# TRANSFORMATIVE TECHNOLOGIES FOR THE FUTURE OF HEALTH IN 2040

POLITECNICO
MILANO 1863

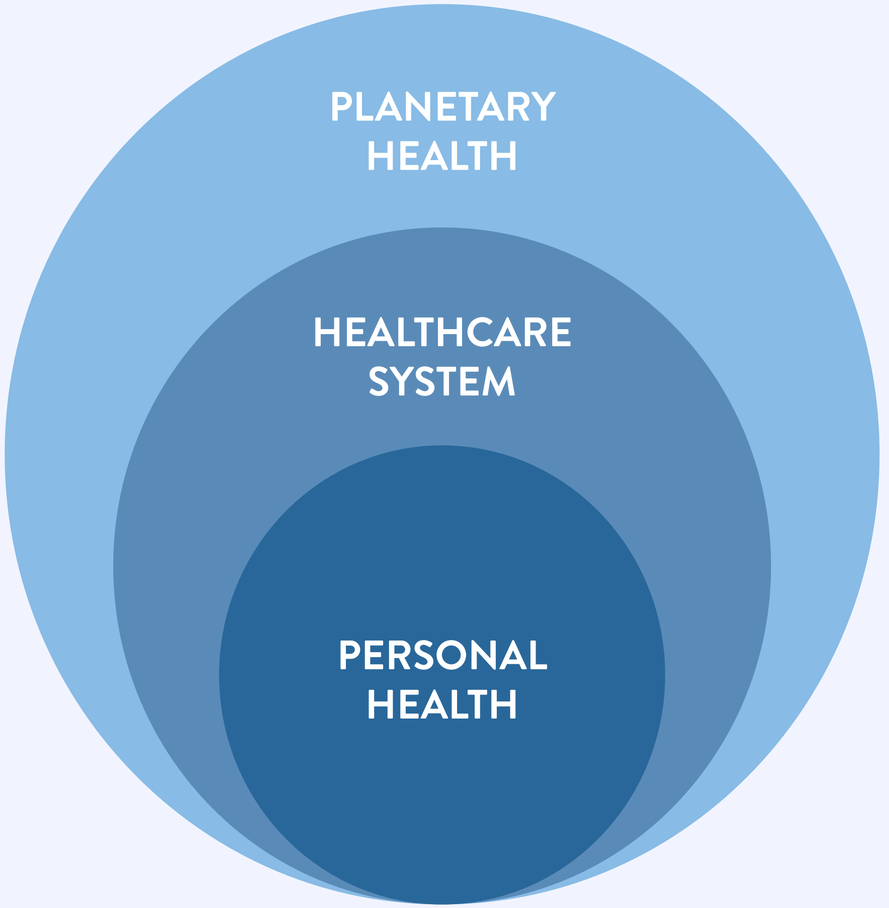
TECHNOLOGY FORESIGHT

# VISION: ONE HEALTH

## A multidimensional perspective on health

FORESIGHT METHODOLOGICAL FRAMEWORK

One integrated approach applied consistently across all steps and exercises to ensure coherence, comparability, and amplified impact.




- Opportunities
- Risks
- Requirements
- Impacts
- Barriers
- Signals of change
- Stakeholders
- Experts

TOP TECHNOLOGIES + INSIGHTS + TAKE-HOME MESSAGES

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# Foreword

The development of an inclusive, resilient, and sustainable health system relies on the adoption of innovative technologies, a robust understanding and awareness of their use, and coordinated action between public and private stakeholders, capable of addressing health in an integrated way across the individual, the planet, and the effective functioning of healthcare systems.

As Technology Foresight at Politecnico di Milano, we have devoted three years to analysing the most disruptive technologies shaping the future of health, within a time horizon extending to 2040. By applying foresight methodologies and tools and drawing on the contributions of numerous experts from both academic and professional spheres, we have explored the opportunities and challenges associated with the future of health across its three dimensions: personal health, healthcare system, and planetary health.

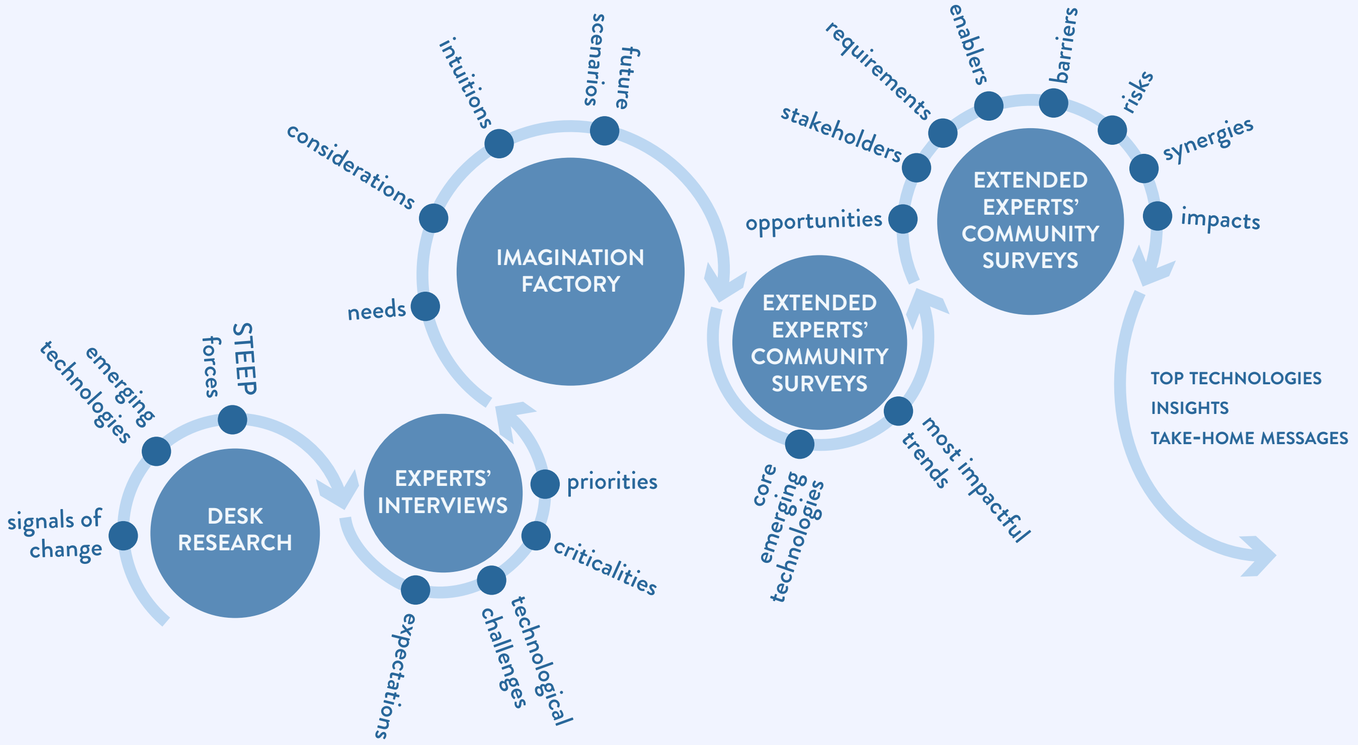
At the end of this research, a growing need clearly emerges to create a health system that places prevention at its core. The promotion of personalised interventions, together with the decisive role played by lifestyles and environmental contexts in human health, outlines a clear direction that both the scientific community and public institutions must consider. This requires moving beyond fragmented approaches and building a health system capable of transcending a view of well-being as the exclusive outcome of individual care, recognising instead that it is the result of a balance between individuals, communities, and ecosystems.

