources.

Andrés urged participants to consider the realities of multidimensional poverty when working with communities. Many times, local people face urgent issues such as lack of access to water or nutritious food that they would prioritise over projects like renewable energy. Adopting a systems approach can help address these multifaceted challenges together and ensuring the inclusion of local communities.

Exploring the use of critical systems heuristics in community-based projects

Dr Pedro Pablo Cardoso Castro, University of Exeter

To help demonstrate the importance of collaborating with communities, Pedro shared a story. In Bogotá, a group of researchers and development workers discovered a community without toilets in their homes, so they decided to create a project to address this. They organised themselves, found funding, and delivered hundreds of toilets to the community. However, they returned a year later and found the toilets were being used as plant pots. Pedro emphasised that though this story is not unique to Colombia, it shows what happens when an engineered intervention does not consider the needs and resources of communities.

In the example, the community was not considered and therefore the central issue, which was access to clean water, made the toilets unhelpful to them. Critical systems heuristics (CSH) can help avoid scenarios such as these, offering a framework of critical, reflective questions to identify gaps and assumptions in a project. Concluding his presentation, Pedro reiterated, “Systems thinking begins when you start to look at the situation from the eyes of others.”

“Systems thinking begins when you start to look at the situation from the eyes of others.”

Group activity

Following the presentations, participants put into practice CSH methods, breaking into groups and answering questions about example projects. Participants found the exercise helpful yet challenging, as it required balancing immediate practical concerns with forward-thinking strategies. A common thread was the importance of diverse perspectives and the difficulty in maintaining a holistic view while navigating complex systems. Several groups noted the challenge of building trust amongst stakeholders and communities, recognising the need to confront their own biases and limitations.

Groups also stressed the critical role of community involvement and inclusive practices. They discussed the gap that often exists between theoretical frameworks and practical implementation, particularly in improving energy literacy and equitable solutions. They also recognised the need for adaptability and continuous engagement to address the evolving issues in energy systems.

Reflecting on the learnings of the session, Yasmin highlighted that systems thinking tools are not an end in themselves. They prompt further reflection and adaptation as you identify more groups that should be involved in a project.

Red zeppelin (Unsplash)

Circularity and end-of-life technology

Session chairs

Professor Aída Luz Villa Holguín, Universidad de Antioquia

Alejandra Tabares Pozos, Universidad de Los Andes

Annabel Membrillo, Universidad del Medio Ambiente

Presentations

1. The circular economy as strategy in the use of critical minerals for clean energy transition

   Professor Aída Luz Villa Holguín

2. Circularity in renewable energy planning

   Alejandra Tabares Pozos

3. The iceberg tool as a systemic lens to circular challenges

   Annabel Membrillo

Key takeaways:

- New technologies should not create more waste but rather can employ circularity and make waste a resource to be used.
- Renewables should not perpetuate wasteful practices of non-renewable systems, for instance by sourcing materials from conflict regions or worsening conditions for local communities.
- New projects must be designed with the future in mind, planning for what happens when a piece of technology comes to its end of life.
- Iceberg models can help foster understanding of the underlying factors driving a challenge, as well as the opportunities for change.
- Systems approaches can help create open channels for communication across collaborators.
- Top-down and bottom-up approaches are needed to drive transformation.

With a shift towards renewable energy comes increased resource needs. To ensure that renewable energy systems do not create ulterior sustainability issues, innovators must consider the full lifespan of technologies. In this session, participants learned about circularity, the technological end of life, and systems thinking techniques to support them as they work towards a more sustainable and inclusive energy system.

The circular economy as strategy in the use of critical minerals for clean energy transition

Professor Aída Luz Villa Holguín, Universidad de Antioquia

Aída kicked off the third session by explaining the need for circularity in energy systems. With the increasing adoption of renewable energy sources and batteries to meet climate change goals, the demand for various minerals like aluminium, copper, steel, silver, and silicon is set to rise significantly. For instance, the demand for lithium for batteries is expected to increase 18-fold by 2050. This surge is driven, in part, by the need for batteries in electric vehicles which use minerals like cobalt and high-purity silica for solar panels.

E-waste is also an emerging issue as many technologies combine a variety of materials that cannot be recycled, or which do not have systems in place to reutilise them. The transition away from fossil fuels will require a higher number of mines for these resources. These materials are vital for the energy transition but pose supply risks due to trade policies or limited availability. At the same time, many regions where critical materials are abundant face socio-political challenges, meaning that increased mining can have negative impacts on local communities.

The circular economy offers a solution to these challenges by promoting the reuse of materials and products, extending their lifecycle and improving waste regeneration. This approach transforms the linear path of material use into an interconnected and circular one. However, problems remain, such as the high demand for cobalt from unstable regions and the carbon-intensive process of obtaining graphite. There is also a need for greener processes for extracting minerals.

Circularity in renewable energy planning

Alejandra Tabares Pozos, Universidad de Los Andes

Despite the vast potential of and need for circularity, the world is becoming less circular. In 2021, the global economy was 9% circular, while in 2023, it was only 7.2% circular. Reiterating the urgency of creating more sustainable systems, Alejandra outlined several pressing issues to achieve circularity.