**Donatella Sciuto**
Rector, Politecnico di Milano

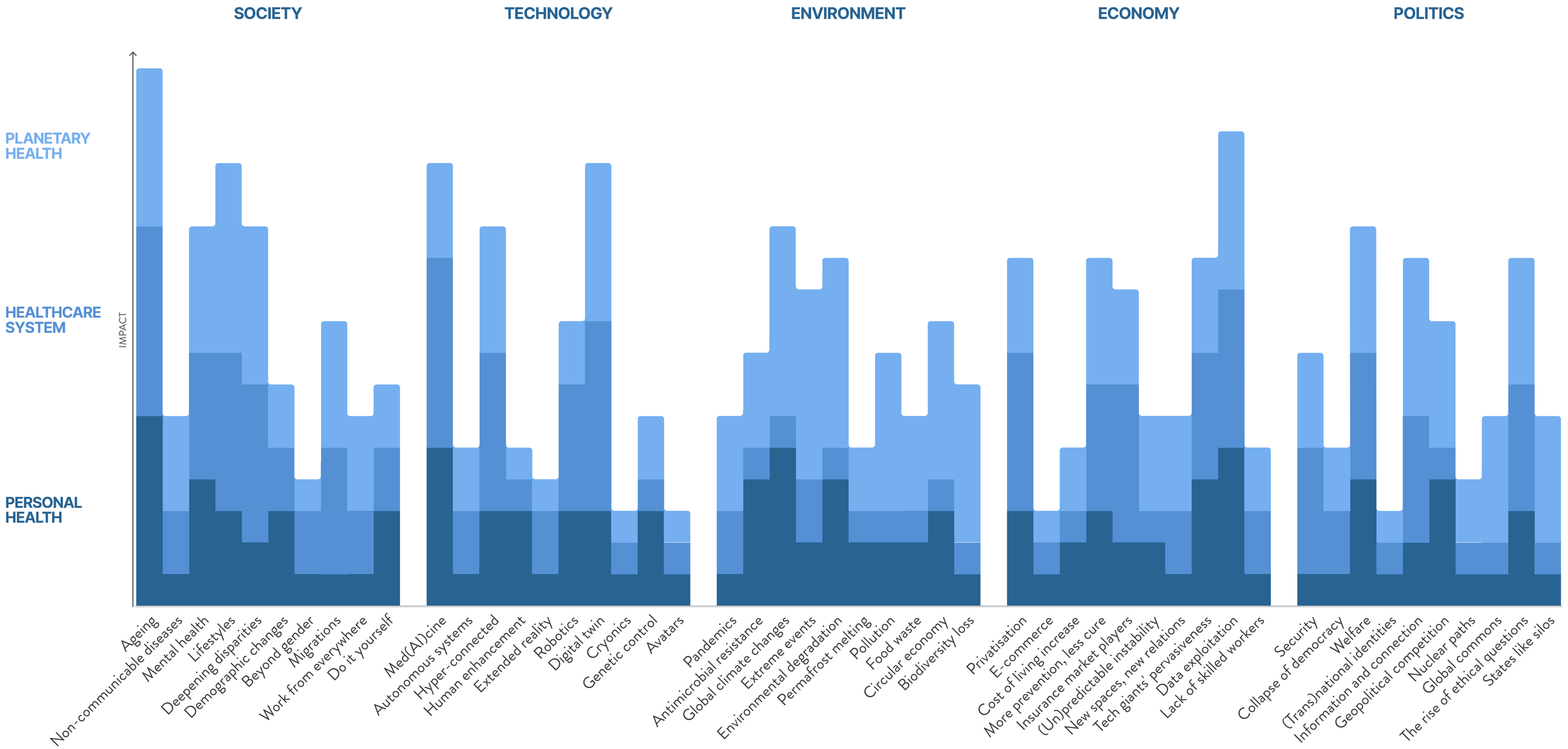
# Technology Foresight at Politecnico di Milano

The methodology follows a three-phase framework, from Preparation to Foresight to Insight.
Desk research activities gather evidence and drivers of change associated with STEEP forces to prepare the field and complement expert's evidence, serving as a guide to expand the area of research and reframing the landscape under analysis. A technology scanning activity allows to collect an overview of prominent technologies and innovations of interest for the context, considering their transformative potential.

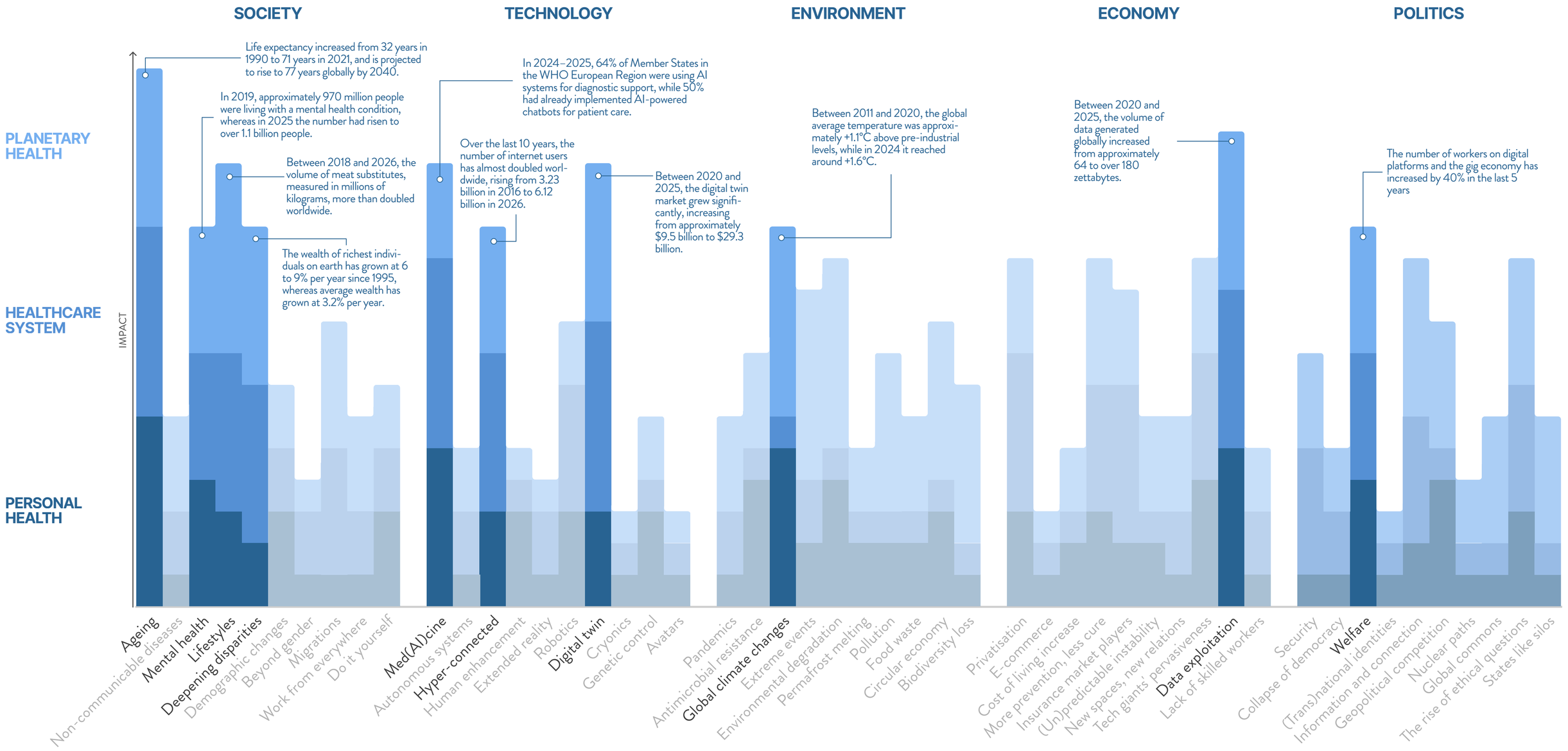
Internal and external experts are engaged for providing critical specialised knowledge and vision through individual interviews and in-person factories, ensuring a multi-angled evaluation. The process enables to explore how technologies might impact the future, with a distinction between preferable and non-preferable outcomes, to build the necessary resilience to either adapt to or actively contribute to shaping a better future.



# Driving forces shaping the future of health



# Driving forces shaping the future of health

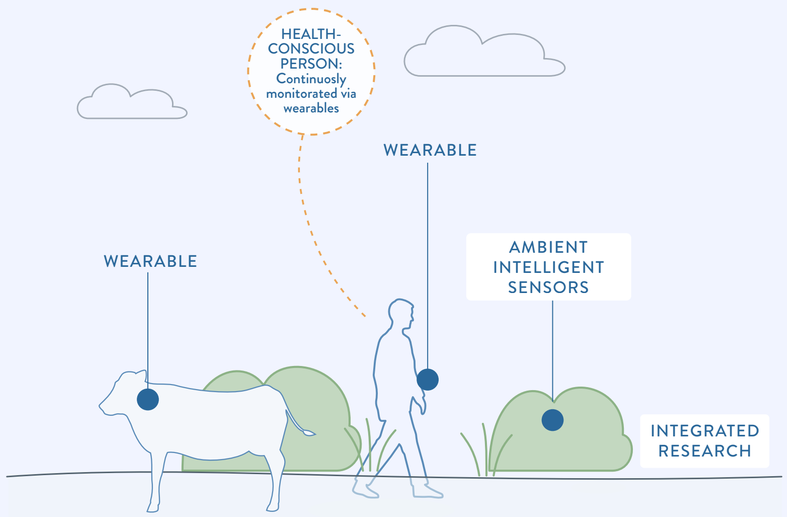


# Health in 2040

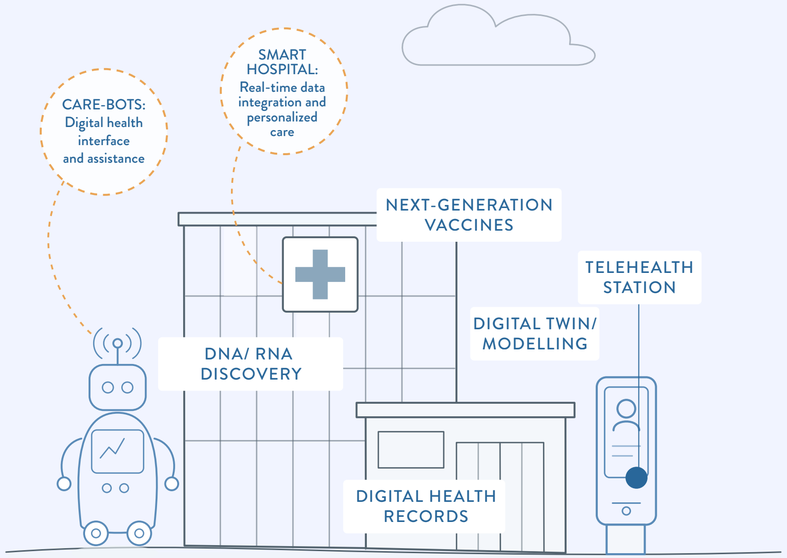
## How technologies might shape the way we take care of our and the planet health

Adopting a **One Health** perspective, the emerging technologies identified during this three-year study are assessed for their role as strategic drivers in tackling future challenges in personal health, healthcare system, and planetary health.