There are several prevailing challenges to achieving circularity. The first is raw material extraction. Many renewable technologies have high material requirements which depletes critical materials and creates a shortage of metals. Another challenge is waste generation as many renewable technologies such as wind turbines are not currently recyclable or do not have the structures in place to reuse or recycle their materials. Though these are sustainable energy sources, they are not designed with circularity in mind.

In addition, eco-design is a challenge as it may be more sustainable in some regards, but it is often not designed for circularity or durability, thus creating more waste. The final challenge Alejandra highlighted was manufacturing and stock management, which creates problems across the installation, maintenance, and logistics of products. Specifically, on this, there is a data gap on usage that could better inform decisions if filled.

However, Alejandra offered several tactics for addressing these issues:

- focus on renewable sources of materials
- stretch the lifetime of technologies
- use waste as a resource
- design with the future in mind
- strengthen and advance knowledge sharing
- adopt new business models.

She also underlined the need for economic and policy frameworks to ensure the success of circular systems. The policy playing field must be levelled to incentivise circular practices over wasteful, extractive ones. Fiscal policy must also reflect the true prices of resources. For example, high environmental costs should be represented in the price of materials. Ultimately, policy must also build circular expertise and skills to ensure long-term success. Closing her presentation, Alejandra underlined the need to integrate circularity into all actions – from individuals to businesses, cities, and countries – and called for more education to build the expertise and skills to make long-lasting change.

The iceberg tool as a systemic lens to circular challenges

Annabel Membrillo, Universidad del Medio Ambiente

Tying in systems thinking to the discussion around circularity, Annabel explained the iceberg model. On its surface, an iceberg may appear one way, but when diving deeper, it may be completely different. In the model, imagining a challenge as an iceberg allows us to see patterns that may have not been visible without deeper consideration.

Annabel used renewable energy as an example to demonstrate an iceberg model. On the surface level, also known as the event level, she identified what can be immediately seen: there is a shift towards renewables occurring because non-renewable energy produces negative impacts. Looking at the second level down the iceberg, the pattern level, she shared graphs of increasing emissions and use of the components that comprise renewable energy.

The third level examines structure. This level aims to identify what is causing the pattern, usually a structure. In this case, Annabel pointed to the negative impacts of non-renewable energy systems. The final level focuses on mental modelling, which is the beliefs or attitudes that allow a structure to continue. At this level, she emphasised the lack of knowledge about sustainable energy and circular models, and the need to change mindsets.

Group activity

After Annabel's presentation, the session chairs grouped participants to create iceberg models for a selected project. Afterwards, participants reconvened to reflect on the experience. They agreed that the iceberg model was useful in understanding and addressing complex systems. Many groups noted the difficulty in translating abstract data into practical interventions, such as was done in Annabel's third level example, emphasising the need for a structured approach to navigating these complexities. Participants also appreciated the model for facilitating open team communication and enabling diverse perspectives.

Additionally, the groups underscored the importance of addressing root causes rather than just symptoms. Leadership was identified as essential to design effective strategies, as well. Participants closed the session by underlining the need for both top-down and bottom-up approaches to make lasting change, including improved education on energy issues.

The session finished by underscoring the importance of planning for end of life to prevent harm to human health and the environment. To learn more about this issue, explore the Engineering X Safer End of Engineered Life programme.


AGUA

Professor Alexánder Gómez Mejía

Universidad Nacional de Colombia

Contextualising the symposium's discussions, Professor Alexánder Gómez Mejía delved into the challenges and current developments in the just energy transition in Colombia. Currently, 23% of the country's energy comes from renewables, higher than the 14% global average. There is also high political will to mitigate climate change, though the main focus of emissions mitigation in Colombia is agriculture, forestry, and land use. At the same time, energy access in the country is divided: around 97% of the population can access energy through the national grid, but almost 20% are also energy-poor. This leaves around 800,000 people without access to energy.

Colombia's energy comes from a mix of fossil and renewable sources. However, the transition to more renewable energy results in several challenges. Several regions, for instance, are rich in hydropower resources, but transporting this energy to other areas requires further infrastructural development. Additionally, the reliance of renewables on the weather means they are highly variable. To drive the just transition forward, Alexánder called for several key actions:

- coordination between regions of the country
- education of communities on energy usage
- involvement of local and Indigenous communities
- creation of new energy storage tools
- shifting to smaller, decentralised energy plants to serve community needs
- digitisation to coordinate between the many different energy system actors
- improved regulation.

Closing his keynote, Alexánder underlined: "Driving this mission means going through the levels of technical readiness, but the final level of research is living labs – working directly with communities and learning about real environments even if it is challenging."

"Driving this mission means going through the levels of technical readiness, but the final level of research is living labs – working directly with communities and learning about real environments even if it is challenging."

Carlos Enrique Vélez Restrepo

Empresas Públicas de Medellín EPM

Carlos Enrique Vélez Restrepo has worked to deliver energy access to people across Colombia, collaborating with both the public and private sectors to create energy communities. These are groups of citizens that cooperate around energy for their community. The development of these groups relies on three pillars:

- Environmental – reducing energy consumption and increasing the use of renewables.
- Economic – creating savings for the user and investment opportunities for the community.
- Social – providing local employment and giving the community ownership over the system and its maintenance.