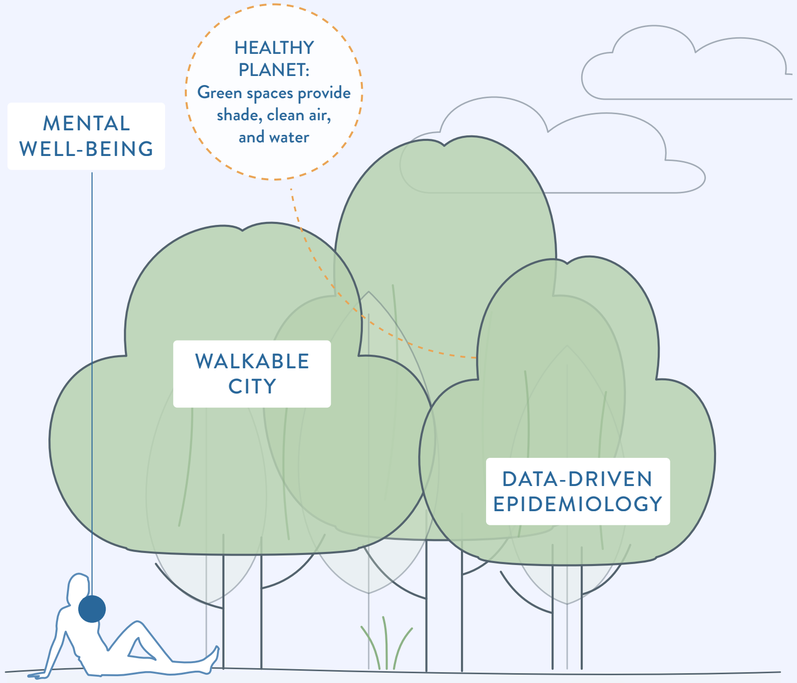
These interconnected domains operate across multiple dimensions, capturing the holistic scope of health.
Out of more than 60 analysed technologies, this report features the top three per dimension with the greatest transformative potential.




### PERSONAL HEALTH




### HEALTHCARE SYSTEM




### PLANETARY HEALTH

# Expert views

## The temporal dimension of health

The future of health in 2040 may not be shaped only by new medical discoveries, but by a deeper change in the way we think about health itself. The main shift could be from a reactive model, where we act only when symptoms appear, to a more continuous and anticipatory one.
In this perspective, health is no longer seen as something to recover after illness, but as a condition to be followed, protected and adjusted over time. Care would no longer be limited to single moments, i.e. a visit, a diagnosis, a treatment, but could become a form of ongoing support throughout a person's life.

> *"Technology is reshaping the healthcare journey, but decisions about its timing should remain with each individual. Everyone should be enabled to choose and manage their own health path throughout their lifespan."*
>
> *Luca Vago, Professor, Università degli Studi di Milano*

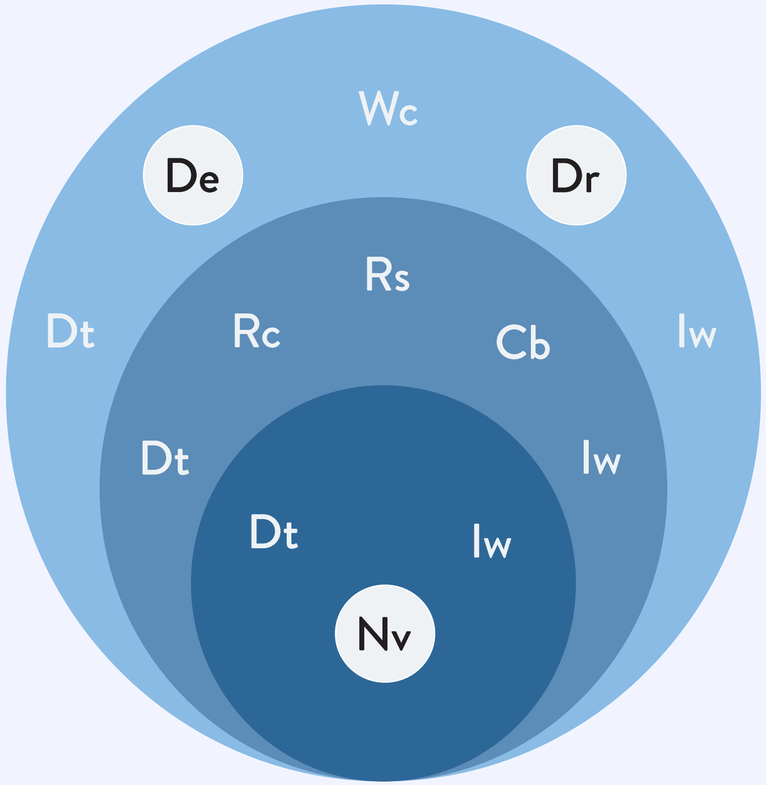
New technologies may make this possible by combining biological data, lifestyle information, and environmental factors. Rather than offering standard responses when a problem emerges, healthcare could become more personal, timely, and connected to the real context people live in.

This future, however, is not guaranteed. It requires major changes in healthcare systems, regulations, and economic models, many of which still reward treatment more than prevention. It also raises delicate questions about how technology should be used, and for whose benefit.

> *"The longevity dividend is not produced in hospitals: it is generated in the cities, homes, and technologies designed for humans to flourish, not to be managed."*
>
> *Franco Molteni, Clinical Director, Villa Beretta*

The goal of continuous care should not be to place people under permanent surveillance, but to create the conditions in which they can truly inhabit the time that longevity makes available to them.
However, the extended lifespan that science and medicine are making possible could be eroded by fragmented care, the burden of chronic disease management, or technologies that turn life into a sequence of data points to be optimised rather than moments to be lived.
For this reason, the future "time of health" does not depend only on technological progress. It also depends on our ability, as a society, to rethink care, build trust and accept health as a continuous responsibility rather than something we deal with only in moments of crisis.

# Technology deep dive




**Next-generation vaccines — Nv**

Biotech breakthroughs, especially in mRNA platforms, are making vaccines faster to design and easier to adapt to emerging pathogens. In the future, they could become more personalised, potentially tailored to individual risk profiles and specific contexts. Their role may also expand beyond infectious diseases, supporting prevention strategies for conditions such as cancer or autoimmune disorders. If successful, they could help move medicine further upstream, from treating disease to preventing its biological triggers. Key challenges remain in manufacturing, regulation, and fair global access.

**Data-driven epidemiology — De**

The growing availability of real-time, large-scale data is changing epidemiology from a mainly retrospective discipline into a more anticipatory one. By combining AI, health records, environmental data, and behavioural patterns, it may become possible to detect risks earlier and respond with more targeted public health actions. This could support a more continuous monitoring of population health and faster decision-making. At the same time, its impact will depend on data quality, transparency, interoperability, and public trust.

**DNA/RNA discovery — Dr**

Advances in reading and engineering DNA and RNA are deepening our understanding of disease mechanisms, genetic variability, and interactions between humans, animals and the environment. These tools could lead to more precise therapies, earlier identification of risks and, in some cases, interventions before disease develops. They also strengthen the shift toward proactive and personalised health. However, their use raises major ethical questions around equity, consent, access, and the boundaries of acceptable intervention.

# Expert views

## The spatial dimension of health

The future of healthcare in 2040 may be marked by a profound redefinition of the places where healthcare is delivered and provided, from prevention to cure to rehabilitation. At the centre of this transformation lies a shift from a model in which care is concentrated in specialised facilities to a constellation of interconnected physical and digital spaces, in which healthcare extends into every corner of everyday life.

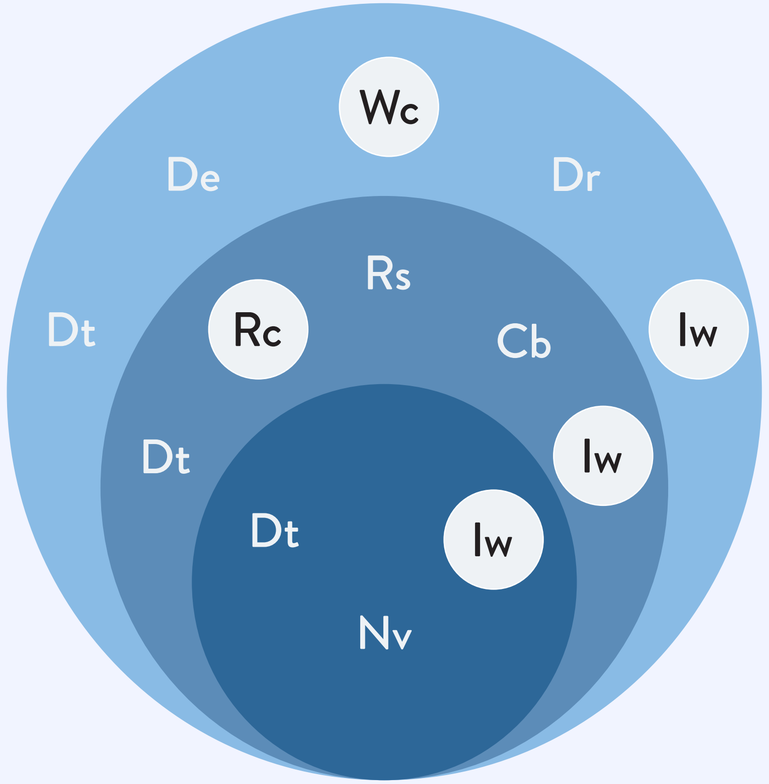
> *"The concept of public health moves from a medical (individual) approach, to a social (collective) approach, strongly influenced by the environmental, economic, cultural, educational issues."*
>
> *Carlo Signorelli, Professor, Università Vita-Salute San Raffaele*

Thanks to remote monitoring systems, telemedicine devices, and smart healthcare solutions, the home is set to become a primary clinical hub. The city is transformed into an increasingly walkable and active infrastructure for prevention, and digital environments become spaces for continuous and personalised care.

Yet, this vision risks remaining purely potential in the absence of adequate support for the development and diffusion of enabling technologies. And the fragmentation of care settings requires new forms of coordination between spaces and infrastructures to avoid exacerbating existing inequalities or creating new ones.
Furthermore, the growing reliance on energy and material resources, which are required for the operation of both physical and digital infrastructure, makes it essential to establish regulatory frameworks and global coordination capable of operating within environmental limits, in order to build an integrated, accessible, and sustainable system, capable of reconciling human well-being with that of the planet as one and the same thing.

> *"Materials will no longer be static elements with a linear life cycle, but dynamic, adaptive and multifunctional systems, capable of transforming and regenerating in symbiosis with the human body. The boundary between space, material and organism will become fluid: a distributed and co-evolving ecosystem that functions as a continuous, living protective layer, shifting the focus from the treatment of disease to the ongoing seamless safeguarding of human wellbeing."*
>
> *Annalisa Giancaterini, Medical Director, ASST Brianza*

# Technology deep dive




**Implantable/Wearable devices/Ambient intelligence sensors — Iw**

Implantable and wearable devices enable continuous monitoring of physiological conditions, supporting a more integrated and coordinated approach to health management at the ecosystem level. Ambient intelligence sensors allow the detection, processing, and communication of collected information. They may be deployed within the surrounding physical space or integrated into organisms present in the environment, operating as distributed infrastructures for continuous sensing. Looking ahead, the development of these technologies will increasingly move towards the creation of intelligent environments capable of dynamically adapting to the individual. In this perspective, physical spaces will tend to evolve into distributed cognitive systems, able to modulate the user's experience in real time.

**Remote care system/Telemedicine — Rc**

Telemedicine refers to the delivery of healthcare services by professionals in cases where distance is a critical factor, using information and communication technologies to prevent, diagnose, and treat diseases and injuries. Remote care systems enable continuous patient monitoring and the transmission of health data to healthcare professionals, supporting a more constant and distributed form of care that extends beyond the boundaries of hospital facilities. These technologies are expected to evolve towards increasingly integrated predictive models, capable of supporting both prevention and the personalisation of treatment. But their widespread adoption raises significant challenges in terms of data security and equitable access.

**Walkable city — Wc**

The walkable city is an urban model where the design of spaces and the integration of technologies contribute to making the urban environment more accessible, safer, and more sustainable. This model improves quality of life by promoting a helthier lifestyle and contributes to the mitigation of urban microclimates, as well as to the reduction of air and noise pollution. Overall, it has a positive impact on multiple dimensions of urban life, promoting more efficient mobility, public health, social well-being, and greater inclusion. At the same time, walkability should not become an accessibility barrier, nor should it lead to excessive dependence on technology when needs are not easily reach.