In Medellín specifically, he helped to develop an energy community for Comuna El Salvador. The project connected 24 households to energy through solar panels on their rooftops and an existing grid to distribute the energy. The energy produced would then be logged in a digital platform and provide tokens to each family for the amount of energy produced. Then, they could use the tokens to pay their bills.

The digital platform also allowed community members to better understand their own energy usage, providing notifications when more energy was being used than the average. As a result, people were more informed on sustainable energy consumption, saving on average 37% on their bills. To ensure its success, the programme also facilitated workshops to inform the community on how to use the digital platform and apply the learnings.

However, the project was not without challenges, which provided learnings for the future. Building trust with communities is critical – they must be transparently informed on not only the project but its impacts and benefits. Local energy structures were also difficult to manage, as people were required to pay 'reactive' energy costs or estimated usage in advance. Communities must also be supported to keep the system running. This means ensuring the project is economically feasible and is not reliant on high-priced, inaccessible tools and equipment, while also ensuring they have the training necessary.

Insight session

After three days of discussion around challenges in energy systems, as well as opportunities for systems approaches to help bridge gaps in the sector, participants came together for a final insights session. Event chairs hosted a panel of participants – including Adam Cooper, Alexánder Gomez, Alba Avila, Luis Carvajal and Mumbe Mwangangi – from across sectors and regions to reflect on learnings and offer real-life examples of innovation in energy systems advancing equitable access.

Panellists agreed that to ensure a just and equitable transition, education is needed – not only for the young professionals who will be implementing projects but also for communities. In communities, this can give them the capacity to maintain new local energy projects or infrastructure and allow them to understand and adapt their energy usage. They also underlined that public-private partnerships can be an important tool for driving innovation in the energy sector. Civil society can also leverage its skills to better connect with marginalised communities, helping to create the microsystems that will likely be needed to develop more sustainable energy grids for remote or low-resource communities. Closing out the panel session, Yasmin emphasised the potential of the network paradigm – an organising principle that looks at a system of many interconnected parts and how they interact – to help drive progress in the energy transition: "The network paradigm has to become a serious theme for anyone who is thinking systematically about challenges this complex."

After the panel session, symposium participants were invited to brainstorm systems changes they hoped to see over the short-, medium-, and long-term to facilitate a just transition in energy systems.

Yasmin Rahman (UKSPIA)

Short-term goals

The short-term group focused on the next one to five years, emphasising the need for stronger connections and education between researchers, their collaborators, and communities:

Improving community engagement

- building local capacities
- improving trust between communities and researchers/innovators
- providing education.

Creating stronger networks

- bolstering existing networks of innovators such as the Frontiers and Engineering X community
- sharing knowledge, especially of project successes and failures and best practices.

Advancing systems thinking

- making systems thinking more common knowledge
- applying systems thinking to improve stakeholder engagement.

Developing and adopting new tools for more sustainable energy systems

- employing circular models and planning for end-of-life
- using microgrids to deliver energy to more communities.

Medium-term goals

The medium-term group looked at systems changes for five to 10 years in the future, building on the strong collaborations outlined in the short term to advance sustainability in the energy sector:

Improving energy regulation

- extending responsibility to energy producers/ providers for the full lifespan of technology
- implementing right-to-repair to reduce waste
- improving carbon pricing mechanisms
- implementing multi-level governance
- global strategies and solutions for end-of-life technology
- ensuring inclusive policymaking.

Adopting sustainable, innovative, and inclusive tools and technologies

- digitising more of the energy grid
- creating tools to capture wasted heat for energy
- adopting circular approaches and e-waste management strategies
- developing technology locally
- employing regenerative approaches and tools.

Facilitating collaboration

- building South-South collaboration networks
- integrating Indigenous knowledge in service and social systems design
- openly sharing data throughout all the energy supply chain
- developing private-public partnerships
- fostering energy literacy
- developing the younger generations of engineers with holistic skills.

Advancing transparency

- ensuring accurate energy pricing that considers environmental impacts
- improving value chain transparency
- providing transparent information on climate impacts.

Long-term goals

The long-term group examined systems changes for beyond 10 years in the future, brainstorming goals that would ensure a sustainable, equitable energy transition:

Concretising policy and structures for sustainable energy use

- creating energy communities
- implementing progressive taxation as a part of energy policy
- using data and engineering in public policy
- ensuring transparency
- integrating renewable energy sources into the wider grid.

Continuing to innovate

- investigating new and more effective sources of energy
- reaching 90% circularity
- integrating artificial intelligence (AI) in energy distribution
- shifting from sustainable to regenerative tools and approaches.

Ensuring inclusivity

- including all affected stakeholders in decision-making
- reducing inequalities
- including marginalised communities in energy projects.

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David Gabric, Unsplash

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For more information, including eligibility, please visit raeng.org.uk/frontiers, engineeringx.raeng.org.uk and follow X @RAEngGlobal

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