# Expert views

## The agency dimension of health

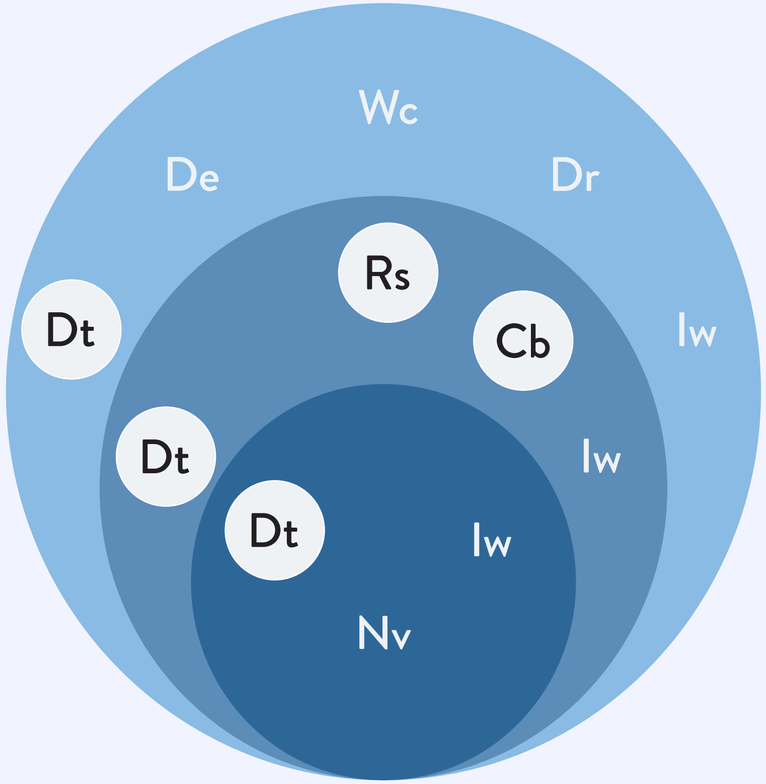
In the evolving landscape of future healthcare, agency is being redefined within a hybrid ecosystem where human, digital, and robotic agents collaborate to transform prevention, treatment, and rehabilitation. The citizen is no longer a passive recipient but an active participant, empowered by hyper-connectivity and digital tools that enable decentralised interaction with healthcare, shifting care from clinical settings to the patient's environment. Digital agents and intelligence such as Digital twins and intelligent monitoring systems expand prevention beyond the individual to entire interconnected ecosystems. Through predictive models and real-world data, they enable early disease detection and highly personalised prevention and treatment plans. At the same time, remote surgery and telecommunication networks reduce geographical barriers, making specialised surgical care accessible even in remote or fragile contexts. In rehabilitation and long-term care, agency is further enhanced by carebots and robotic aids that support patient autonomy, especially at home. These tools do not replace healthcare professionals but assist them by handling routine tasks, allowing physicians to focus more on the patient's narrative dimension and a more holistic, empathetic approach to care.

> *"Technology and data driven solutions are big enablers to balance healthcare systems sustainability but professionals commitment and citizen empowerment is essential to create value."*
>
> *Elena Bottinelli, Head of Innovation and Digitalisation, Gruppo San Donato*

However, this shift requires strong ethical governance. It is essential to prevent risks such as social isolation or psychological stress caused by excessive digital monitoring. The goal is a complementary human-machine relationship where technological agency promotes equitable access and universal well-being rather than privilege for a few.

> *"The goal of new technologies such as artificial intelligence and robotics is to enhance human agency rather than replace it. By empowering patients and augmenting healthcare professionals, these technologies can help deliver more personalised care to more people, allowing clinicians to focus on what remains uniquely human: empathy, judgment, and trust."*
>
> *Maurizio Cecconi, Professor, Humanitas University*

# Technology deep dive




**Care-bots — Cb**

Care-bots are devices designed to monitor patients' health status and provide both physical and emotional assistance to individuals in hospital, residential care facilities, or receiving care at home. These are networked technologies capable of collecting, storing, and processing data from various local sources as well as from the cloud. This technology supports the development of predictive medicine and facilitates the integration of clinical and epidemiological data, while also carrying out inspection activities in hard-to-reach environments.

**Digital twin/Modelling — Dt**

A Digital twin is a set of virtual information constructs that mimic the structure, context, and behavior of a natural, engineered, or social system. In healthcare, it acts as a dynamic virtual replica of a patient (or specific organs/systems), continuously updated with real-time data to inform value-driven decision-making. Beyond the individual level, this technology is evolving into a tool for systemic governance. It will be possible to develop Digital twins of entire cities, directly connected to administrative, urban planning, and healthcare systems to anticipate public health risks.

**Remote surgical robotics — Rs**

Remote robotic surgery represents a technological frontier that allows a surgeon to perform procedures on a patient located in a different geographical area by integrating advanced robotics, ultra-fast connectivity, and real-time sensory feedback. Through remote control, the physicians guide robotic arms that faithfully mimic their movements, ensuring extreme precision thanks to haptic feedback systems that restore the tactile sensitivity of tissues. This technology is fundamental for breaking down geographical barriers and democratising access to high-level specialised care, bringing surgical excellence to isolated or fragile contexts.

# Acknowledgements

Participants in interviews and factories are listed below. We thank them for their invaluable contributions and insights.

AT POLITECNICO DI MILANO

→ Andrea Aliverti *
→ Lina Altomare
→ Giuseppe Andreoni
→ Manuela Antonelli
→ Guido Baroni
→ Giuseppe Baselli
→ Andrea Bassi
→ Alessandro Biamonti
→ Anna Maria Bianchi
→ Francesco Briatico
→ Maddalena Buffoli
→ Enrico Caiani
→ Gabriele Candiani
→ Maria Rita Canina
→ Stefano Capolongo
→ Marco Carminati
→ Renato Casagrandi *
→ Francesco Causone
→ Stefano Ceri
→ Maurizio Cesana
→ Veronica Cimolin
→ Matteo Clementi
→ Bianca Colosimo
→ Maria Laura Costantino
→ Antonio Da Silva Ferreira De Carvalho
→ Luca Dedè
→ Gabriele Dubini
→ Silvia Faré
→ Davide Fassi
→ Venere Ferraro
→ Giancarlo Ferrigno
→ Carlo Fiorini
→ Marco Gribaudo
→ Mario Grosso
→ Alberto Guadagnini
→ Alessandra Guglielmi
→ Francesca Ieva
→ Emanuele Lettieri *
→ Francesca Malpei
→ Lorenzo Mari
→ Cristina Masella
→ Scira Menoni
→ Pierangelo Metrangolo
→ Francesco Migliavacca
→ Eugenio Morello
→ Ilaria Oberti
→ Maria Chiara Pastore
→ Alessandra Pedrocchi
→ Umberto Perego
→ Pietro Piazzolla
→ Barbara Piga
→ Tiziana Poli
→ Dario Polli
→ Maurizio Quadrio
→ Manuela Raimondi
→ Marco Rasponi
→ Alberto Redaelli
→ Francesco Romano
→ Fabio Salice
→ Laura Sangalli
→ Daniela Sangiorgi
→ Massimo Tadi
→ Marco Tarabini
→ Paola Taroni
→ Massimo Tavoni
→ Paolo Trucco
→ Michele Ugolini
→ Marco Verani
→ Stefano Zanero
→ Paolo Zunino

EXTERNAL EXPERTS

→ Sergio Abrignani
→ Valentina Bollati
→ Gianni Bonelli
→ Elena Bottinelli
→ Maurizio Cecconi
→ Francesco Dentali
→ Annalisa Giancaterini
→ Franco Molteni
→ Fabrizio Pregliasco
→ Valentino Sevino
→ Carlo Signorelli
→ Luca Vago

RESEARCH FELLOWS

→ Ingrid Alloni
→ Teresa Bonaventura
→ Vittoria Mesoraca
→ Alberto Speroni

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# The future of health trilogy

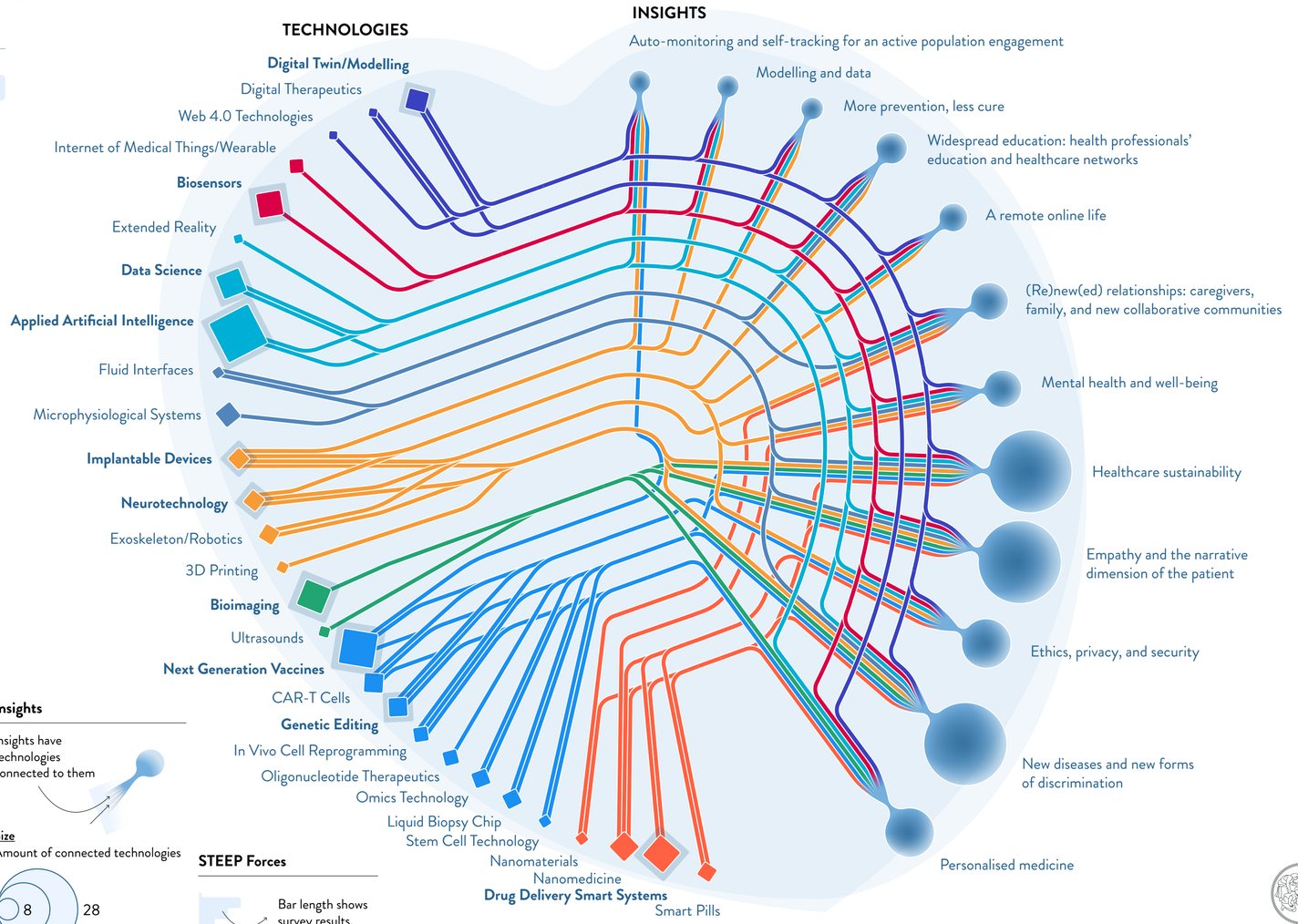
## TRANSFORMATIVE PERSONAL HEALTH TECHNOLOGIES IN 2040

STEEP Forces, Technologies and Insights

### STEEP FORCES

**Social**
- Ageing
- Non-communicable diseases
- Mental health
- Lifestyles
- Deepening disparities
- Demographic changes
- Beyond gender
- Migrations
- Work from everywhere
- Do it yourself

**Technological**
- Med(AI)cine
- Autonomous systems
- Hyper-connected
- Human enhancement
- Extended reality
- Robotics
- Digital twin
- Cryonics
- Genetic control
- Avatars




**Environmental**
- Pandemics
- Antimicrobial resistance
- Global climate changes
- Extreme events
- Environmental degradation
- Permafrost melting
- Pollution
- Food waste
- Circular economy
- Biodiversity loss

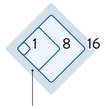
**Economic**
- Privatisation
- E-commerce
- Cost of living increase
- More prevention, less cure
- Insurance market players
- (Un)predictable instability
- New spaces, new relations
- Tech giants' pervasiveness
- Data exploitation
- Lack of skilled workers

**Political**
- Security
- Collapse of democracy
- Welfare
- (Trans)national identities
- Information and connection
- Geopolitical competition
- Nuclear paths
- Global commons
- The rise of ethical questions
- States like silos

### HOW TO READ IT

**Technologies**

Size
Amount of votes




Highlight
Most relevant technologies emerged from the participants' survey results

Colour
Category
- Digital
- Wearable & Sensors
- Data, XR & AI
- Others
- Devices
- Imaging
- Genetics
- Nano

**Insights**

Insights have technologies connected to them



Size
Amount of connected technologies




**STEEP Forces**



Bar length shows survey results.

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# The future of health trilogy

## TRANSFORMATIVE TECHNOLOGIES FOR THE HEALTHCARE SYSTEM IN 2040

STEEP Forces, Technologies and Insights

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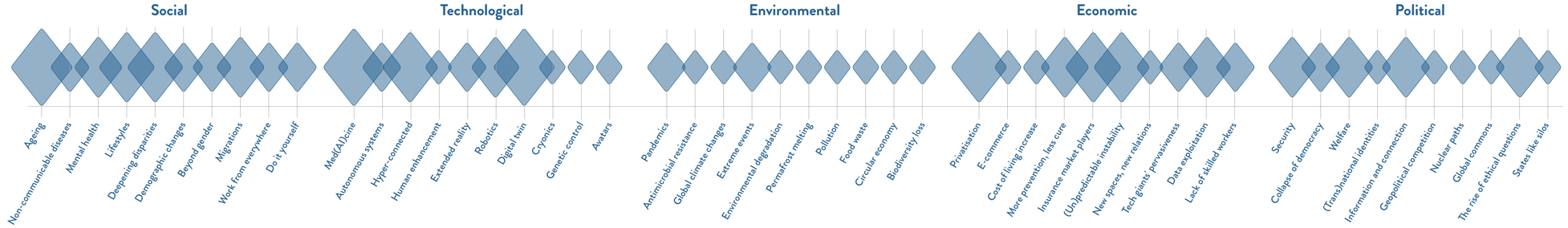
### STEEP FORCES




### TECHNOLOGIES

- Am — Ambient intelligence sensors
- As — Medical operator assistance systems
- At — HCI assistive technologies
- Cb — Service robots (care-bot)
- Dc — Digital clinical research platforms
- Dm — Digital twin/modelling
- Dt — Digital medicine and therapies/therapeutics
- Id — Implantable/Wearable Devices
- Md — (Medi-)drones
- Pd — Portable medical diagnostics
- Rm — Remote care system/ Telemedicine
- Sr — (Remote) surgical robotics
- Us — Universal electronic record systems
- Wt — Web 4.0 technologies
- Xr — Extended reality

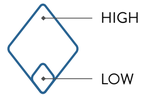
### INSIGHTS

- The place of care is the patient
- The health continuum
- Flexible and convertible spaces
- Your health, (y)our choice
- New health professionals
- Medical data is the new gold

### HOW TO READ IT

**STEEP Forces**

Size
Expected impact




**Technologies**

Border and fill style
Insight correlation strength

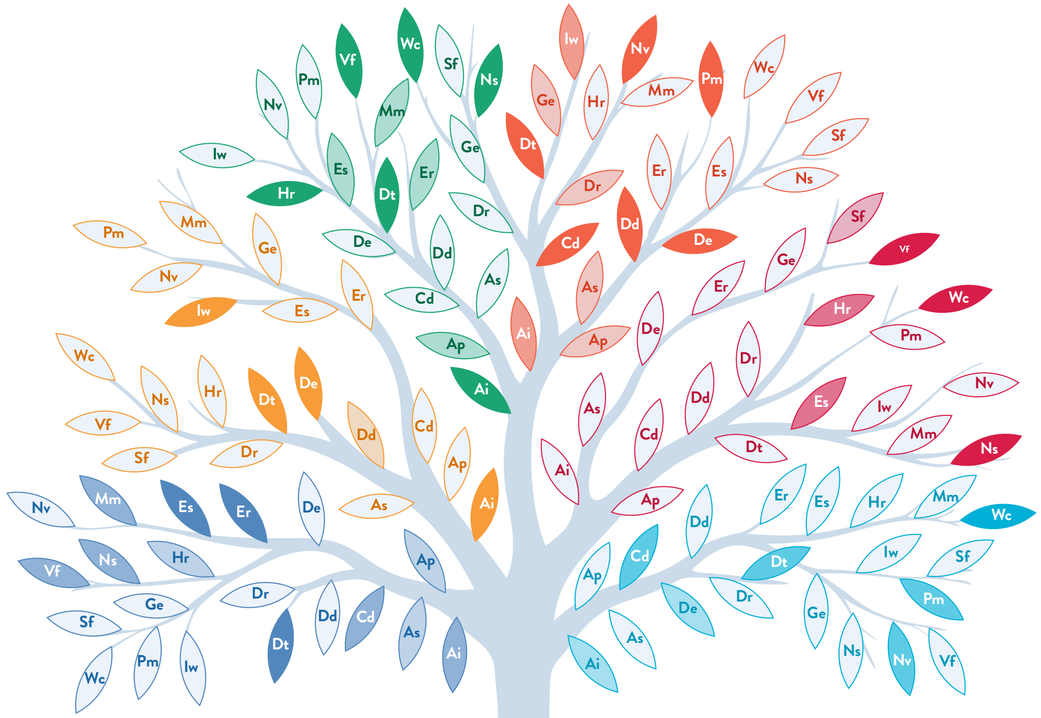
# The future of health trilogy

## TRANSFORMATIVE TECHNOLOGIES FOR PLANETARY HEALTH IN 2040

STEEP Forces, Technologies and Insights

### TECHNOLOGIES

- **Ai** Ambient intelligence sensors
- **Ap** Artificial photosynthesis
- **As** Agrophotovoltaic system
- **Cd** Carbon dioxide removal
- **Dd** DNA/RNA discovery
- **De** Data-driven epidemiology
- **Dr** Drones
- **Dt** Digital twin/Modelling
- **Er** Energy recovery
- **Es** Energy storage systems
- **Ge** Genetic engineering
- **Hr** Habitat restoration
- **Iw** Implantable/Wearable devices
- **Mm** Metamaterials
- **Ns** Nature-based solutions
- **Nv** Next-generation vaccines
- **Pm** Plastic metabolisation
- **Sf** Synthetic food
- **Vf** Vertical farming
- **Wc** Walkable city



### INSIGHTS

- The materiality of digital health
- From WEARables to AWAREables
- Urban equiA(c)tion: health as infrastructure
- Plan(et) for health
- Health commons
- From ego-systems to eco-systems

### HOW TO READ IT

**Technologies**

**Fill style:** Insight correlation strength

Weak · Moderate · High · Strong

**STEEP Forces**

**Size:** Expected impact

LOW IMPACT

HIGH IMPACT

### STEEP FORCES

**Social**

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See more at https://www.foresight.polimi.it/

TRANSFORMATIVE PERSONAL HEALTH TECHNOLOGIES IN 2040